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EFFECTS OF DEPTH OF UNDERWATER STRUCTURES OF FADS ON CATCH OF BIGEYE TUNA (*THUNNUS OBESUS*) IN THE TROPICAL WATERS OF THE WESTERN PACIFIC OCEAN

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Effects of depth of underwater structures of FADs on catch of bigeye tuna (*Thunnus obesus*) in the tropical waters of the western Pacific Ocean

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Abstract:

The main target species of Japanese purse seine operating in the tropical waters of the western Pacific Ocean is skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*), which account for nearly 98 % of their total catch in weight and the remaining is bigeye tuna (*Thunnus obesus*) according to the catch based on logbook data. The recent study of the vertical distribution of the three species around drifting FADs (fish aggregating devices) indicates that the skipjack tuna distribute relatively shallower depth layer compared to other two species. A typical FAD consists of floating foundation and underwater structures, which is used-up fishing net. Therefore shortening the length of the underwater structure of FADs (depth of FADs) might be effective to reduce the bigeye tuna catch. Relationship of the species composition of purse seine catch and the depth of FADs was investigated by port samplings and by logbook, of 77 sets and 556 sets, respectively from April 2007 to March 2008. We conducted three analyses for each dataset which assessed effects for presence/absence of bigeye catch, effects for catch ratio of bigeye to total catch per set and effects for catch amount of bigeye per set. Although significant effects of depth of FADs are found in some scenario, the expected effect that bigeye is more likely to be caught FADs with deeper depth is not detected.

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INTRODUCTION

Japanese purse seine operated in the western Pacific Ocean tropical waters all year round and the total catch per year of the fishery varied from 220,000 to 260,000 MT in recent five years (Anonymous, 2008). The main target of Japanese purse seine fishery operating in the western tropical Pacific Ocean are skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) which account nearly 98 % of total catch weight, according to catch statistics based on logbook data. The remaining catch is bigeye tuna (*Thunnus obesus*) which is non-targeted species and caught with target species mainly by operation on the floating object including FADs (fish aggregating devices). The fork length of bigeye caught by this fishery is mainly ranged from 30 to 70 cm (Anonymous, 2008). Reduction of the small and immature bigeye tuna catch must be effective for efficient use of the bigeye resources from the point of view to increase the yield per recruitment and the spawning per recruitment. The recent study of the vertical distribution of the three species around drifting FADs indicates that the skipjack tuna distribute relatively shallower depth layer comparing to yellowfin and bigeye tunas (Matsumoto et al. 2007). A typical FAD consists of floating foundation and underwater structures, which is used-up fishing net. Therefore the shortening the length of the underwater structure of FADs (it is called as “depth of FADs” hereafter) might be effective to reduce the small bigeye tuna catch.

From April 2007 to March 2008, a study on the relationship between the depth of FADs and the ratio and amount of bigeye in the catch was conducted. This investigation was collaborated by Japan Far Seas Purse Seine Fishing Association, two fishing markets (Yaizu and Makurazaki ports), Japan Fisheries Resource Conservation Association and National Research Institute of Far Seas Fisheries, Fisheries Research Agency (NRIFSF, FRA) leaded by Fishery Agency of Japan. This type of collaborative work is recommended in Conservation and Management

Measure 2006-01 (WCPFC 2006). We reported preliminary results of this study in Scientific Committee 3rd regular session of WCPFC (Satoh et al. 2007). The purpose of this study is to assess effect of the depth of FADs on bigeye catch in purse seine fishery in the western Pacific Ocean tropical waters.

METHODS

Data collection

Data of the species composition in weight and the depth of FADs were collected by port sampling and by logbook from April 2007 to March 2008. We tentatively assumed that the depth of underwater structure of natural log was 0 m.

Port sampling: Data was collected in Yaizu port and Makurazaki port, which are the main landing ports of the fishery in Japan, by staffs of the fish market and NRIFSF. Three bunches of fish were randomly scooped by the unloading net from the well, which was filled with catch derived from only one set on floating object and the fishes were identified species, weighed. The amount of fish identified and weighed were about 1.5 metric tons for each catch. During this research period, depth of FADs including floating object used for each set was recorded by fishing master and written in hatch plan of each cruise.

Logbook data: Fishing data and location, set type and the catch in weight by species recorded in the logbook was used. As in the case in hatch plan, the depth of FADs including floating object was recorded in logbook for each set by the purse seiner.

Data analysis

The two datasets, port sampling and logbook data were analyzed separately. Three analyses for each datasets assessed effects of depth of FADs on presence/absence of bigeye catch using GENMOD procedure of SAS software (vers. 9.1, SAS Inst., Inc.), effects on the ratio of bigeye tuna catch to total catch per set using GLM procedure of

SAS/STAT package and effects on catch amount of bigeye per set using GENMOD procedure. Final models were selected after variable selection with backward stepwise F test or χ^2 test with a criteria of P-value = 0.05 except for a variable of "depth of FADs". The determinants of depth of FADs, season, longitude, latitude were treated as categorical variable and total catch of all species was considered as continuous variable. In order to avoid missing data in a cell, the categorical variables were grouped appropriately for each data set and analysis. The details of these analyses are as follows;

Analysis 1

Binomial generalized linear model to model presence/absence of bigeye

Log [(rate/ (1-rate)] = Intercept + depth of FADs (m) + season + latitude + longitude + total catch per set (t) + interaction

where the rate is 1 if catch of bigeye is larger than 0, and the rate is 0 if catch of bigeye equal to zero. E [X] = rate, X ~ binomial (p), link function is logit function. The total catch per set is available for logbook.

Analysis 2

General linear model with transforming ratio of bigeye catch out of total by logit transformation

Log [Ratio of bigeye/ (1- Ratio of bigeye +0.0000001)] = Intercept + depth of FADs (m) + season + latitude + longitude + total catch per set (t) + interaction + error

where error ~ normal (0, σ2). The total catch per set is available for logbook.

Analysis 3

Negative binomial generalized linear model to model catch amount of bigeye

Log [catch amount of bigeye] = Intercept + depth of FADs (m) + season + latitude + longitude + interaction

where catch amount of bigeye is integer part of catch of bigeye + 0.5 (t) if catch of bigeye is not zero. Catch amount of bigeye ~ negative binomial (p), link function is log function.

RESULTS

Data set

The species composition data, information of fishing location and depth of FADs of 77 purse seine sets (46 cruises) and 557 purse seine sets (98 cruises) were collected from port samplings and logbooks, respectively. The numbers of set with absence of bigeye catch were 28 and 317 sets, respectively. The sample of the port sampling covered 1.5 % of a well on average (Table 1). The depth of FADs of both data sets distributed from 0 to 75 m.

In the tropical waters Japanese purse seine fishing grounds were distributed widely between 10˚N, 130˚E and 10˚S, 180˚ (Anonymous 2008). Either of our two data sets reasonably covers this fishing ground (Fig. 1). Although there was some missing and small number of data in several categories, the depth of FADs, season and total amount of catch of both datasets distributed widely to figure out the actual condition of the fisheries (Figs. 2, 3 and 4),

Bigeye catches in nominal data

Bigeye tuna did not seem to be caught well with deeper depth of FADs in both datasets (Fig. 2). While there was clear seasonal changes of which bigeye was less caught especially in summer rather than in other seasons (Fig. 3). The changes related with fishing location were also found in both datasets, which resulted that bigeye was relatively well fished in the southeast part of fishing ground (Fig. 4). The ratio of presence of bigeye in catch increased when the amount of total catch (including skipjack, yellowfin, bigeye and others) increased, whereas the ratio of bigeye decreased (Fig. 5). Therefore, the effects of season, location and total catch were considered as explanatory variables for the data analyses.

Data analysis

Results of analysis 1 for each dataset were showed in Table 2 and Fig. 6. In the case of analyses using port sampling data, depth of FADs did not have significant effect on bigeye catch. Although significant effect was shown in logbook analysis (Chi-Square = 15.51, P = 0.0084), the result did not indicate that higher bigeye catch would caused by deeper underwater structure of FADs. The highest ratio of bigeye presence and largest catch amount of bigeye were observed in 20 m depth, however the ratio in less than 10 m depth was not lowest (Fig. 6 (B)). The interaction of fishing location and total catch of all species had strong effect that bigeye tuna were more likely to be fished in east of 150˚E rather than in west of 150˚E (Table 2, Fig. 6 (A)). The effect of continuous variables of total catch in logbook was estimated as positive effect.

Results of analysis 2 for each dataset were showed in Table 3 and Fig. 7. The effects of depth of FADs were insignificant with both datasets (port sampling; F = 1.14, P = 0.2907, logbook; F = 1.65, P = 0.1475). With respect to the dataset of port sampling none of explanatory variable was significant determinant for the ratio of bigeye. The total catch and interaction of longitude and latitude were significant with the dataset of logbook (total catch; F = 89.32, P < 0.001, season*longitude; F = 9.54, P = 0.0023). The total catch of all species per set had negative effect on ratio of bigeye (not shown). In east of 150˚E and southern hemisphere the ratios of bigeye were estimated to be higher than in west of 150˚E. The effects of longitude appeared to do opposite in northern hemisphere (Fig. 7 (C)).

Results of analysis 3 for each dataset were showed in Table 4 and Fig. 8. Significant effect of depth of FADs was found in the dataset of logbook (Chi-Square = 20.24, P = 0.0011). The highest effect of depth of FADs was estimated in 20 m depth and the lowest ratio was found in 40 m depth (Fig. 8 (B)). The interaction of season and longitude was significant with the dataset of port sampling (Chi-Square = 7.7, P = 0.0055). From May to August the effect of longitude with the dataset of port sampling was larger than other season (Fig. 8 (A)). With respect to the dataset of logbook, in the east of 150˚E the amount of catch of bigeye per set was estimated higher than in the west of 150˚E (Fig. 8 (B)).

DISCUSSION

Although significant effects of depth of FADs are found in some scenario, the expected effect that bigeye is more likely to be caught with deeper depth of FADs is not supported by the results. Lennert-Cody et al (2008) reported that the depth of floating object is important for predicting the presence of bigeye of purse seine in the eastern Pacific Ocean. In their study, the possibility of bigeye presence is lowest in near 0 m, which is different with our result, and it is highest in near 20 m depth, which is resembled with this study and slightly decreases if depth of FADs is deeper than 20 m, which is not agree with result in this report. Lennert-Cody et al (2008) indicated that the effect of mixed layer depth on presence/absence of bigeye is relatively high. It is well known that mixed layer depth is shallow in the eastern part Pacific Ocean, and deep in the western Pacific Ocean. The effects of depth of FADs might differ with mixed layer depth. However in the EPO, the effect was most pronounced especially in the offshore and southern area (from equator to 20˚S), while in the inshore and northern area the effect appeared to have little effect (Lennert-Cody et al 2008). In this study significant interaction of depth of FADs and location is not found.

Bigeye is more likely to be caught in southeast part of Japanese purse seine fishing ground. Lennert-Cody et al (2008) also pointed the location of purse seine set is the strongest determinant of bigeye tuna catch. The effect of season is different with location in our dataset of port sampling. The catch of bigeye is small in summer and at western part of fishing ground. On the contrary, the result of Lennert-Cody et al (2008) indicated that the effect of month was relatively low. The probability of presence of bigeye would increase with rising of total catch of all species, whereas the ratio of bigeye decreases in our dataset. The result may indicate that magnitude of school of bigeye is relatively small compared to those of skipjack and yellowfin if they aggregate with FADs.

Unfortunately, the expected effect of the depth of FADs was not found. We noticed a problem for accuracy of the depth of FADs, which was based on fisherman's report and they collected the information when they made each FADs on deck. Moreover, materials and weight of FADs, which could affect actual depth of FADs, were not collected. Therefore the real depth in-water is not available and may be different from that estimated by fisherman. Nevertheless the numbers of both datasets are considered enough for this analysis. In order to reduce catch of bigeye in actual operation, shortening depth of FADs seems not to be so effective at least in western Pacific Ocean.

Acknowledgement: We would like to thank fish market stuffs for collecting data. We are also grateful to Japan Far Seas Purse Seine Fishing Association, Japan Fisheries Resource Conservation Association for their arrangements of this study.

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Table 1. Number of cruise and set, coverage of measurement to total catch per set (measurement coverage).

Data set		port sampling	log book
Number of cruise		46	98
Number of set	Total	77	557
	FADs	68	387
	Log	9	170
	absence of bigeye catch	28	317
Measurement coverage (%) (avg (SD))		1.5 (1.3)	-

Table 2. Bigeye tuna (*Thunnus obesus*). Analysis 1, effects of depth of underwater structures of FADs (depth of FADs) and other significant explanatory variables on presence/absence of bigeye catch of the data sets of (A) port sampling (scale =1.0) and (B) logbook (scale =1.0).

(A) port sampling

Source	DF	ChiSq	P
depth of FADs	1	0.64	0.4254
longitude	1	10.42	0.0012

(B) logbook

Source	DF	ChiSq	P
depth of FADs	5	15.51	0.0084
total catch	1	14.4	0.0001

Table 3. Bigeye tuna (*Thunnus obesus*). Analysis 2, effects of depth of underwater structures of FADs (depth of FADs) and other significant explanatory variables on the ratio of bigeye tuna catch to total catch per set of (A) port sampling and (B) logbook.

(A) port sampling

Source	DF	SS	MS	F	P
depth of FADs	1	2.6	2.6	1.14	0.2907

(B) logbook

Source	DF	SS	MS	F	P
depth of FADs	5	5.6	1.1	1.65	0.1475
total catch	1	60.6	60.6	89.32	<.0001
longitude	1	3.9	3.9	5.72	0.0175
latitude	1	0.1	0.1	0.08	0.7765
longitude * latitude	1	6.5	6.5	9.54	0.0023

Table 4. Bigeye tuna (*Thunnus obesus*). Analysis 3, effects of depth of underwater structures of FADs (depth of FADs) and other significant explanatory variables on catch amount of bigeye per set of (A) port sampling (dispersion = 2.0320, standard error = 0.2317) and (B) logbook (dispersion = 2.2706, standard error = 0.3716).

(A) port sampling

Source	DF	ChiSq	P
depth of FADs	1	0	0.9558
season	1	4.73	0.0297
longitude	1	6.69	0.0097
season * longitude	1	7.7	0.0055

(B) logbook

Source	DF	ChiSq	P
depth of FADs	5	20.24	0.0011
longitude	1	22.77	<.0001

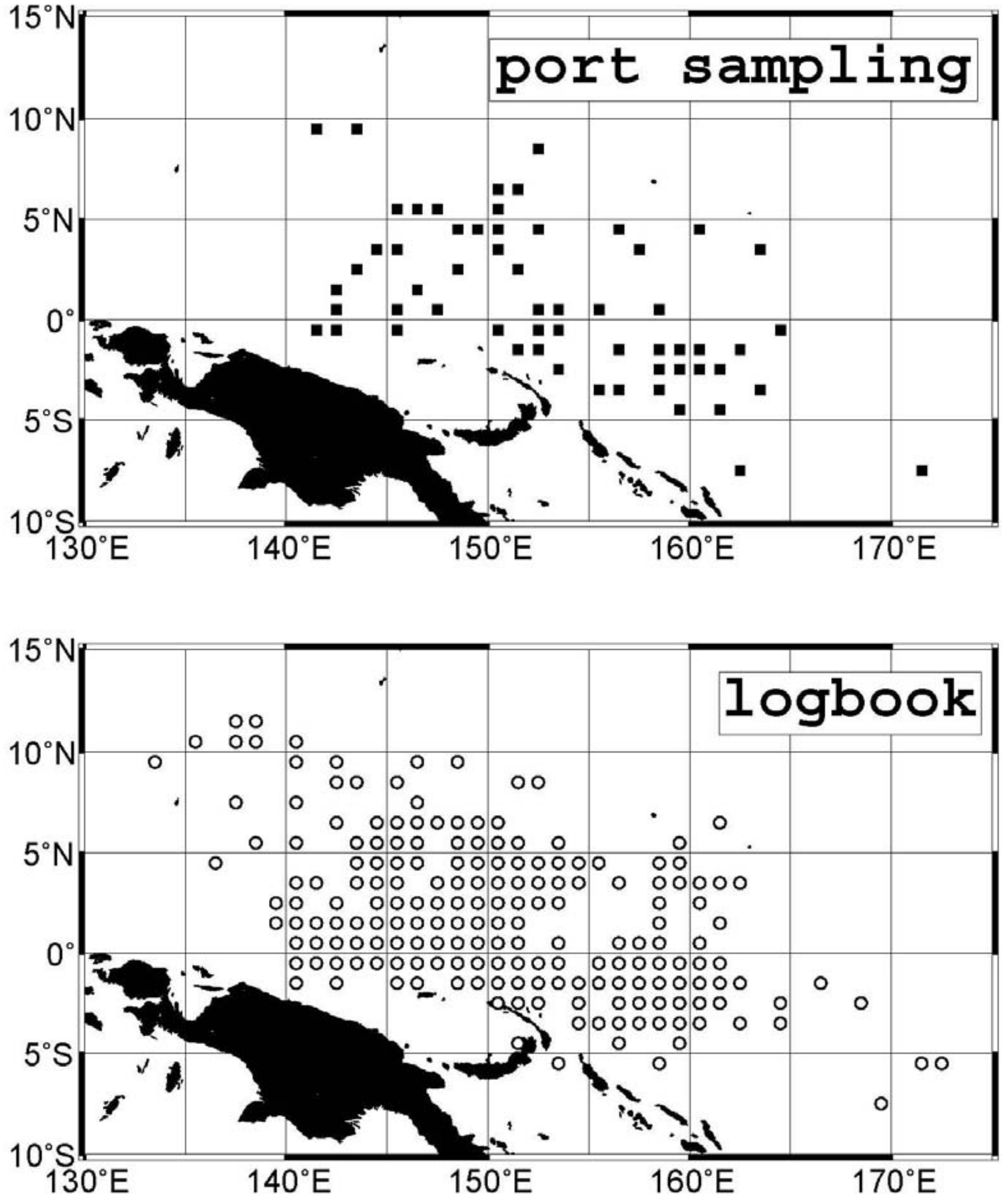

Fig. 1 Fishing grounds of Japanese purse seine in this study. Upper panel (Solid square, ■) and lower panel (open circle, ○) show the positions of data set of port sampling and log book, respectively.

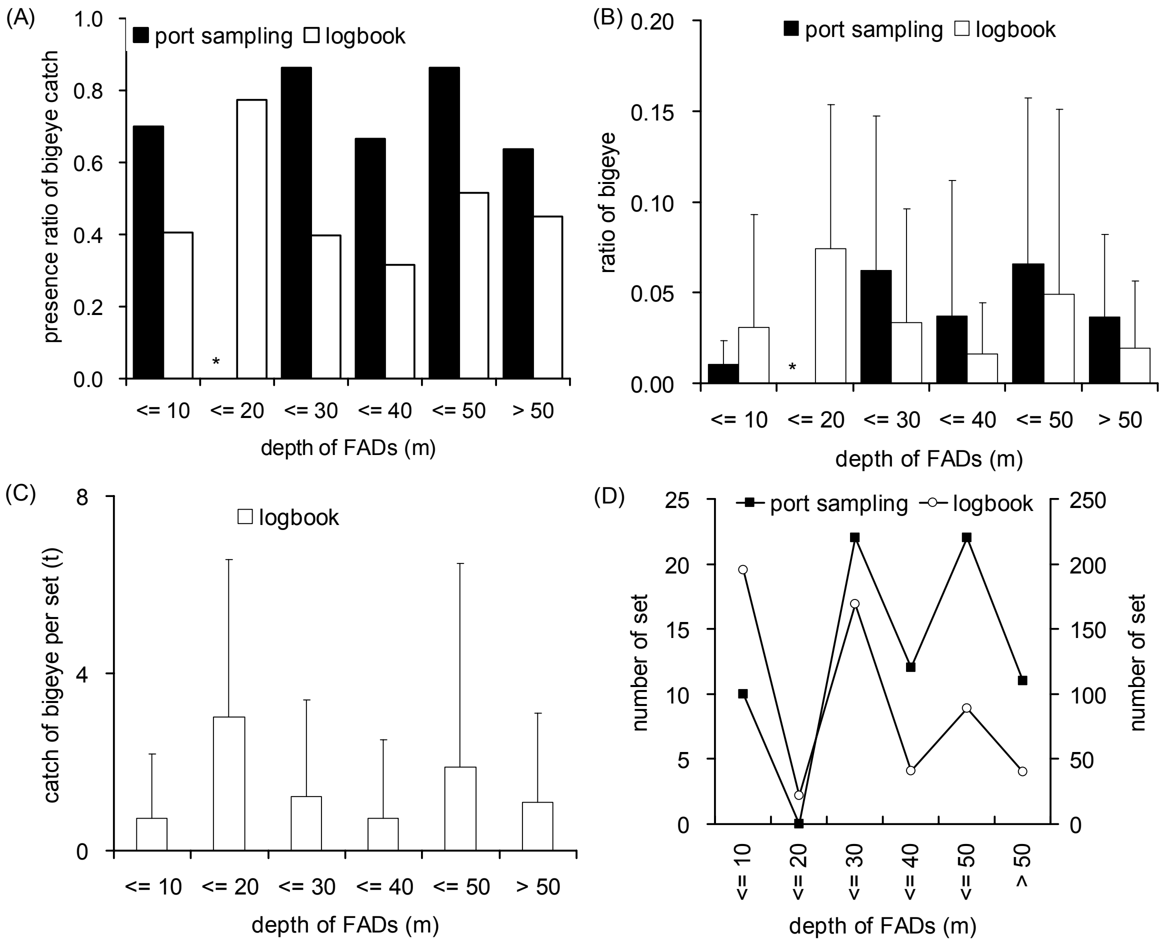

Fig. 2 The relationships between length of underwater structure of FADs (depth of FADs) and (A) ratio of number of set with positive catch of bigeye to total number of set, (B) ratio of bigeye catch to total catch per set, (C) amount of catch of bigeye per set. (E) Number of set. * : no data.

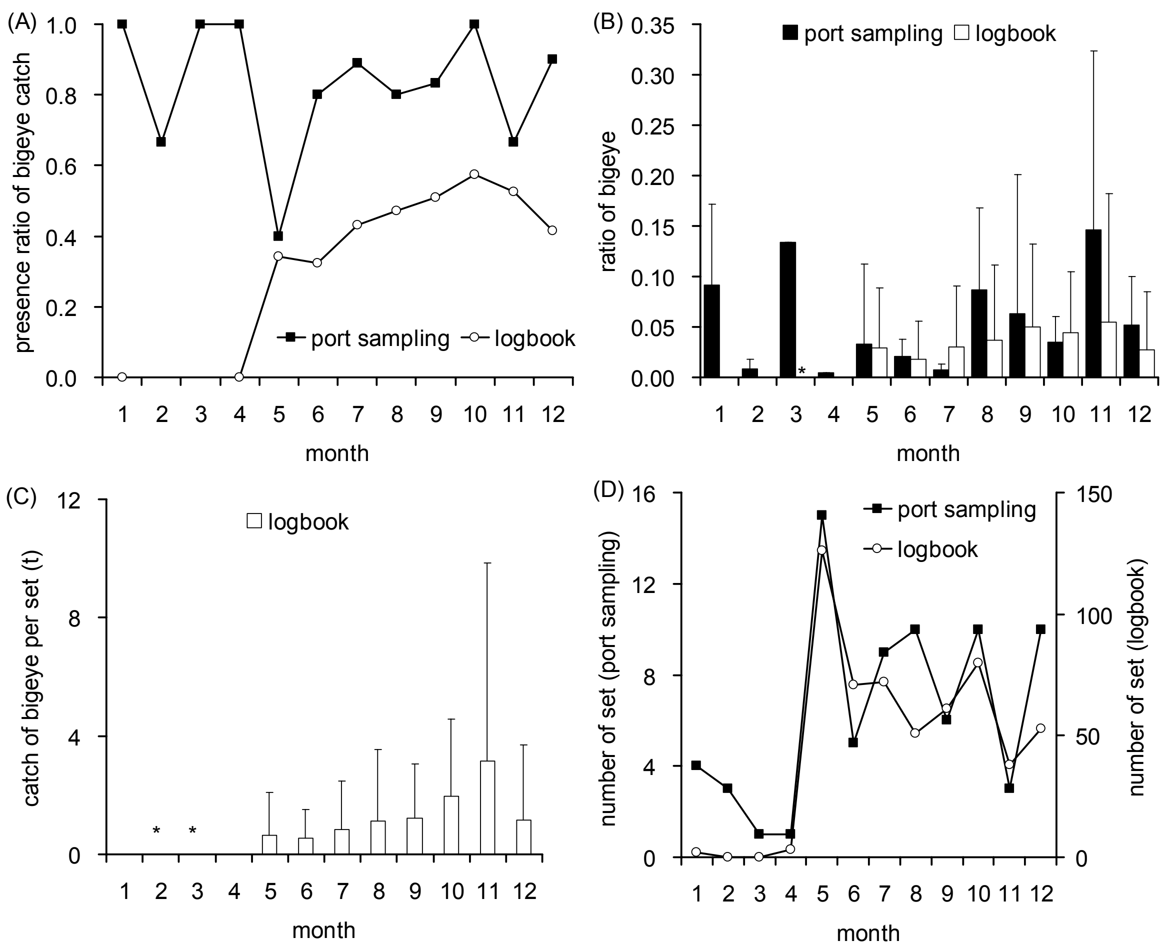

Fig. 3 Seasonal changes of (A) ratio of number of set with positive catch of bigeye to total number of set, (B) ratio of bigeye catch to total catch per set, (C) amount of catch of bigeye per set. (D) Number of set. * : no data.

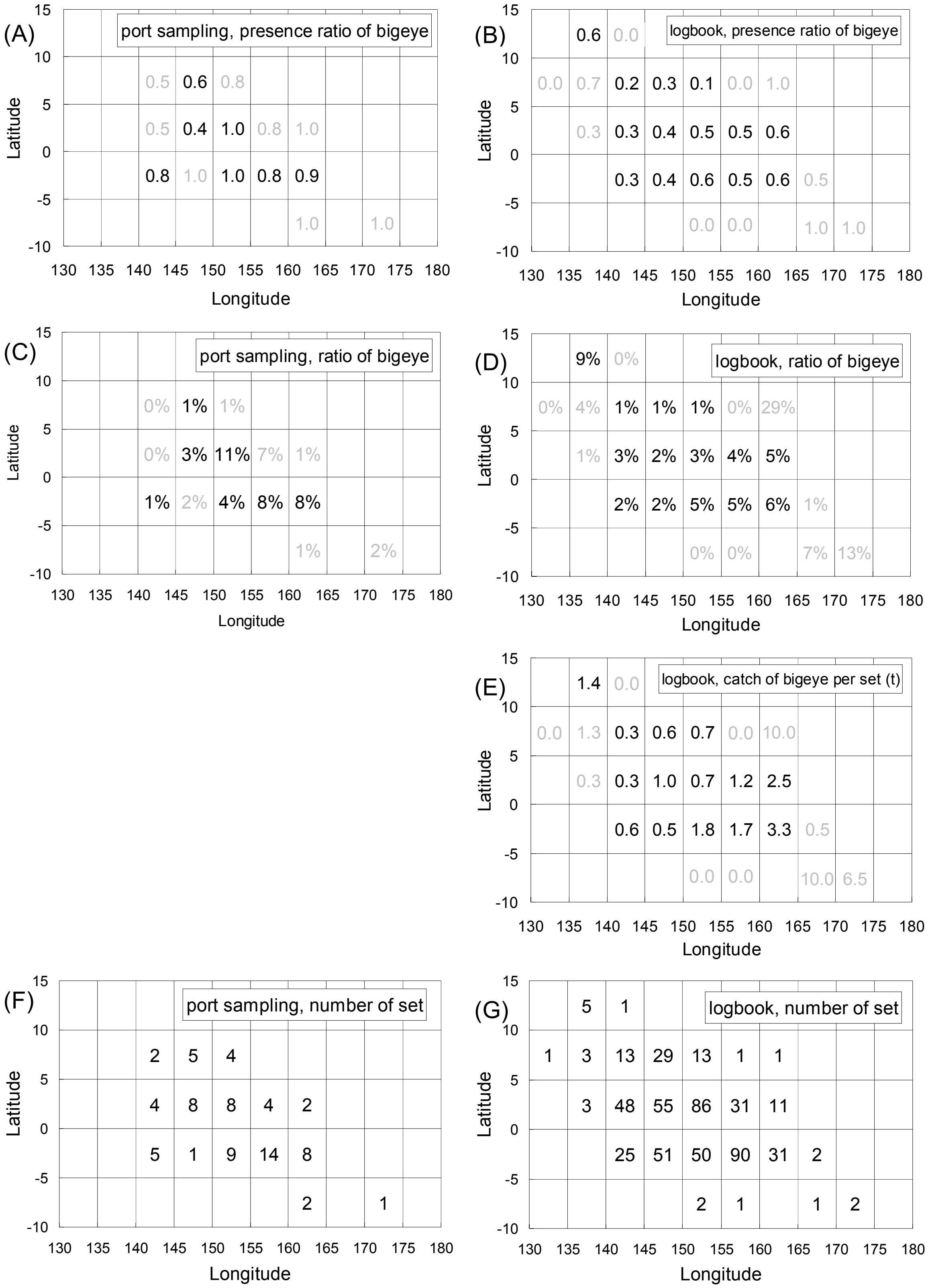

Fig. 4 Horizontal distribution changes of (A, B) ratio of number of set with positive catch of bigeye to total number of set, (C, D) ratio of bigeye catch to total catch per set, (E) amount of catch of bigeye per set. The figures in each 5 by 5 degrees rectangle are applied to gray if the number of set within the rectangle is under five sets. (F, G) Number of set.

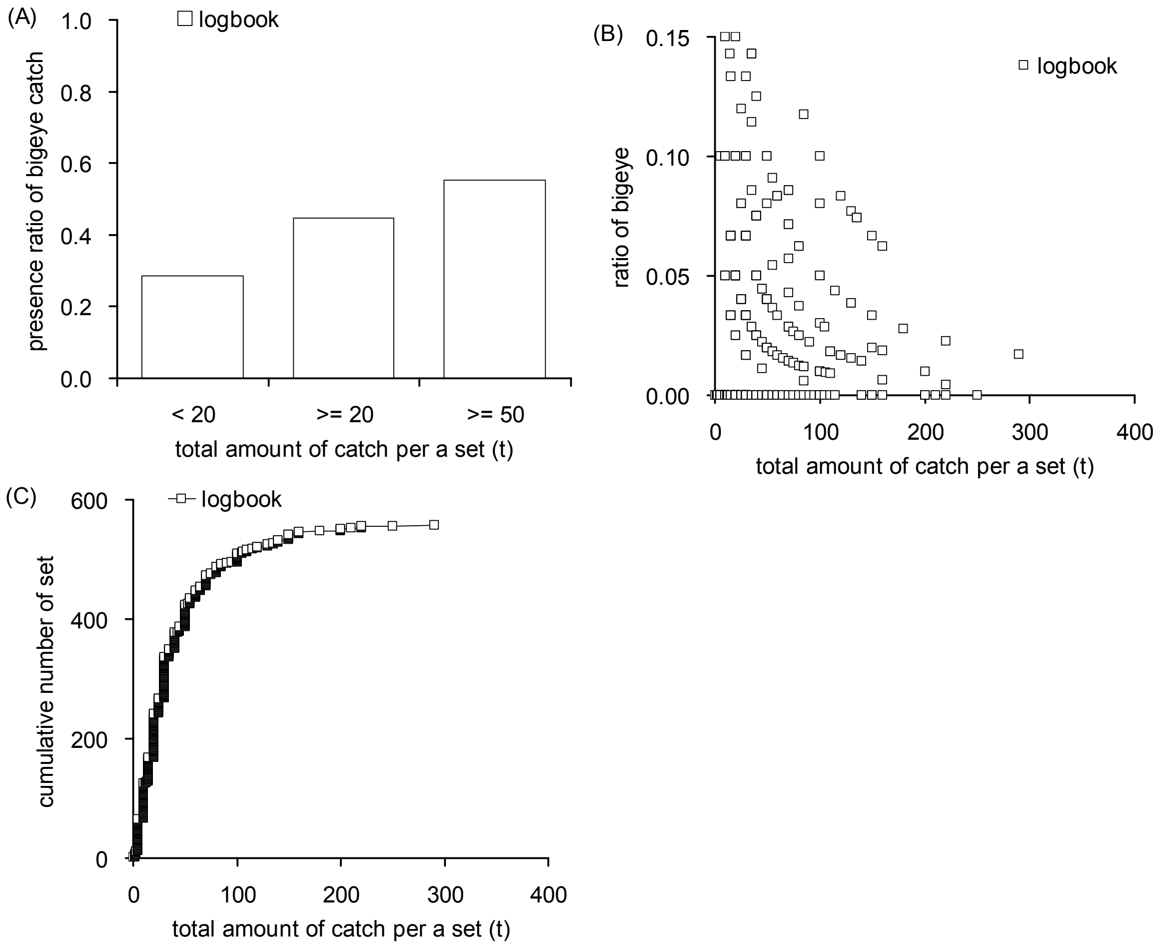

Fig. 5 Relative changes of total catch amount (including skipjack, yellowfin, bigeye and others) of bigeye catch per set to (A) ratio of number of set with positive catch of bigeye to total number of set, (B) ratio of bigeye catch to total catch per set. (C) Cumulative number of set.

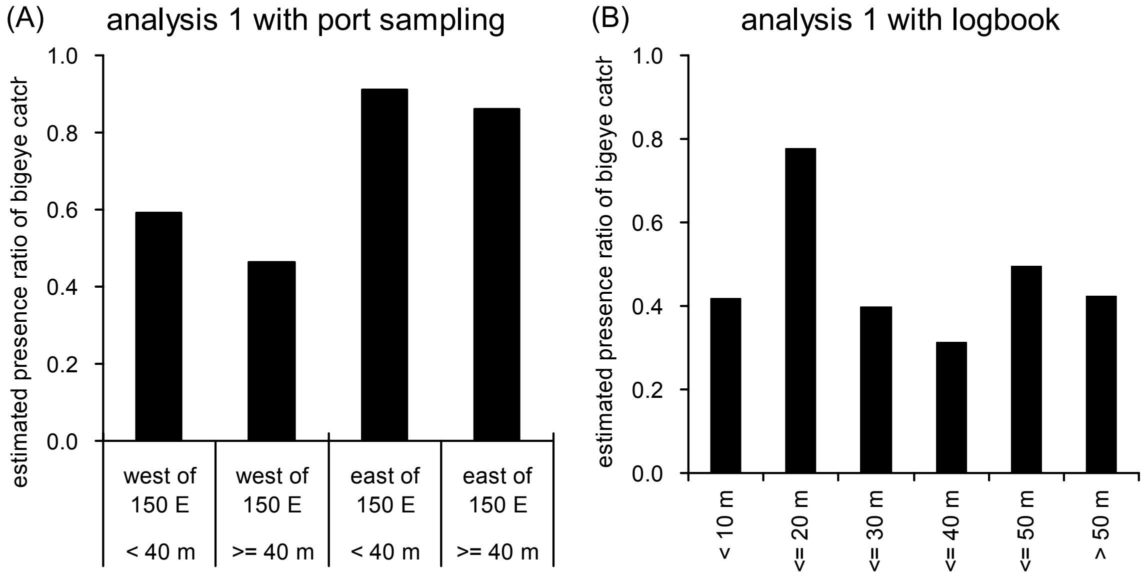

Fig. 6 Results of analysis 1 (binomial generalized linear model to model presence/absence of bigeye) for two datasets (A) port sampling and (B) logbook. < 10 m, <= 20m, <= 30 m, <= 40 m, <= 50 m, > 50 m, < 40 m and >= 40 m indicate length of underwater structure of FADs (depth of FADs).

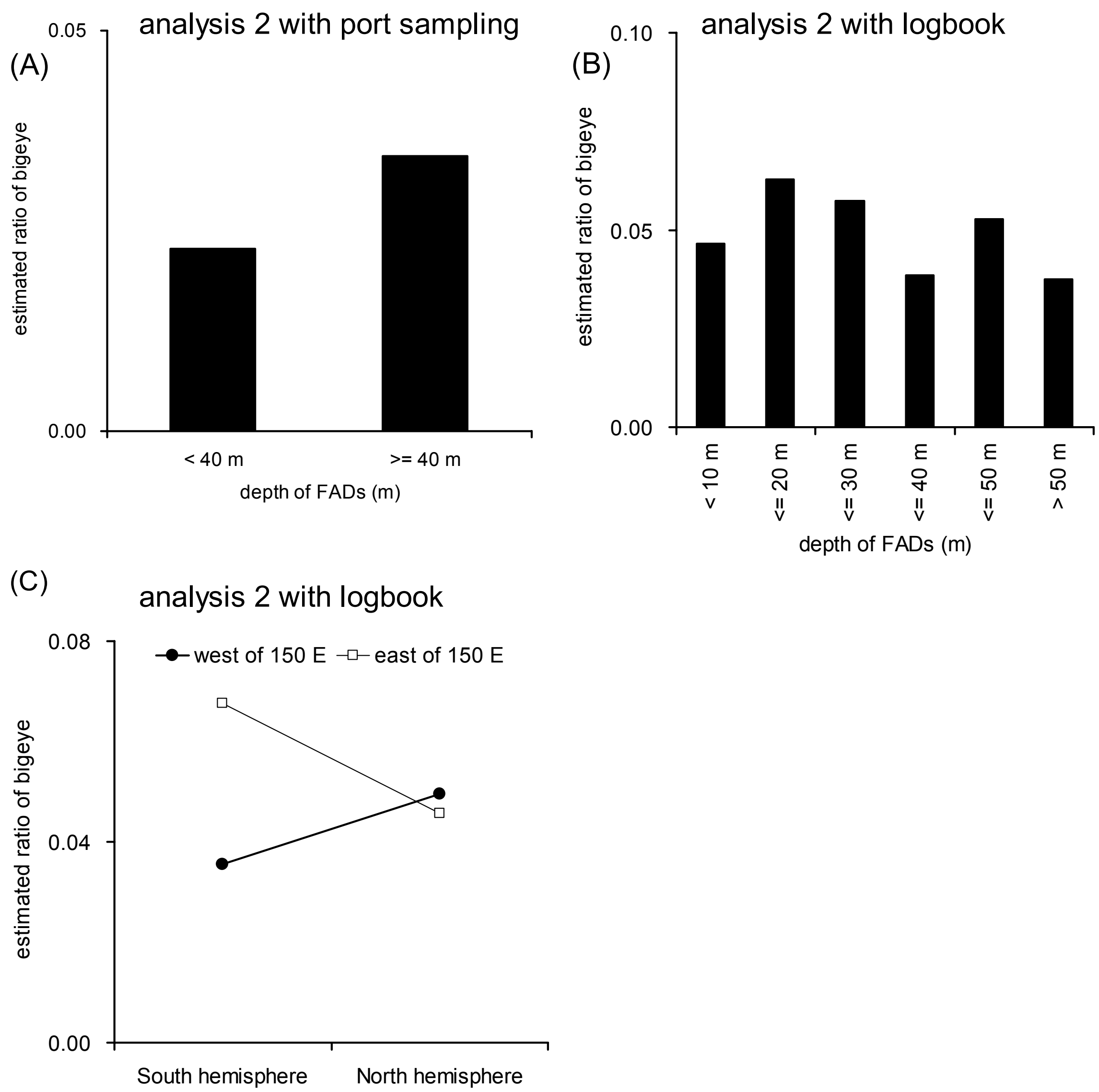

Fig. 7 Results of analysis 2 (general linear model with transforming ratio of bigeye catch out of total by logit transformation) for two datasets (A) port sampling and (B and C) logbook. < 10 m, <= 20m, <= 30 m, <= 40 m, <= 50 m, > 50 m, < 40 m and >= 40 m indicate length of underwater structure of FADs (depth of FADs).

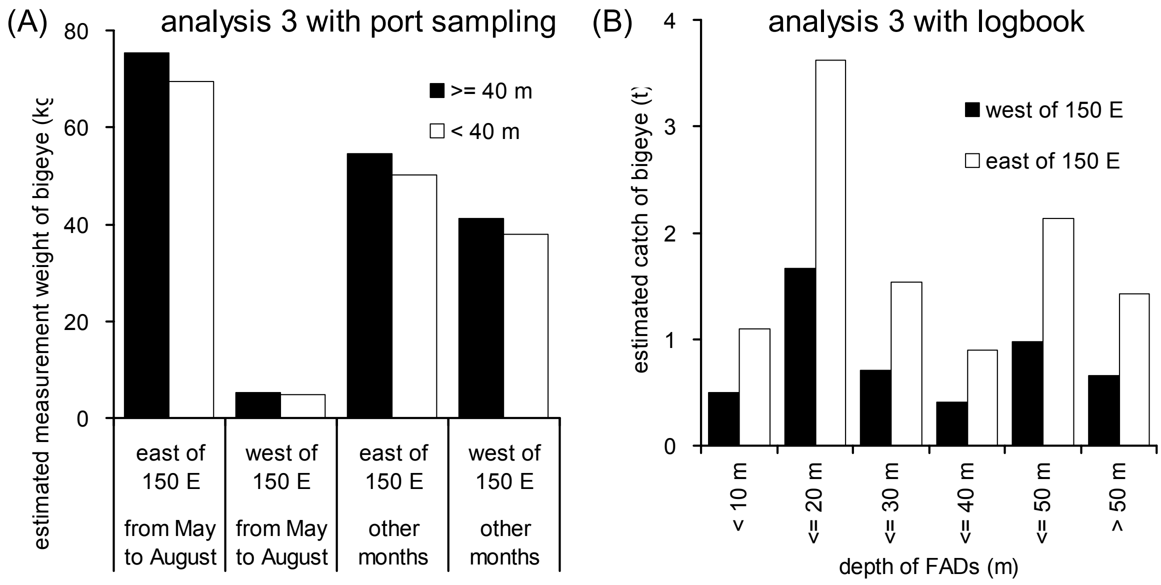

Fig. 8 Results of analysis 3 (negative binomial generalized linear model to model catch amount of bigeye) for two datasets (A) port sampling and (B) logbook. < 10 m, <= 20m, <= 30 m, <= 40 m, <= 50 m, > 50 m, < 40 m and >= 40 m indicate length of underwater structure of FADs (depth of FADs).