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RESEARCH PAPER

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Factors Influencing Successful Fishing of Tuna Free-Swimming Schools in the Equatorial Western Pacific Ocean

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Abstract

The fishing strategies of tuna purse seine fleets in the equatorial western Pacific Ocean have been characterized by a reversion to pursuing free-swimming schools of skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) in recent years. This has prompted industry to evaluate how to improve their fishing success on unassociated sets. In this study, we determined which potential factors had a significant impact on the fishing result using data collected by observers in the equatorial western Pacific Ocean. The results showed that fishing success was significantly influenced by the average sinking speed of the gear, daylight conditions, and current speed in deep layer. Fast sinking speed will reduce the chance of escape for schools under the sinking net, improving the success ratio. Success rates were higher during the periods of low light intensity, such as dusk. The net sinking speeds were affected by current speed in deep layer, which often were associated with low success rates. The influential factors and their relative influence were listed, which will help fishermen to more effectively transfer their efforts from associated sets towards unassociated sets, contributing to the sustainable use and conservation of tuna stocks in the equatorial western Pacific Ocean.

Introduction

The main fishing methods in the tuna purse seine fishery involve setting on surface free-swimming schools and floating object-associated schools, referred to as unassociated sets and associated sets, respectively (SPC, 1989; Itano, 1998; Gillett, Mccoy, & Itano, 2002; Morgan, 2011). The success rates of unassociated sets is remarkably low, as free-swimming schools are known to move quickly during this fishing process, requiring a higher degree of skill and experience from the skipper (SPC, 1989; Itano, 1998; Gillett, Mccoy, & Itano, 2002). Floating object-associated schools tend to concentrate and be stabilized under floating objects (logs, rafts, seaweed, man-made fish aggregation devices, marine mammals, etc.), making them easier to locate and capture (SPC, 1989; Itano, 2007). As a consequence, associated sets, especially those sets made on man-made fish aggregation devices (FADs), have produced the majority of yields and fishing efforts in tuna purse seine industry during the past few decades (SPC, 1989; Itano, 1998; Gillett, Mccoy, & Itano, 2002; Williams & Terawasi, 2011).

In the western Pacific Ocean, the proportion of tuna purse sets made on FADs, compared with free-swimming schools, has fluctuated from 60-70% (Miyake, Fonteneau, & Menard, 2010). FADs-associated schools typically have a larger biomass than free-swimming schools, meaning more tuna can be caught during an individual purse seine set (Fonteneau, 1991), yet this type of school is primarily composed of smaller, less valuable tunas, which diminishes the impact of increases in production on profitability (Gillett, Mccoy, & Itano, 2002). For this reason, there has been a return to vessels setting more on free-swimming schools with the intention of catching higher value tunas (Gillett, Mccoy, & Itano, 2002; Itano, 2007). Beyond that, industrial-scale purse seining on FADs leads to high fishing mortality of yellowfin (*Thunnus albacares*) or juvenile bigeye (*Thunnus obesus*) tuna and a serious negative impact on tuna population resources, which is of concern to some regional fisheries management organizations (Fonteneau, 1991; Fonteneau, Ariz, Gaertner, Nordstrom, & Pallares, 2000; Marsac, Fonteneau, & Menard, 2000; Itano, 2007; Hallier & Gaertner, 2008). In order to maintain bigeye and yellowfin tuna stocks at levels capable of producing the maximum sustainable yield in the western Pacific Ocean, the Western and Central Pacific Fisheries Commission (WCPFC) implemented a series of compatible measures to limit fishing effort on associated sets since 2008 (Hampton & Harley, 2009). For example, a 3-month FAD closure was carried out for all FAD sets in exclusive economic zones and high seas in each year (WCPFC, 2018), and these increasingly stringent measures caused purse seiner owners and fishermen to transfer partial fishing efforts to free-swimming schools as well (ICCAT, 2005).

The fishing strategy of fleets in the western Pacific Ocean has generally reverted to targeting free-swimming schools over the years (Gillett, Mccoy, & Itano, 2002; Gillett & Lewis, 2003; Morgan, 2011). Since then, improving free-school fishing success has become a main concern of the industry and studies were conducted to analyze how various environmental factors affect the success rate of seining free-swimming schools. Green (1967) discussed the relationship between fishing success and characteristics of the thermocline in the eastern tropical Pacific and found the highest success occurred in thin mixed layers over thermoclines with sharp temperature gradients. Murphy and Niska (1953) observed that tuna schools were able to escape under the sinking net when the footrope of net could not reach the depth of thermocline. Lehodey (2000) noted that a shallowing of the thermocline in the western Pacific Ocean during El Niño events assists purse seine fishing. These studies have indicated some factors could affect purse seine fishing results in different ways and to different extents, but most of them only took a single factor into the consideration of fishing process, without regard to the fact that purse seining is a process simultaneously influenced by multiple factors. Inada *et al*. (1997) researched the different impacts of various factors on the success ratio of catches during purse seining operations in the western tropical Pacific Ocean fishing grounds and discussed relationship of each factor to fish catches independently, but without consideration for the integrated effect of all factors.

In addition to environmental conditions, other factors, such as gear performance and captain experience, will affect fishing success (Karakulak, 2003; Hosseini & Ehsani, 2014; Zhou, Xu, Tang, & Wang, 2015; Tang *et al*., 2017). We evaluated the impact of 3 types of potential factors (gear-sinking performance, environmental conditions, and captain's experience), which included 10 predictor variables, to explore the integrated effect of various factors on free-swimming schools fishing success in this study and determined which have significant impacts on fishing success. The results will help fishers understand the approaches to increase the success rate on unassociated sets and encourage them to reduce the use of FADs to effectively facilitate the conservation of tuna stock in the equatorial western Pacific Ocean.

Materials and Methods

Fishing Trips

Six commercial trips were made within the fishing area between longitudes 145°-175°E and latitudes 5°N-10°S in the equatorial western Pacific Ocean from 2011-2016 (Figure 1). Data from 94 unassociated sets were obtained from scientific observers aboard 2 Chinese tuna purse seine vessels "Jin Hui No. 7" and "Jin Hui No. 9" (Table 1). The schools' types of most unassociated sets were pure skipjack tuna (*Katsuwonus pelamis*) schools, and the rest were mixed schools with skipjack tuna and yellowfin tuna. When the catch of a set was greater than 5 tons it was defined as fishing success, and otherwise, a fishing failure.

Data Measurement and Treatment

Maximum sinking depth, averaged sinking speed, current speed at 10 m, current speed at 70 m, current speed at 120 m, daylight condition, upper depth of thermocline, longitude, latitude, and captain's experience were classified into 3 groups, representing factors which may affect the success rate on unassociated sets. All factors were selected in the light of previous studies (Green, 1967; SPC, 1989; Inada *et al*., 1997; Karakulak, 2004; Tang *et al*., 2017), and fishing success on each predictor variable was evaluated based on observed data before fitting a statistical model.

Sinking Performance

Maximum sinking depth and average sinking speed were usually used as gear-sinking performance indicators (Tang *et al*., 2017). Sinking depth was measured with 10 temperature depth recorder sensors

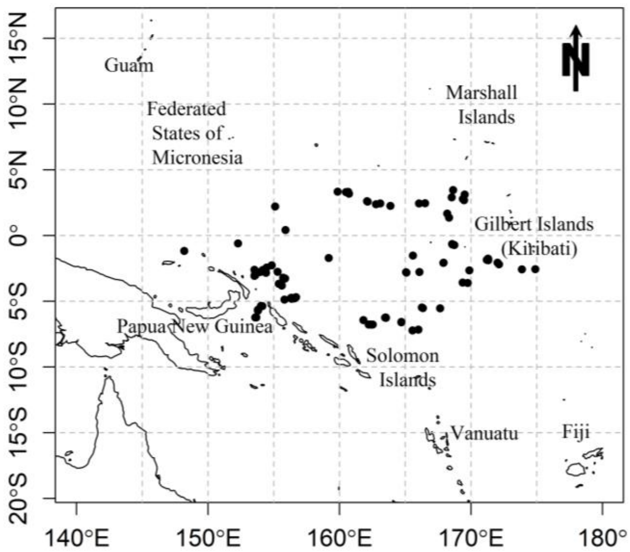

Figure 1. Fishing locations (black dots) of Jinhui No. 7 and Jinhui No. 9 in the equatorial western Pacific Ocean.

Table 1. Fishing trip information

Trips	Vessel name	Date	Number of unassociated sets	Number of successful sets	Observed success rate on fishing (%)
1	Jin Hui No. 7	2011.10-2011.11	35	17	48.57
2	Jin Hui No. 7	2013.02-2013.03	7	4	57.14
3	Jin Hui No. 7	2014.02-2014.04	12	8	66.67
4	Jin Hui No. 9	2015.03-2015.05	23	11	47.83
5	Jin Hui No. 9	2015.10-2015.11	15	10	66.67
6	Jin Hui No. 9	2016.02-2016.03	2	0	0.00
Total			94	50	53.19

(TDR-2050, Richard Brancker Research Co., Ltd, Canada) which were attached at equidistant positions of the leadline in an interval of 3 seconds. The sensors have an effective measurement range from 10 to 740 m depths and the depth measurement precision reached 5% of the full-scale range. Of the 10 fixed sensors, the central one was considered to be most effective at measuring the maximum sinking depth. The ratio of maximum sinking depth to duration of the complete sinking process was calculated as the average sinking speed of the gear. Additionally, the corresponding temperature at each measured depth was also recorded by TDR-2050 sensors, which were used to calculate the upper depth of thermocline.

Environmental Conditions

Thermocline depth, current velocity, and daylight condition were regarded as potential oceanographic descriptors that affected free-swimming school fishing success (Green, 1967; SPC, 1989; Inada *et al*., 1997). The upper depth of thermocline (*T*) was estimated using the sinking depth and temperature data recorded by TDR-2 050 sensors. The threshold standard of the thermocline was:

$$\left|\frac{\Delta Tem}{\Delta Z}\right| = 0.05\ ℃ \cdot m^{-1} \quad (1)$$

where *Tem* is temperature and *Z* is depth. If the absolute value of vertical temperature gradient was greater than or equal to 0.05 °C·m^{-1}, the water layer depth was defined as *T* (Song, Zhang, & Zhou, 2008). The vertical temperature gradient is calculated as:

$$G_z = \frac{Tem_{z+1} - Tem_z}{T_{z+1} - T_z} \quad (2)$$

where Tem_Z and T_Z are the arithmetic average values of temperature and depth binned together in increments of 10 (i.e., 0-10 m, 10-20 m, 20-30 m…etc.) and G_Z is the vertical temperature gradient value between the standard depth T_Z and T_{Z+1}.

Current speeds were acquired by a Doppler flow meter (JLN-628, Japan Radio Co., Ltd, Japan) in 3 layers of 10, 70, and 120 m, which correspond to the representative depth in sea surface, middle layer, and deep layer, respectively.

Daylight conditions, or the relative light intensity at corresponding fishing periods, were categorized into 2 groups: light condition (setting between 6:00 am to

16:00 pm) and dark condition (setting before 6:00 am or after 16:00 pm). This variable was included to describe fishing conditions with good and poor light intensity, which affect the ability of tuna to visually perceive fishing activity.

In addition, latitude and longitude were included in the model to implicitly represent the spatial variability in sea conditions.

Captain's Experience

In tuna purse seine fisheries, a captain's fishing experience is an important factor that influences the result of a set to great extent (Karakulak, 2004). Logically, the captain's fishing experience should be proportional to his age and years working at sea. However, the history of Chinese far-seas tuna purse seine fishery is very short and most captains in this industry transferred from coastal fisheries, such as coastal light-purse seine and trawl fisheries (Chang & Zhang, 2014). The experience in fishing tuna free schools of two captains from "Jin Hui No. 7" and "Jin Hui No. 9" was very similar and therefore difficult to effectively assess the difference between two captains' effect on fishing by using variables like experience (in years at sea) or age. In order to determine whether captain's experience or skill will affect the fishing result, captain's name (captain A and B) was used as a categorical variable to indirectly represent fishing experience in this study.

Model Development

For the situation that some factors may not linearly related to the sinking process (Tang *et al*., 2013), a generalized additive model (GAM), which allows more flexibility in addressing both linear and non-linear relationships (Lehmann, 2002), was developed to quantify the relationship between fishing success and various factors based on data collected by at-sea observers during the commercial fishing operations of Chinese tuna purse seine vessels.

The information on predictor variables included into initial GAM was listed in Table 2, eight of which are continuous variables with the remainder as two categorical variables. The response variable is categorical, with the fishing result of sets noted using values 1 and 0 to indicate either success or failure, respectively. The GAM used a logit link function with a binomial error distribution to estimate the probability of fishing success (p). The link function related response variable to all candidate predictor variables representing various potential factors. The initial GAM is given as followed:

$$\text{logit}(p) = \text{Dc} + \text{Cap} + \text{s}(Lat) + \text{s}(Long) + \text{s}(T) + \text{s}(D) + \text{s}(S) + \text{s}(V_{10}) + \text{s}(V_{70}) + \text{s}(V_{120}) + \varepsilon \quad (3)$$

where *Dc*: daylight condition; *Cap*: captain's name; *Lat*: latitude; *Long*: longitude; *T*: upper depth of thermocline; *D*: maximum sinking depth; *S*: average sinking speed; V_{10}: current speed at 10 m; V_{70}: current speed at 70 m; V_{120}: current speed at 120 m; s: spline smoother; ε: residual error following a binomial distribution.

Based on Akaike's information criterion (AIC), a backward stepwise regression procedure was used to select a subset of variables among a list of candidates in initial model. With considerations for model fit and the number of parameters in use, the model with the smallest AIC value is regarded as the best model. In addition, a measure of relative influence was calculated for each variable retained depending on the percentage of total deviance explained per degree of freedom.

Model Validation

Cross validation is a model evaluation approach that indicates how well a model can make new predictions for cases it has not already seen (Starkweather, 2011). Here, a commonly accepted validation strategy, the 10-fold cross validation was employed to estimate the discriminatory ability of final model. Dataset was randomly split into 10 folds. Nine folds were combined to be a training set for fitting the model and the remaining one was used as a test set for testing the model performance by calculating the area under the curve (AUC) of the receiver operating

Table 2. Summaries of predictor variables used for model development

Groups	Variables	Units	Minimum	Maximum	Mean	Standard deviation(SD)
Gear-sinking performance	*D*: maximum sinking depth	m	145.24	278.60	199.79	29.09
	S: averaged sinking speed	m/s	0.12	0.25	0.19	0.02
	V_{10}: current speed at 10 m	m/s	0.00	0.40	0.10	0.09
	V_{70}: current speed at 70 m	m/s	0.00	1.30	0.39	0.28
	V_{120}: current speed at 120 m	m/s	0.00	1.50	0.58	0.29
Environmental condition	*Dc*: daylight condition	-	-	-	-	-
	T: upper depth of thermocline	m	75.27	195.39	142.07	25.60
	Long: longitude	deg	148.20	174.90	-	-
	Lat: latitude	deg	-7.22	3.45	-	-
Captain's experience	*Cap*: captain's name	-	-	-	-	-

characteristic (Fielding & Bell, 1997). A score of 1 indicates fishing results are perfectly discriminated, while a score of 0.5 indicates that a model has no discriminatory ability (Swets, 1988). This procedure was repeated 10 times until each fold was used as a test data set, and the evaluation was averaged over the 10 runs.

Relationship between Response and Predictor Variables

Partial dependence plots (Friedman, 2001) were used for plotting the relationships between tuna free-swimming schools fishing success and each predictor variable after accounting for the average effects of all other variables in the final model. The fitted functions from the partial dependence plots provide an indication of how fishing success on unassociated sets related to each predictor variable.

Results

Observed Fishing Success

According to observed fishing success (Figure 2), the success rate on unassociated sets under dark conditions was 0.74 and 0.45 under light conditions. Two captains had similar fishing success when seining free schools. With respect to spatial variability, sets which had latitude ranged in 1.5°S - 0.5°N possessed the lowest success rate and longitude ranges had a similar fishing success close to 0.5. A declining trend in fishing success was found in grouped current speeds at 70 m and 120 m, while an inverse trend occurred in grouped current speed at 10 m. There was no constant trend in fishing success between each group of upper depth of thermocline and maximum sinking depth, while higher success rates were found to be associated with higher net sinking speeds.

Model Results

Daylight condition, current speed at 120 m, and average sinking speed of gear were found to be significant terms (P<0.05) (Table 3). Latitude, longitude, current speed at 10 m, and maximum sinking depth were not found to have a significant effect on the fishing success, while the model containing these variables gave the smallest AIC value. Therefore, a total of 7 variables were retained in the final model (Table 3), which explained 35.3% of total deviance. The four most influential variables, as determined by the calculation of relative influence, were average sinking speed, latitude, daylight condition and current speed at 120 m (Table 4).

Model Validation

The AUC value of the final GAM was 0.87 and it was adjusted to 0.82 after employing a 10-fold cross validation. The cross validated value evaluates the discriminatory ability of the model more accurately, indicating the model could effectively discriminate between fishing results, which included response variable and suggested reasonable predictive ability.

Relationship between Response and Predictor Variables

The prediction of final model indicated that predictors were linearly related to fishing success, except for latitude. A high fishing success occurred

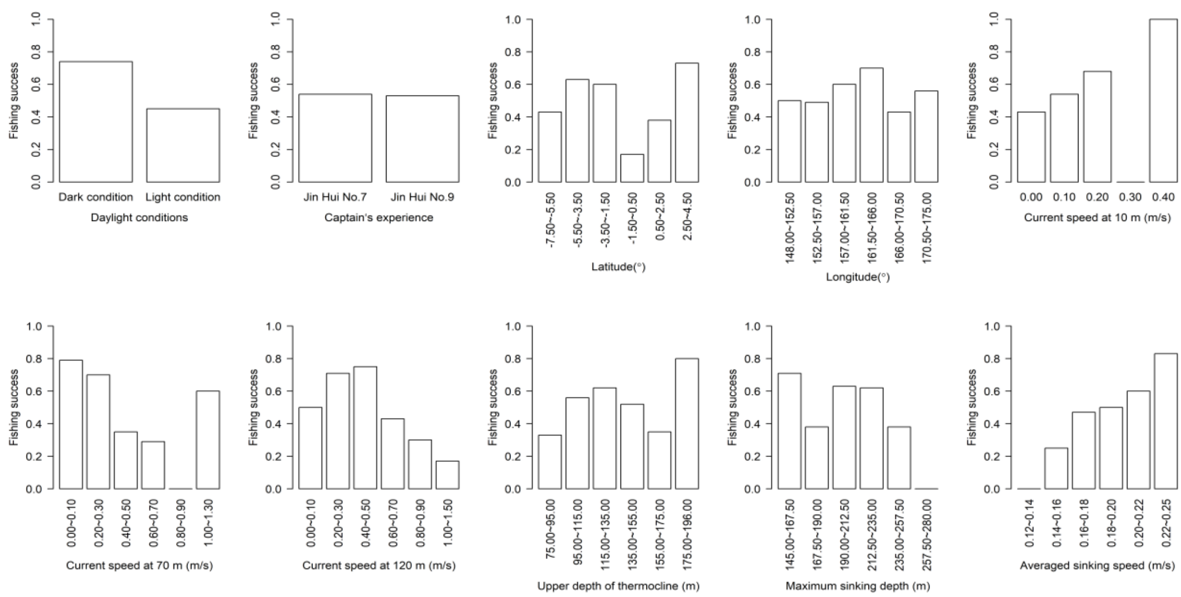

Figure 2. Fishing success rate of each potential factor, using observed data. The ratio of the numbers of successful sets to total sets was calculated as the observed fishing success.

Table 3. Statistical results of the final generalized additive model

Variables	Estimate	Standard error	Z value	Pr(>|z|)	AIC
Intercept	1.233	0.546	2.260	0.024	106.234
Dc	-1.573	0.650	-2.418	0.016	110.680
Variables	Estimated degrees of freedom	Reference degrees of freedom	χ^2	*P*-value	AIC
Lat	3.474	3.844	9.355	0.051	112.110
Long	1.000	1.000	2.601	0.107	109.712
V_{10}	1.210	1.388	2.400	0.140	107.472
V_{120}	1.000	1.000	8.622	0.003	111.017
D	1.369	1.651	4.574	0.115	108.556
S	1.000	1.000	6.157	0.013	111.752

Note: The AIC value for this model as the designated variable was dropped. With all variables included, AIC is equal to 106.234

Table 4. Ranked relative influence of model terms as a percentage of total deviance explained per degree of freedom

Model terms	Relative influence (%)
Average sinking speed	30.39
Latitude	18.76
Daylight condition	14.63
Current speed at 120 m	10.14
Longitude	5.90
Maximum sinking depth	5.14
Current speed at 10 m	4.78

between 1°S and 4°S or north of 2°N. The partial dependence plots revealed that fishing success on unassociated sets increased as current speed at 10 m and average sinking speed increased, while longitude, current speed at 120 m, and maximum sinking depth were negatively correlated to fishing success. In addition, fishing success was greater in dark conditions than in light conditions (Figure 3).

Figure 4 showed how success rates on unassociated sets depend on the integrated impact of several critical variables, with considering the average effect of other predictors retained in the final model. High success rates occurred with higher averaged sinking speed of the gear and lower current speed in deep layer. Compared to the light conditions, the fishing success under dark conditions was easier to get a greater rate when the other two variables were set to a same level.

Discussion

Average Sinking Speed of Gear

Average sinking speed of gear was the most critical factor affecting the fishing success, according to the rank of relative influence. Increased sinking speed can effectively shorten the time fish have to escape while purse seining in fishing grounds with a relatively deep thermocline (Wang *et al*., 2014). As Inada *et al*. (1997) indicated, the set will fail for surface schools unless the center portion of the footrope reaches the thermocline within 2 minutes in the western tropical Pacific Ocean. In fact, the Japanese fleet has identified that the key to improving free fishing efficiency is increasing the net sinking speed to decrease fish escape (WCPFC, 2015). The mean of the average sinking speed of the study is 0.19 m/s, using this value, the net success was 57% and 87% in light and dark condition, respectively, with other factors held at their average values. If the sinking speed is increased by 7% by using larger mesh nets with knotless net panels, as Japanese vessels have done, the model predicts that success will be improved to 67% and 91%, respectively. Therefore, increasing sinking speed is a feasible, effective way to improve success rate.

Daylight Condition

Daylight condition was another critical factor affecting the fishing success in our study. The visibility in seawater varies greatly over the course of a day, corresponding with the position of the sun in the sky and the resulting intensity and depth of light directed into the ocean. Since most tunas are active visual predators (Fonteneau & Taib, 1994), the variation of visibility in seawater may limit the visual field of tunas and produce differences in the fishes' ability to escape at different times of day. For instance, the schools are often unable to see and dive below the net in pre-dawn darkness, which is one of the reasons the success rate on associated sets in the western Pacific Ocean is so high during the early morning hours (Gillett, Mccoy, & Itano, 2002; Itano, 2007). This hypothesis can be also supported by observations made by at-sea observers that fishes' gills and fins were always tangling with the net when hauled aboard in the late afternoon. The success rate on unassociated sets was higher in dark

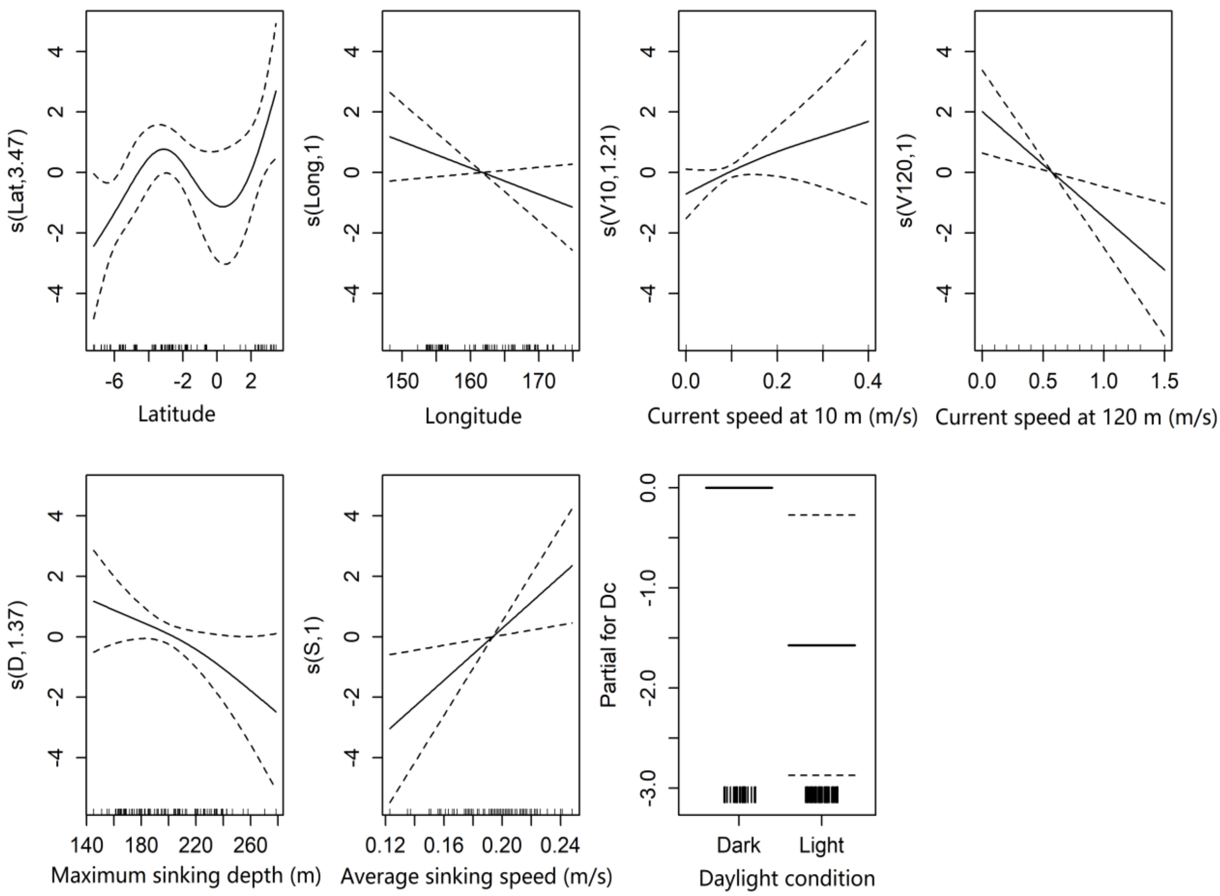

Figure 3. Variation of fishing success on unassociated sets predicted by the final model using seven predictors. Dashed lines represent two standard error confidence intervals.

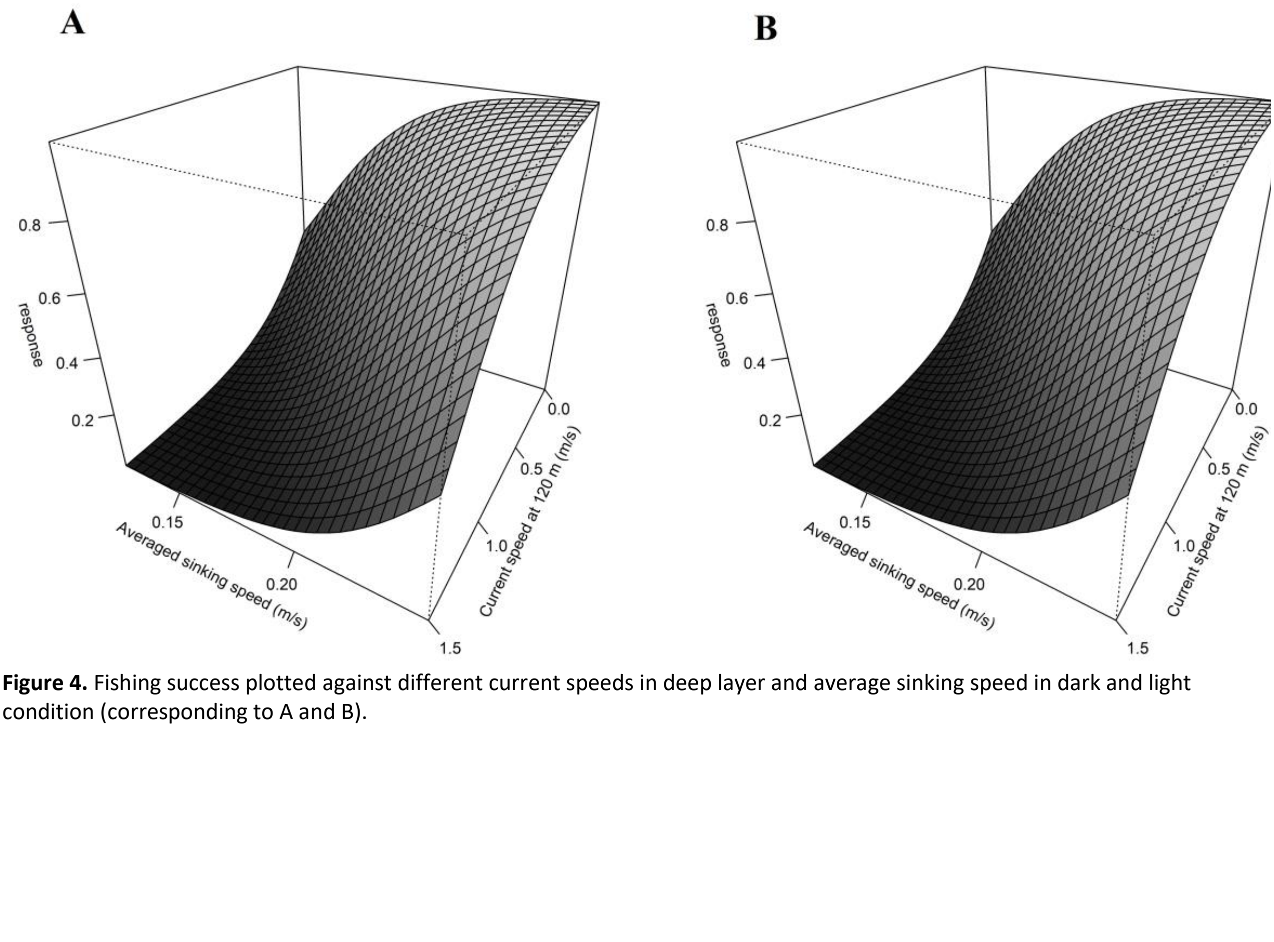

Figure 4. Fishing success plotted against different current speeds in deep layer and average sinking speed in dark and light condition (corresponding to A and B).

conditions than in light conditions, which also supports our hypothesis. For the reasons given above, one of the explanations for the low rate of aborted hauls in dark condition is likely to be the reduced visibility of the net.

Other foreign fleets also believe, via experience, that seining on free-swimming schools during the early morning or late afternoon increase the chance for success (SPC, 1989). However, most unassociated sets occurred during the day with high light intensity, while only 3% of total unassociated sets occurred before sunrise (Harley et al., 2009), motivating fishers who do not currently employ the strategy of seining in dark fishing conditions to adjust their fishing tactics to achieve better results. We also advocate for more refined measurements of light intensity or the clarity of the water during fishing, rather than a binary categorical classification. This may more effectively describe the effect of daylight conditions on the success rate of unassociated sets.

Current Speed in Deep Layer

Of the three current speeds at different layers, only current speed in the deep (120 m depth) layer significantly influenced set success, while current speeds in sea surface and middle layer did not. This is likely because compared to the low current speeds in sea surface and middle layers, higher current speed appeared frequently in deep layer. The high current speed in deep layer produced greater water resistance, forming a negative effect on the sinking process of the net while pursing fish schools, resulting in a higher failure rate. A similar conclusion was drawn by Inada *et al*. (1997), who concluded that complex currents in the subsurface layer affected the behavior of the sinking net frequently in the western tropical Pacific Ocean fishing grounds, and such gear performance influenced success ratio of the sets.

The Upper Depth of Thermocline (Thickness of Mixed Layer)

Previous studies have verified that characteristics of the thermocline could affect the success of the surface fishery, as the sharp temperature gradient within the thermocline is a natural barrier to limit the vertical migration of tunas so that it prevents the schools from escaping under the sinking net (Brill, 1994; Brill, Lowe, & Cousins, 1998; Rill & Lutcavage, 2001). For instance, Brock (1959) discovered surface fisheries for tunas seem to be confined to those areas which possess a relatively shallow mixed layer. Tester and Staff (1957) found that the shallow mixed layer was a possible cause for relatively high catches of albacore. Blackburn and Williams (1975) indicated that areas of high apparent skipjack tuna abundance in the eastern tropical Pacific were limited to areas where the mixed layer thermocline is less than 40 m deep. However, the upper depth of thermocline didn't influence the success rate significantly (P>0.05) in this study, possibly due to the thermocline in the western Pacific Ocean, which is commonly deeper in contrast to other oceans such as the eastern tropical Pacific and western Indian Ocean (Itano, 2007). As Evans, Mclain, and Bauer (1981) indicated, successful skipjack tuna sets in the eastern tropical Pacific were limited to mixed layer depths of less than 85 m, while the mean of thermocline depth in the western Pacific Ocean in this study is 142.07 m with SD of 25.36. The deeper the mixed layer is, the longer the net will take to reach the thermocline and the fish schools will have more opportunity to escape capture, is essence stripping the thermocline of its barrier effect.

Multiple Approaches to Increase Success Rate on Unassociated Sets

Gear innovation is an effective way to improve the success rate on seining tuna free schools. Most modifications to purse seine technology, especially improvements on fishing gear in the western Pacific Ocean, were driven by a desire to improve the success rate on unassociated schools during the 1980s (Itano, 1998; Itano, 2007). As one of the basic styles of net commonly used in the western Pacific tuna fishery, Japanese purse seines are characterized by large, vertical panels of lightweight, knotless nylon webbing with thin twine and large mesh sizes (Itano, 1998). Such a net structure usually facilitates a faster sinking speed due to the reduced water resistance (SPC, 1989; Itano, 1998), which helps produce a higher success rate. Compared to Japanese nets, U.S. style nets were heavily built in construction of knotted, horizontal strips, initially designed to be used in the eastern tropical Pacific with a shallow thermocline and plankton rich water (Gillett, Mccoy, & Itano, 2002; Itano, 1998; Itano, 2007). Over time, U.S. nets were adjusted to become lighter in construction with larger mesh sizes, similar to Japanese seines, for use in the western Pacific Ocean (Itano, 2007). Nevertheless, the U.S. vessels retained the use of knotted webbing and objected to complete adoption of the Japanese style to fishing in areas of strong current and withstand high pursing speeds (Gillett, Mccoy, & Itano, 2002; Itano, 2007).

Many other seining techniques and strategies have been also adopted to pursue a high success rate besides modifying the fishing gear. In some cases, lengthening the time that schools stay near the surface is equivalent to reduce the duration of net sinking and likely creates a similar effect of increasing catch success and production. In the Australian bluefin tuna (*Thunnus maccoyii*) fishery, a live bait carrier was used to chum tuna schools and coax them to stay around the surface longer during the setting operation (SPC, 1989). Japanese fleets similarly applied a sprayer to simulate the large disturbances caused by surface baitfish concentrations (Wang *et al*., 2014).

Future Work

The negative impact on the tuna stock status and ecosystems via FAD fishing methods has fostered a trend of strengthening management measures for controlling and reducing high FAD usage within regional fishery management organizations. At present, the main attractions of free-swimming school sets are not only related to the higher commercial value of fishes captured, but also related to achieve a conservation-oriented goal to promote the long-term sustainable use of tuna fishery resources. As a result, such organizations are actively encouraging tuna purse seine owners to transfer their efforts towards free-swimming schools through the technology improvement and accumulated experience, the progress of which require more studies.

This study focused on the relationship between fishing success and various influential factors by employing a generalized additive model based on observers' data. The results indicated that several fishing strategies could be adopted to encourage fishers to increase efforts on capturing free-swimming tuna schools. This includes taking full advantage of dark conditions and reduced visibility of the net, increasing sinking speed of the net via improving gear performance, and avoiding areas with strong currents. However, factors influencing the success of targeting free-swimming schools are not limited to those discussed within this study. Other indicators should be considered to account for factors that are hard to quantify (e.g. captain's experience and skill). Therefore, more complete data collection and investigation is required to discover and scale the effect of influential factors and other potential factors, such as captain's experience at sea, the sound stimuli in water (Hosseini & Ehsani, 2014), reactive behavior of the schools, in addition to other environmental factors. This will help to create a more comprehensive analysis of the integrated impact of all potential factors on tuna free-swimming school set success.

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