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Preliminary evaluation of differences in habitat quality between FADs-associated and unassociated schools of yellowfin tuna *Thunnus albacares*

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Abstract

The use of drifting fish aggregation advices (FADs) by tuna purse seine fleets has greatly expedited tuna catches since the 1990s. The large increase in the number of FADs calls for studies to evaluate potential ecological impacts on the entire life cycle of tunas. The effects of FADs on habitat selection should be a research priority since altered life history traits could be the consequence of inappropriate habitat selection. We evaluated the quality of available habitat for free swimming schools and drifting-FAD-associated schools for yellowfin tuna (*Thunnus albacares*) in the Western and Central Pacific Ocean (WCPO). We quantified the habitat quality with an Integrated Habitat Index (*IHI*) developed using a quantile regression model based on available environmental variables. The preliminary results showed that the free swimming schools tended to have higher 95% Confidence Intervals (CIs) of *IHI* values compared to the FAD associated schools (0.2933-0.3608 versus 0.1037-0.1181), suggesting that they encountered higher quality habitat. However, the habitat model used in this study only explained 27.5% of the deviance. The additional abiotic and biotic factors may be required in the Integrated Habitat Index model to more accurately quantify the habitat quality for associated and unassociated schools in the further studies.

Key words: drifting fish aggregation devices (DFADs), purse seine, yellowfin tuna *Thunnus albacares*, habitat selection, Integrated Habitat Index

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1. Introduction

Tropical tunas and other pelagic fishes are often attracted to floating objects, forming aggregations under or around them (Bromhead *et al.*, 2000). Tuna purse seine fisheries exploit this behavior by introducing fish aggregation devices (FADs) which have effectively increased the efficiency of tuna fishing operations. The increased application of FADs worldwide has left many unanswered questions regarding the impact on life histories and habitat choices of tunas (Marsac *et al.*, 2000; Hallier and Gaertner, 2008; Dagorn *et al.*, 2013).

Condition factors were used to measure tuna well-being (condition) which is assumed to reflect the environmental conditions (Blackwell et al. 2000). Several studies have compared various condition factors of fish aggregating around the FADs to conspecifics in unassociated schools (i.e. free swimming schools) and demonstrated that the presence of FADs may negatively affect the life history of tuna and inferred that reduced biological indicators of tuna associated with FADs are a result of poor habitat quality (Marsac *et al.*, 2000; Hallier and Gaertner, 2008; Jaquemet *et al.*, 2011).

However, previous studies did not quantify habitat quality of fish schools to explicitly evaluate possible differences in habitat suitability between free schools and FADs-associated schools. Habitat quality modeling, commonly done in aquatic ecological studies, usually involves assigning relative values to habitat depending on their importance in providing the requisites for species (Donovan et al. 1987). Various habitat suitability index models had been developed for evaluating potential impacts of environmental changes on the distribution of species (Gillenwater et al. 2006; Love 2011; Lowie et al. 2001). Thus, habitat quality modelling may provide a new approach to explore possible impacts of drifting FADs on tunas.

The goal of this study is to quantify the quality of available habitat between free swimming school and drifting-FAD-associated school of yellowfin tuna (*Thunnus albacares*). We hypothesize that habitat quality is different for free swimming schools and associated schools and examine this hypotheses by developing a habitat suitability index model to quantify the habitat quality. This study can improve our understanding of potential impacts of FADs on habitat selection for yellowfin tuna.

2. Materials and methods

2.1 Tuna purse seine observer survey data

Data were collected from survey cruises by the Tuna Purse Seine Fishery Observer Program from May 2012 to June 2014. Chinese tuna purse seiners, Zhong Tai No.1 caught yellowfin tuna from both free swimming and associated schools in the Western and Central Pacific Ocean (WCPO, Fig.1).

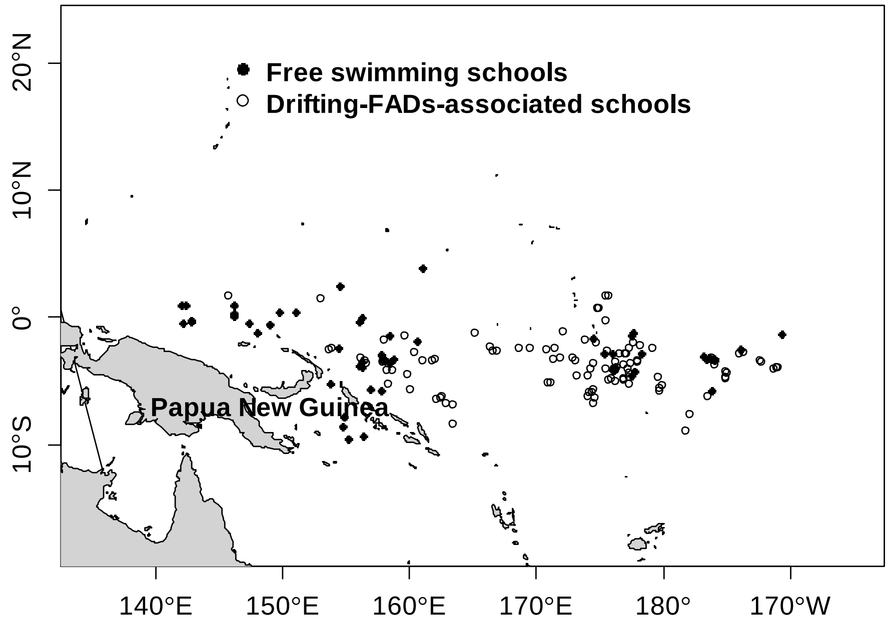


Figure 1: *Location of survey stations in the Western and Central Pacific Ocean from 2012 to 2014*

Data for fifty-nine free swimming schools were comprised of both pure schools of yellowfin and mixed schools of skipjack (*Katsuwonus pelamis*) and yellowfin tuna. Data for one hundred six associated schools were collected for one hundred one aggregations associated with drifting FADs and five logs. Observers recorded a variety of data including date, survey station position, estimated weight of catch (tones) for each set and environmental data.

Fishermen on Zhong Tai No.1 make fishing options and strategy with the help of various of oceanographic information from CATSAT satellite system on board fishing vessel. Daily environmental data including sea surface temperature (℃), sub-surface temperature (℃), thermocline depth (m), the velocity of surface current (knot) and the velocity of wind (knot) were recorded from CATSAT for all sets.

2.2 Quantile Regression Model

The majority of models that link environmental variables with species distributions (e.g., GLM, GAM) are based on the estimation of mean or median (i.e., the central tendency) of species responses to environmental variables (Oksanen and Minchin, 2002). However, the central tendency modeling approach does not properly estimate limiting effects of the environment (Vaz *et al.*, 2008). Regression quantile models have been increasingly used as a way to estimate a more complete range of species' responses to environmental gradients with the highest quantile representing the species maximum abundance given ideal environmental conditions (Eastwood *et al.*, 2003; Vaz *et al.*, 2008; Song and Zhou, 2010). We used a quantile regression model to standardize yellowfin abundance with respect to environmental variables. The model can be described as:

$$Log(B_i) = \beta_0 + \beta_1 F + \beta_2 Lat + \beta_3 Long + \beta_4 SST + \beta_5 T_{150} + \beta_6 D + \beta_7 V_{\mathrm{current}} + \beta_8 V_{\mathrm{wind}} + \varepsilon$$

where B_i is the catch caught by a seiner at sampling station i, which represents the biomass of the aggregation and is assumed to be proportional to the abundance; F is aggregation type (free swimming school = 1 and associated school = 2) with associated school as the reference level; Lat is latitude; $Long$ is longitude; SST is the sea surface temperature; T_{150} is the temperature mean from 0-150 m; D is the upper depth of the thermocline; $V_{current}$ is the velocity of surface current; V_{wind} is the velocity of wind; β_0 is the intercept; β_i, i = 1, 2, 3, 4, 5, 6, 7, 8 are unknown parameters to be estimated; and ε is an error term.

Starting with the full model, single terms were removed by backward elimination based on average P-values at five quantile intervals from the highest quantile (95^{th}) to the lowest (10^{th}). For each iteration insignificant variables ($p>0.05$) were removed, and the reduced model was re-run across all 5 quantiles. Significance tests were again performed to eliminate additional variables according to the same rule until a parsimonious model ($p<0.05$) was identified in at least one quantile. In cases where the resulting model was found to have all variables significant in more than one quantile, the highest quantile was chosen as the area with the highest abundance. More information about quantile choice and model selection can be found in Vaz *et al.* (2008). The optimal quantile regression model was used to predict species abundance to quantify habitat quality at each sampling location.

2.3 Quantification of habitat preference

An Integrated Habitat Index (*IHI*) was used to overcome the disadvantages of traditional *HSI* models based on methods described by Song and Zhou (2010). In traditional *HSIs* the weight of each environmental variable must be chosen based on expert opinion, additionally normal distribution is required for most *HSIs* (Song and Zhou, 2010). The *IHI* for free swimming and associated schools were calculated with the following equation:

$$IHI_i = B_i / B_{max}$$

where B_i is the standardized abundance index at sampling station i, and B_{max} is the maximum value of all B_i (Song and Zhou, 2010). A sampling location with an *IHI* value closer to one implies that the environment of the station is more suitable for yellowfin tuna.

We estimated portions of *IHI*, the average *IHI* value, variance, and the 95% bootstrapped confidence intervals (CIs) for free swimming and associated schools. Bootstrapped CIs are estimated by re-sampling the original data n times (n = number of original *IHI* values) with replacement for 1000 iterations to calculate.

3. Results

The significance test of the coefficients in the selected model showed that the quantile regression models corresponding to the 20th was suitable. The parsimonious model determined aggregation type (*F*), latitude (*Lat*), the sea surface temperature (*SST*) and the upper depth of the thermocline (*D*) to be the significant variables describing yellowfin tuna habitat in this study (Table 1). The parsimonious model explained 27.5% of the deviance in this study.

Table 1: *estimates of the model parameters for the quantile regression model with 20th*

quantile used to standardize the biomass of yellowfin tuna aggregations with respect to environmental variables. The fitted parameters were aggregation type (F), latitude (Lat), the sea surface temperature (SST) and the upper depth of the thermocline (D).

Variable	Estimate	Standard error	t value	Pr (>|t|)
Intercept	18.54629	3.28923	5.63848	<0.001
F	-0.96241	0.34542	-2.78624	0.00598
Lat	-0.12568	0.02223	-5.65325	<0.001
SST	-0.57399	0.11047	-5.19602	<0.001
D	-0.01088	0.00166	-6.56831	<0.001

The residual-fit plot indicated (Figure 2A) that the spread of the residual values was small relative to the spread of the fitted values, and the q-q plot (Figure 2B) indicated the residual distribution appeared to be approximately normally distributed.

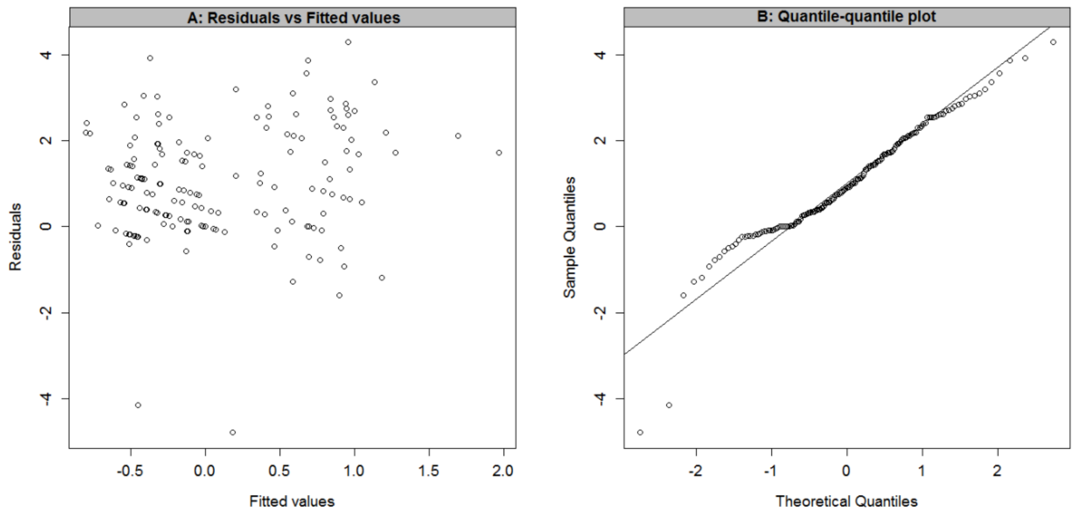


Figure 2: *residuals plot (A) Quantile-Quantile plot and (B) for the regression quantile model*

The distributions of 165 original catch data were display in figure 3. Most of catch per set for both free swimming schools and associated schools were below fifty tones, but some huge catch appeared in the sets on free swimming school.

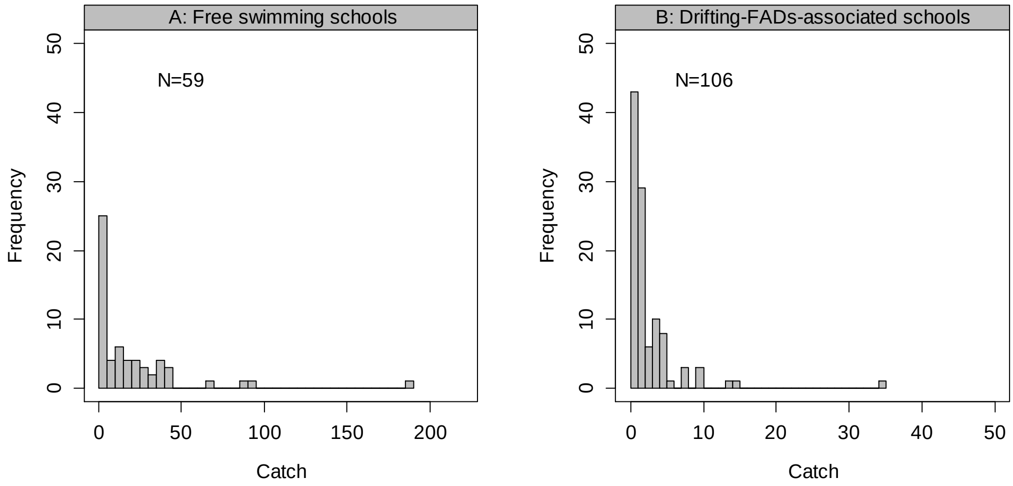
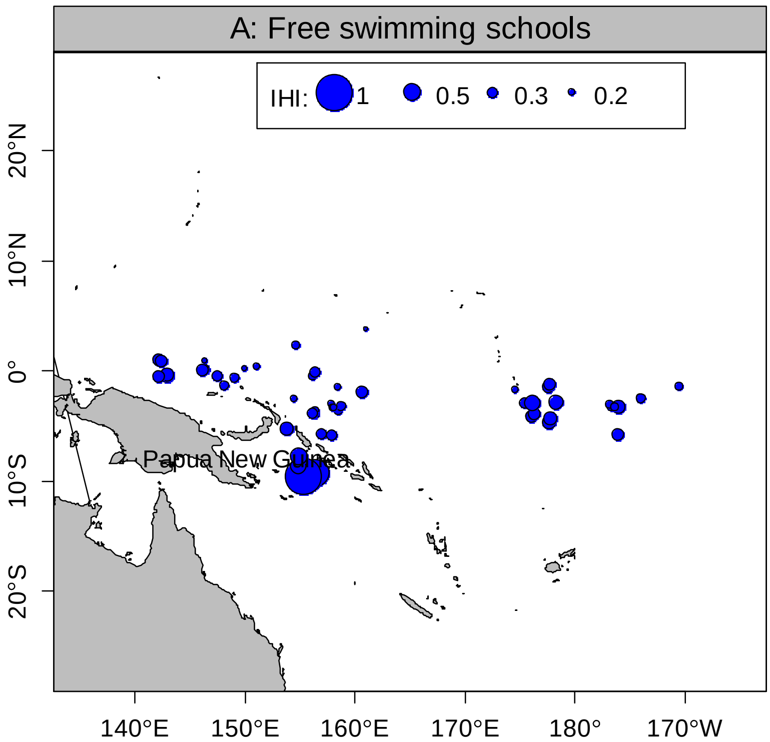


Figure 3: *distributions of catch for yellowfin tuna caught on free swimming schools* ***(A)*** *and associated to drifting fish aggregation devices (FADs)* ***(B)***

The range of *IHIs* for free swimming schools and associated schools were from 0.1395 to 1.0000 and from 0.0627 to 0.3012, respectively. Figure 4 displayed the spatial distribution of 59 *IHIs* for free swimming schools and 106 *IHIs* for associated schools. It was easily observed that there were many higher *IHIs* in free swimming schools (Figure 4).



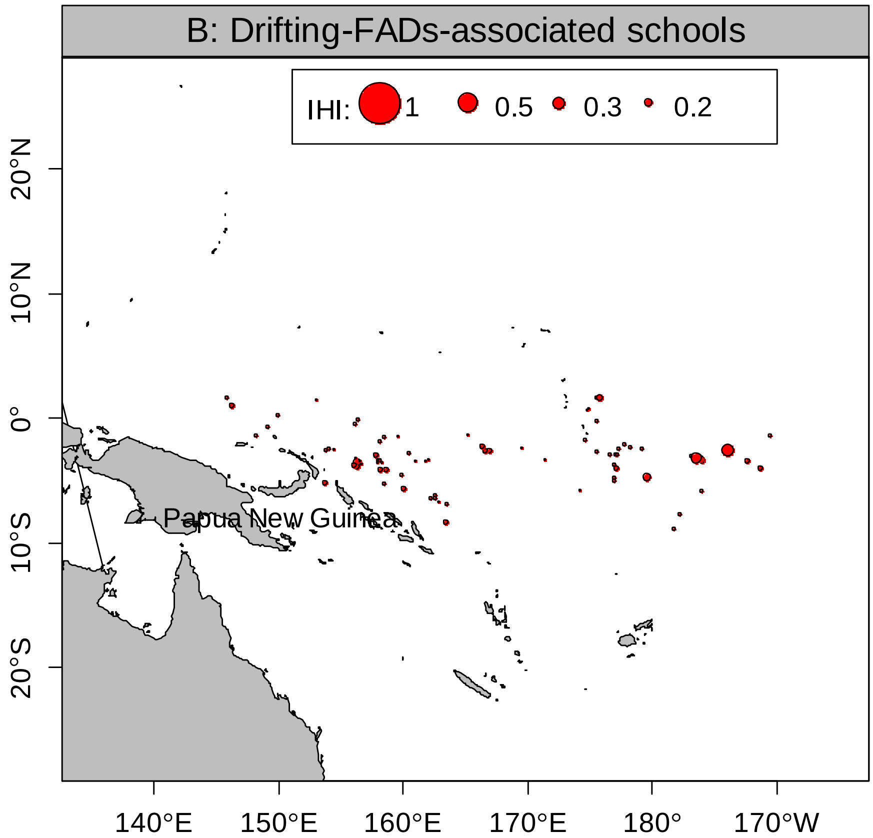


Figure 4: *Integrated Habitat Index (IHI) of each station for yellowfin tuna caught on free swimming schools* ***(A)*** *and associated to drifting fish aggregation devices (FADs)* ***(B)***

The 1000 bootstrapped 95% CIs of *IHIs* means estimated ranged from 0.2933 to 0.3608 for free swimming schools and 0.1037 to 0.1181 for associated schools. There was no overlap in the CIs for *IHI* means for the two schools, and overall the habitat quality for free swimming schools was significantly higher than for associated schools (Figure 5).

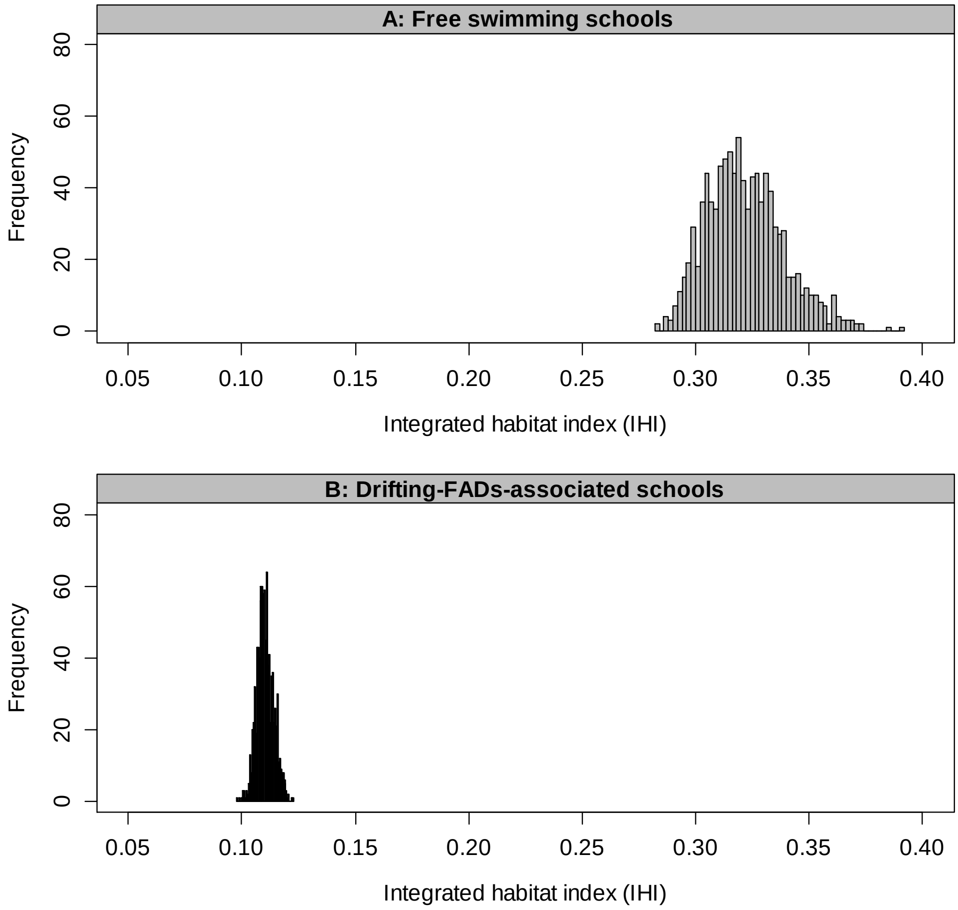


Figure 5: *range of bootstrapped integrated habitat index (IHI) for yellowfin tuna caught on free swimming schools* ***(A)*** *and associated to drifting fish aggregation devices (FADs)* ***(B)***

4. Discussion

It is difficult to test whether FADs have impacts on habitat choice of tuna without data on habitat conditions at study areas. For example, studies in the Indian and Atlantic oceans attributed the lower condition factors to the association of FADs (Marsac *et al.*, 2000; Hallier and Gaertner, 2008). They found the thorax girth, as the condition factor, for yellowfin and skipjack tuna associated with FADs was lower than for those individuals in free swimming schools. These studies inferred that the habitat quality was poor because of low condition factors (Marsac *et al.*, 2000; Hallier and Gaertner, 2008). By contrast, Robert *et al.* (2014) suggest that the poor condition of tuna drives the aggregation behavior around floating objects. They observed that the condition of skipjack associated with naturally occurring logs was lower than for those in free swimming in the Mozambique Channel, and proposed that if a free swimming school is having low foraging success their condition will be reduced, possibly encouraging aggregation behavior around floating objects to seek out conspecifics to increase their foraging capacity (Dagorn and Fréon, 1999; Fréon and Dagorn, 2000; Robert *et al.*, 2014). In the case that this associative behavior is inherent of tuna in poor condition, high densities of FADs cannot be solely responsible for negative impacts on tuna conditions. Thus, specific habitat conditions for study areas inferring the relationship between condition factors and the environment are needed to be evaluated.

The habitat model in this study examines the effect of spatial and environmental factors on the distribution of yellowfin tuna. The habitat modeling shows that free swimming schools were caught in habitat quantified as 0.2933-0.3608 and have a higher level in habitat quality compared to associated schools caught 0.1037-0.1181 in habitat quantified the same (Fig. 5).

Tuna in the form of free schools positively search suitable habitats in response to the dynamic distribution of their prey in an oceanic environment (Bromhead *et al.*, 2000). By contrast, associated schools passively move to a habitat with FADs which often drift with local currents. Thus, the possibility of an associated school encountering a high-quality habitat tends to be lower than that for a free school to some extents. This difference in behavior may partially explain why the integrated habitat quality for the free schools is higher than that for the associated schools in this study. Moreover, free swimming schools are caught during feeding events in many case (SPC, 1989), this implies that free swimming schools are caught in locations where prey availability, and subsequently habitat quality, may be naturally higher than those for associated schooling counterparts. The higher habitat quality for free swimming schools can be (partially) interpreted by this phenomenon.

In this study, the quantile regression habitat model only explained 27.5% of the deviance, which imply 1) other environmental factors such as primary production (chlorophyll-a concentration) and salinity may affect food availability and subsequent tuna distribution should be included in the habitat model, 2) further research should be conducted to adopt other modeling approach (e.g. GAM). In addition, Chinese purse seine fleet prefers to set on associated school. This preference caused that sample size for associated school was much more than that for free school, the variation of indicator for free school also have the wider range than that for associated school.

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