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RESEARCH PAPER

Longline Hook Selectivity for *Branchiostegus japonicus* (Houttuyn, 1782) and *Dentex tumifrons* (Temminck & Schlegel, 1843) in the East China Sea

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Abstract

Bottom longline fishing of red tilefish (*Branchiostegus japonicus*) is one of the most important commercial of fishing in the East China Sea. The present study aimed to investigate hook selectivity in *B. japonicus* and *D. tumifrons*, by means of experiments using three hook sizes (“J”: #15, #13 and #11) and was conducted in the East China Sea from June to August 2018. Altogether 602 *B. japonicus* fish and 858 *D. tumifrons* fish were caught. With respect to the size of the hook used, the total length-frequency varied significantly for both *B. japonicus* and *D. tumifrons* that were caught. The total length and four mouth parameters (upper and lower jaw length as well as height and width of mouth opening) of the two species showed a positive linear relationship. A logistic model created using the maximum likelihood method was used for elucidating hook selectivity; the best fit model with the minimum Akaike’s Information Criterion value was selected as the final model. The 50% selection lengths were 224.827 and 233.179 mm for *B. japonicus*; 201.461 and 202.603 mm for *D. tumifrons* using “J” #13 and “J” #11 hooks, respectively. To preserve the reproductive potential of younger fish in the stocks, the size of the “J” #13 hook was selected as the minimum hook size that should be used for the sustainable development of bottom longline fishing for *B. japonicus* and *D. tumifrons*.

Introduction

The red tilefish (*Branchiostegus japonicus*) and the yellowback sea bream (*Dentex tumifrons*) are small- and medium-sized demersal fish, respectively, that can be found in warm water. They are widely distributed from the coasts of the Honshu island of Japan to the South China Sea (Okumura, 1999; Zhang et al., 2007; Mitamura et al., 2005; Yokota et al., 2006; Xu, Chen, Zhang, & Zhu, 2018). These two species are most abundantly found in the East China Sea (Zhang et al., 2007). The central fishery of *B. japonicus* in the East China Sea resides at the depth of 52–200 m; whereas *D. tumifrons* is found exclusively below 60 m, found at a depth of 120–200 m range (Zhang et al., 2007). The two species show similar living conditions, their habitat consisting primarily of muddy silt substrate. Bottom longline fisheries can therefore catch *B. japonicus* accompanied with a bycatch of *D. tumifrons*. Since the 1990s, *B. japonicus* fishing has been managed using bottom gillnets, bottom trawls, and longline fishing with a small number of proportion catch (Xu et al., 2018). However, the use of gill nets and bottom trawls has been extensively precluded for some elements of the bottom topography (e.g., isolated sea mounts and banks) (Sousa, Isidro, & Erzini, 1999). Conversely, longline fishing is beneficial because it can be used to comb through difficult underwater terrain (e.g., sea bed) and has better species selectivity (Erzini, Goncalves, Bentes, Lino, & Ribeiro, 1998). With the increasing awareness of the Chinese government about the protection of fishery resources and the continuous extension of the fishing moratorium (lasting for 3–4.5 months), use of both trawling and gillnetting has been restricted. During fishing moratorium, with the exception of longline fishing, trawlers and gillnets are not permitted to engage in fishing operations. As a result, longline fishing has been prioritized over the past decades, and has become one of the most dominant fishing gear in the East China Sea. As a typical bottom longline, this system is designed to target the specific living habits and migratory behavior of *B. japonicus*. *B. japonicus* is a diurnal species; they primarily remain in their burrow during the night and are active during the day (Mitamura et al., 2005). They also show strong site fidelity, indicating that this species is possibly not highly migratory (Yokota et al., 2006; Hondoh, Masuda, & Tsuzaki, 2002).

Many studies have investigated hook selectivity, examining various species and hook sizes, by including both recreational fisheries handlines and longlines from commercial fisheries (Yamashita, Shiode, & Tokai, 2009; Tuncay Ateşşahin, Duman, & Cilbiz, 2015; Stergiou & Erzini, 2002; Erzini, Gonçalves, Bentes, Lino, & Cruz, 1996; Peksu, Uzer, Yildiz, Ayaz, & Karakulak, 2020). Although logistic type models and unimodal models are typically used to describe the selectivity of trawls and gillnets, respectively, both these models have been used in size selectivity for hooks, however, there is still no clear consensus on the form of the size selection curve for hook and line gear. (Czerwinski, Juan C. Gutiérrez-Estrada, Casimiro-Soriguer-Escofet, José A. Hernando, 2010; Stergiou & Erzini, 2002; Ralston, 1990; Erzini et al., 1996; Sousa et al., 1999). That size selectivity is influenced by the relationship between fish size and mouth size has been well established (Yamashita et al., 2009; Tang et al., 2016; Erzini, Gonçalves, Bentes, & Lino, 1997). Describing this relationship thoroughly is essential to determine hook selectivity in bottom longline fisheries (Koike, Takeuchi, Ogura, Kanda, & Arihara, 1968; Erzini et al., 1997; Karpouzi & Stergiou, 2003; William et al., 2015). The relationship between fish size and mouth size has shown different results, which are generally linear or may also be non-linear. Erzini et al. (1997) suggested that a non-linear relationship would be both suitable to use unimodel models and logistic type models as a function of hook size; on the country, a liner relationship is more suitable for logistic curve analysis (Sousa et al., 1999; Yamashita et al., 2009). Although *B. japonicus* longline fishing is an important commercial activity in the East China Sea, there has not been sufficient research about hook selectivity. There have been only two studies on the hook selectivity of *B. japonicus* (Yamashita et al., 2009; Yamashita, Ochi, Shiode & Tokai, 2010). In both studies, the logistic type model was proven appropriate for longline selectivity for *B. japonicus*. Yamashita et al. (2009) found that “J” #10 and “J” #12 hooks are currently used are too small to optimize yield per recruit. Then, Yamashita et al. (2010) demonstrated that two different-shaped hooks have no difference in size selectivity. This study aimed to explore the relationship between the two most commercially-important species in the East China Sea (*B. japonicus* and *D. tumifrons*) and different hook sizes used in bottom longline fishing in this area. We aimed to determine the minimum hook size required for selecting mature fishes, and thus provide a reference for the sustainable development of bottom longline fishery.

Materials and Methods

Experimental Area and Data Collection

Experiments were conducted in the East China Sea from June to August 2018 using three hook sizes (“J”: #15, #13, and #11, “XINDA” brand made in China) (Figure 1). The influence of confounding factors was minimized by keeping all factors other than hook size consistent throughout the experiment (e.g., length of the main and branch lines and bait size). Standard fishing equipment was used: the mainline was 2400 m long with a diameter of 1.22 mm; furthermore, 1.2 m long branch lines (0.43 mm diameter) were connected to the mainline at intervals of 2 m. The mainline was coiled in round plastic tubs with rubber rims for fixing the hooks and the number of hooks per tub was 1200. Squid (*Loligo japonica*) baits of similar size and curing were used for all treatment modalities.

To ensure that sufficient samples were collected for the selective analysis, the experiment locations in the traditional fishing ground were decided upon by fishermen. The setting time was approximately 15–20 min, depending on the sea conditions. An hour after setting, the fishermen started to haul hooks to prevent the catch from being eaten by predatory fish species. The entire process of hauling lasted for approximately 2 h. We conducted experiments at six locations and a total of 18 longline sets were carried out. At each location, the longline sets were conducted three times (one set of each hook size with 1200 hooks), and each longline set was conducted using a single hook type. The major catches were *B. japonicus* and *D. tumifrons* in June and August, respectively. The ocean floor topography, where the targeted species were known to inhabit, in the catch area consisted of rugged sand ranging from 60 to 120 m in depth.

For each hook size, 39 hooks were sampled for measuring the relevant parameters of each hook size (i.e., hook length, hook width, front length, and gape)

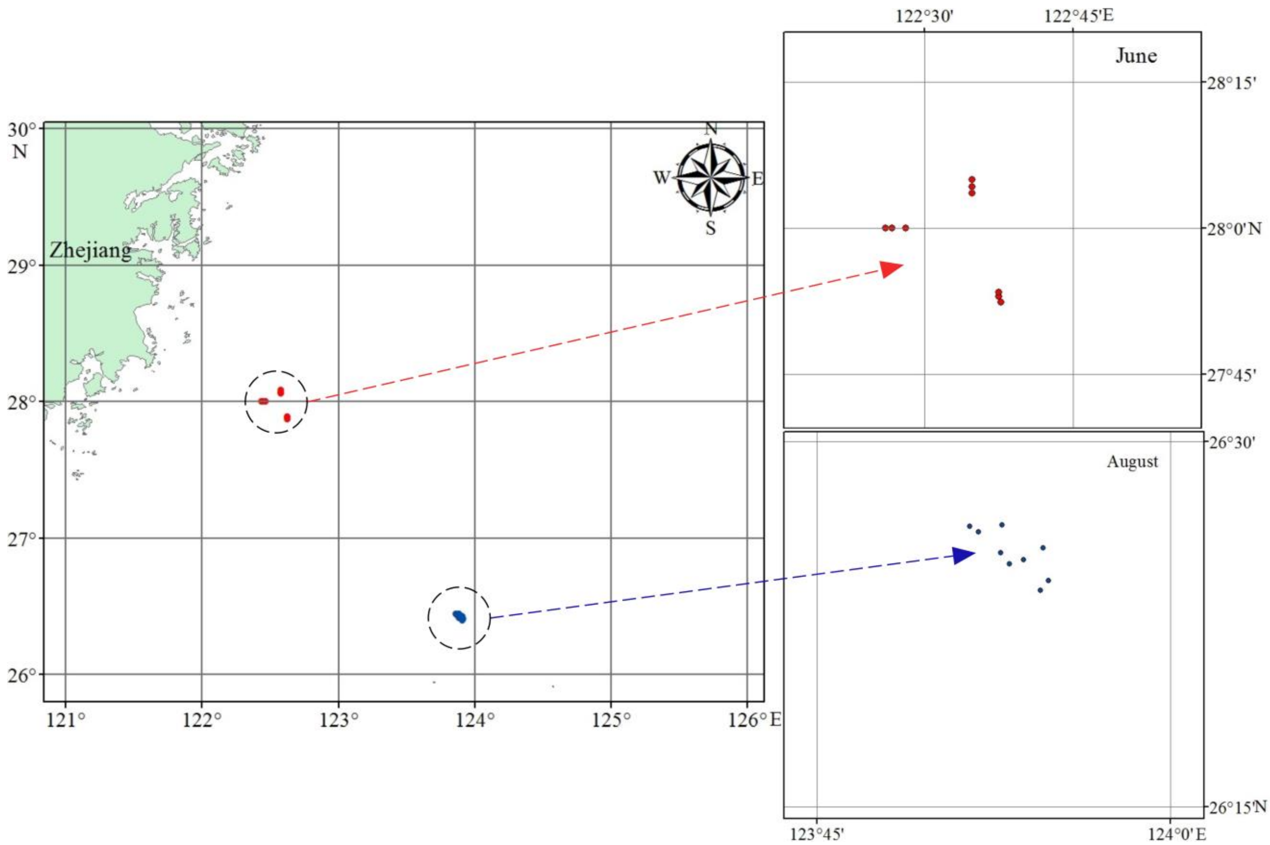

Figure 1. Location of fishing ground where the experiment was conducted (red point: June, blue point: August)

(Figure 2). Vernier calipers were used for measurement, after confirming that they met the requirements of our data analysis with 0.01 mm precision. The total length (from the tip of the snout to the tip of the upper lobe of the caudal fin while extended along the axis of the body) and mouth shape parameters of *B. japonicus* and *D. tumifrons* caught using each hook size were measured to the nearest mm. The mouth shape parameters included the height and width of mouth opening, as well as the upper and lower jaw length (Figure 3). In the text, the subscripts *B* and *D* of mouth shape parameters represent *B. japonicus* and *D. tumifrons*, respectively.

Statistical Analysis

Different models have been used in previous studies for studying hook selectivity. However, Millar (1995) and Erzini et al. (1998) hypothesized that a logistic curve was more appropriate for small–sized species. Therefore, the logistic model was used to determine hook size selectivity in bottom longline fisheries in the East China Sea on the target species described above (Erzini et al., 1998; Alós, Cerdà, Deudero, & Grau, 2008; Yamashita et al., 2009; Czerwinski et al., 2010). The equation of the logistic curve can be expressed as follows:

$$S_{ij} = \frac{1}{1 + e^{-b_i(l_j - L50_i)}} \quad (1)$$

Where S_{ij} is the size selectivity for hook size *i* and size class *j*, b_i is a parameter determining the slope of the selection curve for *i*; l_j is the mid point of the size class *j* and $L50_i$ is the length at 50% selection.

The logistic model implemented in Excel for estimating the selection parameters was proposed by Kirkwood & Walker (1986) and Wulff (1986). It is assumed that the parameters of the selectivity curve are a function of hook size. With reference to Czerwinski et al. (2010), in our case mean length and hook width were used to estimate the parameters of logistic curves as linear functions hook size:

$$b_i = AH_i + B, \; L50_i = CH_i + D \quad (2)$$

Where *A*, *B*, *C* and D are parameter of the linear functions and H_i is the hook width for hook size *i*.

Based on the hypothesis that the fish of length *l* caught with hook size *i* has a Poisson distribution, the parameters of the selection curve can be estimated by maximizing the likelihood function (Erzini et al., 1998; Stergiou & Erzini, 2002; Czerwinski, Erzini, Juan C. Gutiérrez-Estrada, & José Antonio Hernando, 2009).

The models that were obtained were compared using the the Akaike's Information Criterion (AIC); the model with the lowest value was chosen as the best predictive model (Akaike, 1973; Yamashita et al., 2009). The Kolmogorov–Smirnov (K–S) test was used to determine the differences between the size–frequency

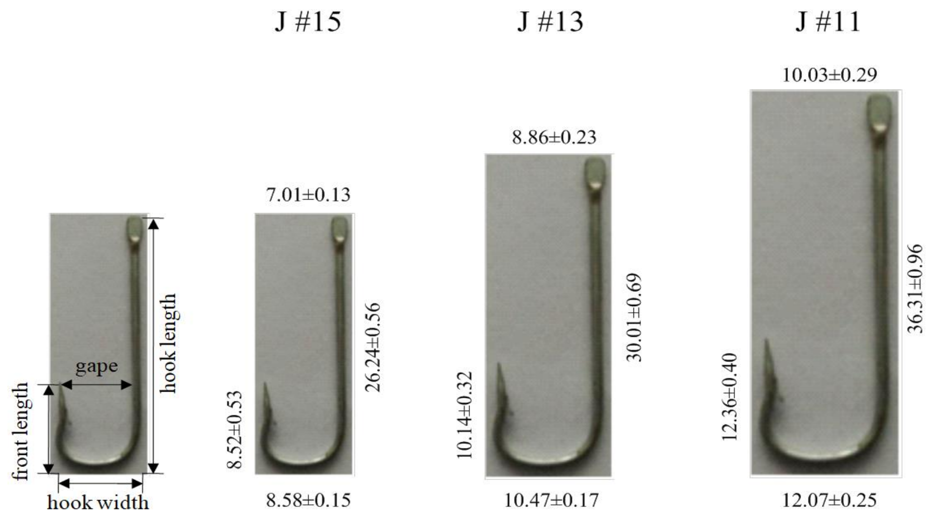

Figure 2. Shape and dimensions of three size hooks used in the selectivity study. Means and standard errors based on a sample size of 39 hooks for each type.

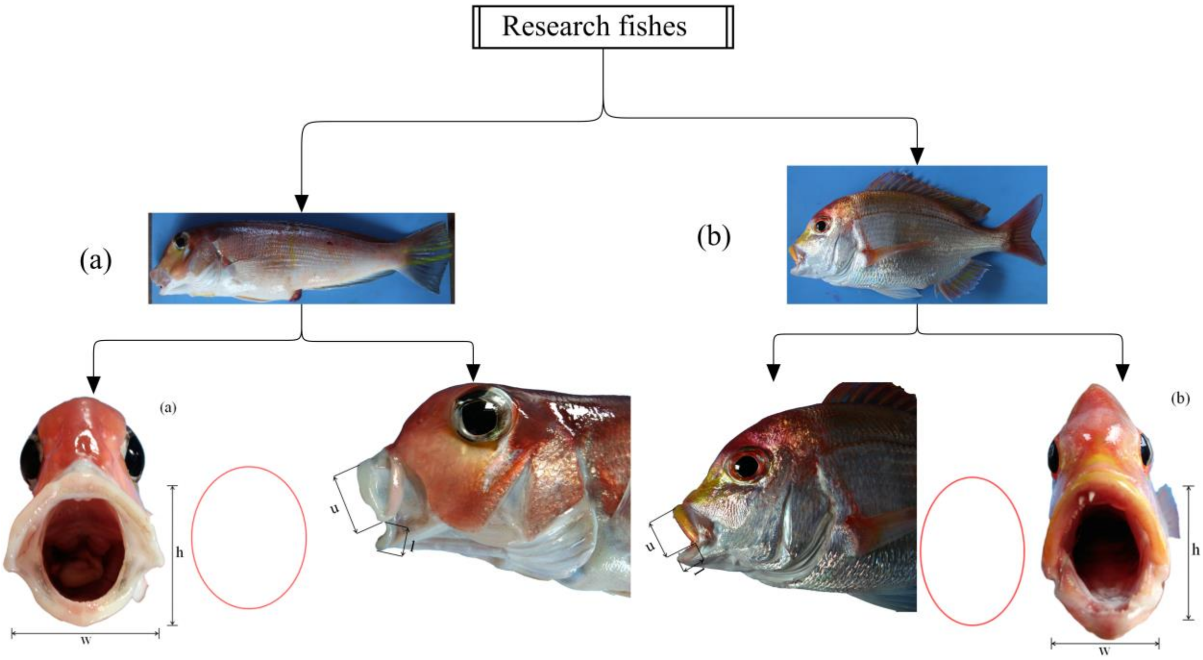

Figure 3. The measured parameters of *B. japonicus* (a) and *D. tumifrons* (b): h=height of mouth opening, w=width of mouth opening, u=upper jaw length, l=low jaw length

distributions, mouth parameters of fish caught by hooks of different sizes and the height to width ratio of the mouth opening of different fish (Siegel & Castellan, 1988; Karakulak & Erk, 2008). The hypothesis of no difference in each hook size width was analyzed by one-way analysis of variance ANOVA. Statistical difference was set at P<0.05.

Results

Comparison of Hook Shapes

Our analysis showed that hook length, front length, and gape with hook width presented a linear relationship (Figure S1). The fitted regression equations were as follows:

$$HL = 2.8134HW + 1.6592 \ (R^2 = 0.9223) \quad (3)$$

$$FL = 1.0820HW - 0.8897 \ (R^2 = 0.9459) \quad (4)$$

$$G = 0.8573HW - 0.2656 \ (R^2 = 0.9547) \ (5) \quad (5)$$

Thus, we used hook width as variable for hook size in the selectivity calculation. All hooks had the same shape, regardless of their size. The findings of our one-way ANOVA demonstrated that there were statistically significant among the three hook sizes used (“J”: #15, #13 and #11) (Figure S2).

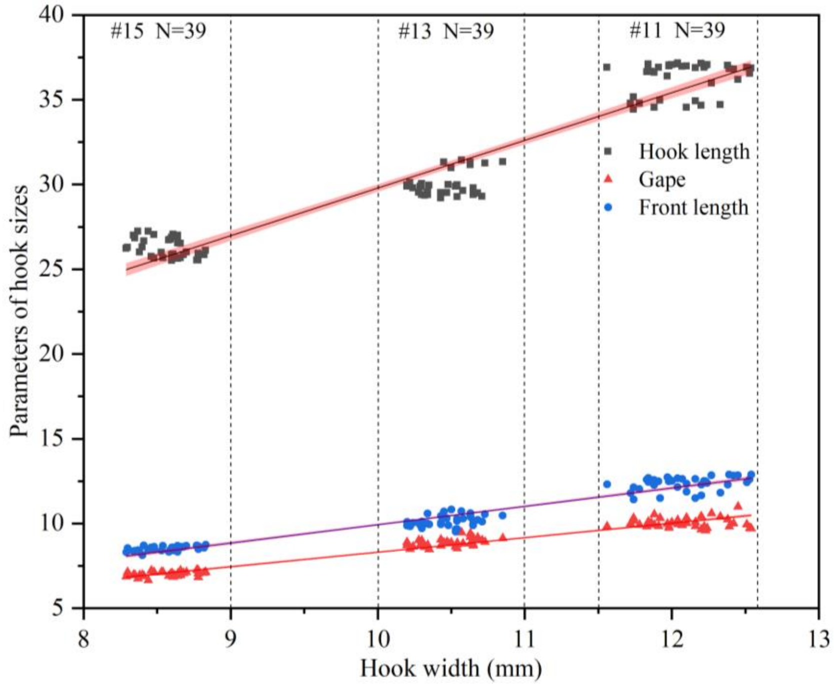

Figure S1. Relationship between parameters of hooks

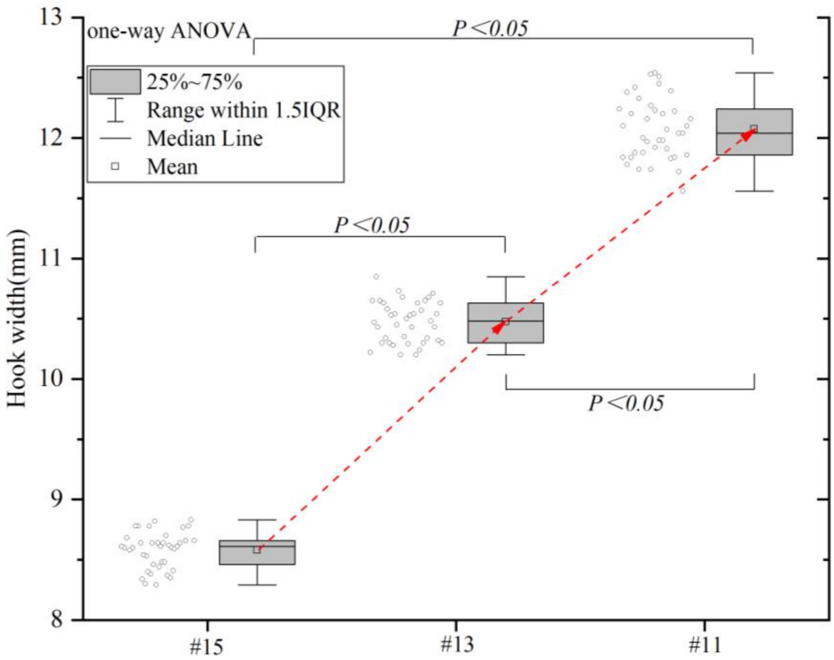

Figure S2. One-way ANOVA of three sizes hook width

Catches

During the experiment, a total of 602 *B. japonicus* specimens were caught: 336 were caught using the "J" #15 hooks, 204 using "J" #13 hooks, and 62 using #11 hooks, respectively (Figure S3). Their total length ranged from 133 to 344 mm, with the length mainly in the range of 197–273 mm, which accounted for 68% of the total number. The average total length in each group was 223±37, 247±36 and 260±27 mm for fish caught using the "J" #15, #13 and #11 hooks, respectively. Furthermore, a total of 858 *D. tumifrons* species were caught: 231 using the "J" #15 hooks, 377 using the "J" #13 hooks, and 250 using the "J" #11 hooks, respectively. Their total length ranged from 118 to 300 mm, with the length mainly in the range of 177–247 mm, which accounted for 68% of the total number. The average total length in each group was 194±30, 215±35 and 224±33 mm for fish caught using the "J" #15, #13 and #11 hooks, respectively. According to the K–S test result (Table1), there were significant differences in the length frequency distributions of both species caught by hooks of different sizes.

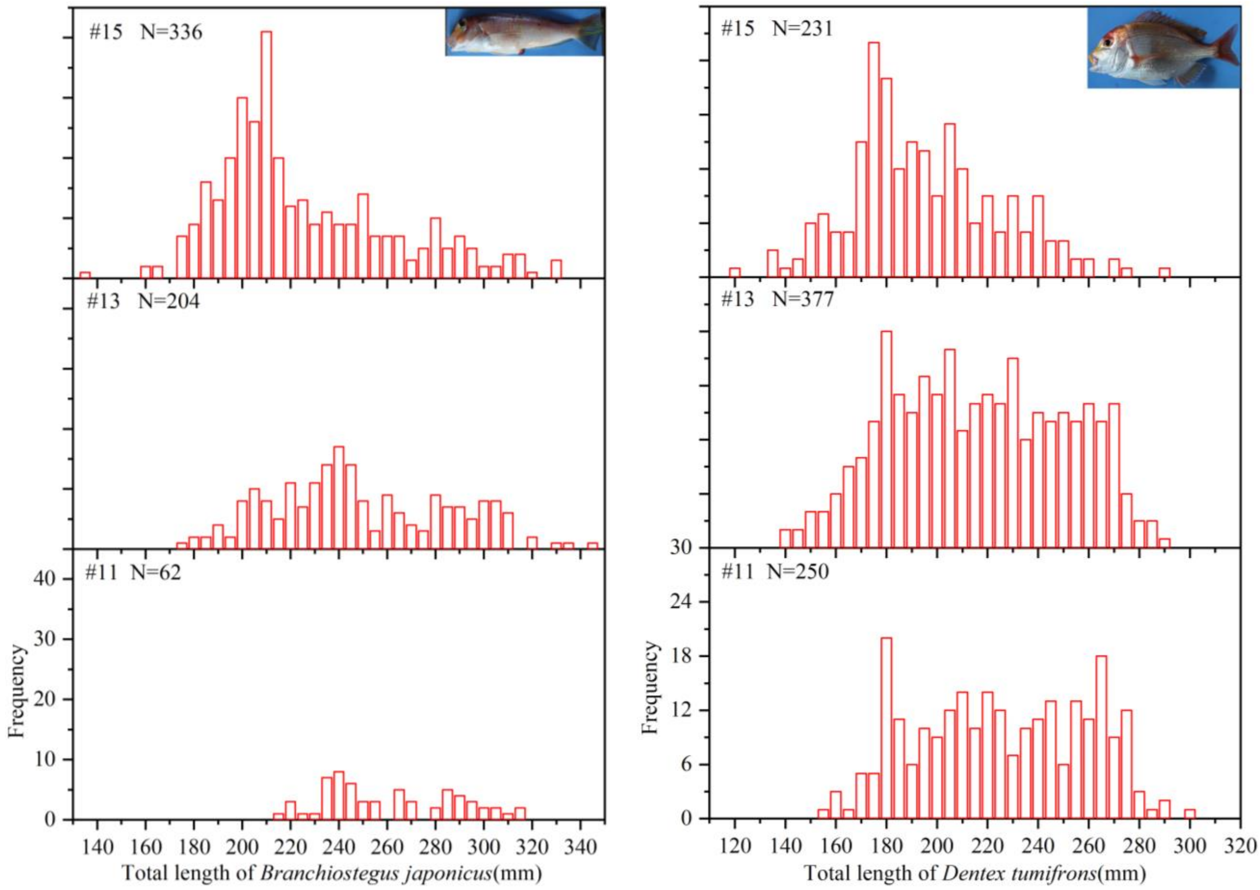

Figure S3. The total length frequency of *B. japonicus* and *D. tumifrons* caught at each hook size

Table 1. Results of the K-S test

Species	Hook 1	Hook 2	D max	Critical values	P values	Decision
	#15	#13	0.3706	0.0585	9.0784E-16	H_0Reject
Branchiostegus japonicus	#15	#11	0.5669	0.0682	3.1214E-15	H_0Reject
	#13	#11	0.2709	0.0834	0.0014	H_0Reject
Dentex tumifrons	#15	#13	0.2724	0.0552	8.3222E-10	H_0Reject
	#15	#11	0.3707	0.0620	5.6099E-15	H_0Reject
	#13	#11	0.1125	0.0543	0.0386	H_0Reject

H_0: There are no significant difference between length frequency distribution (α=0.05, *k*=1.36).

Relationship Between Total Length and Mouth Parameters

Our analysis of mouth parameters revealed that most of those variables were significantly different between the three hook sizes for both species, except for six mouth parameters (Figure S4; Table 2).

In order to increase the fitting, we added some data with 700 *B. japonicus* and 1116 *D. tumifrons* fish species. By fitting the total length and mouth parameters of 1302 *B. japonicus* and 1974 *D. tumifrons* fish species, it was found that the total length and the four mouth parameters of both species presented a linear relationship (Figure 4). The calculated regressions which fitted the above parameters were as follows:

$$u_B = 0.1390TL - 5.6651\ (R^2 = 0.8613) \quad (6)$$

$$l_B = 0.1215TL - 5.6588\ (R^2 = 0.8227) \quad (7)$$

$$h_B = 0.1651TL - 4.3983\ (R^2 = 0.8840) \quad (8)$$

$$w_B = 0.1358TL - 0.0950\ (R^2 = 0.8575) \quad (9)$$

$$u_D = 0.1423TL - 3.3932\ (R^2 = 0.9128) \quad (10)$$

$$l_D = 0.1140TL - 1.7814\ (R^2 = 0.7961) \quad (11)$$

$$h_D = 0.1919TL - 1.7534\ (R^2 = 0.8893) \quad (12)$$

$$w_D = 0.1438TL - 3.8671\ (R^2 = 0.8179) \quad (13)$$

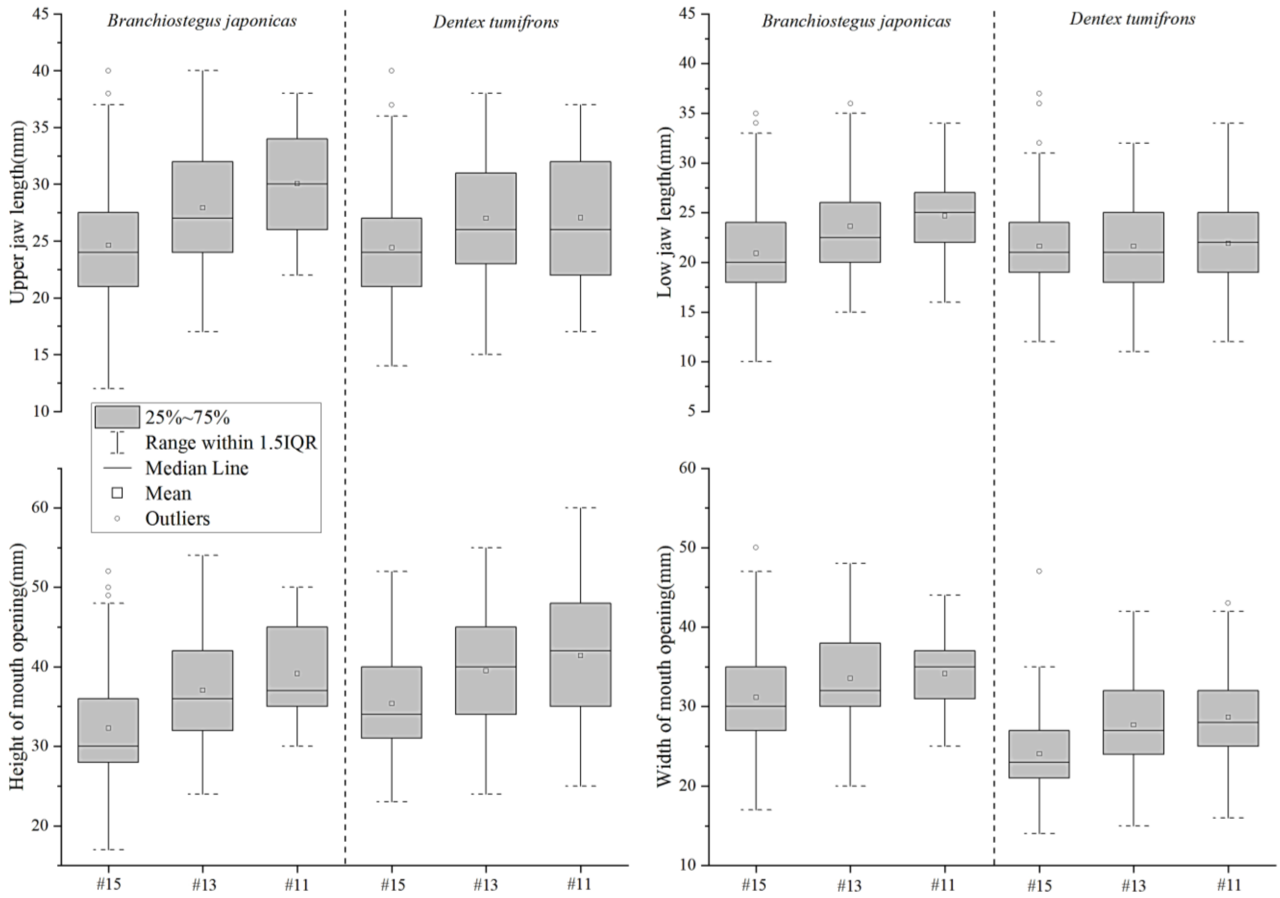

Figure S4. Mouth parameters of *B. japonicus* and *D. tumifrons* with three different hook sizes

Table 2. Results of the K-S test

Mouth parameters	Hook 1	Hook 2	D max	Critical values	P values	Decision
	#15	#13	0.3178	0.0585	9.9749E-12	H_0Reject
u_B	#15	#11	0.5304	0.0682	2.1230E-13	H_0Reject
	#13	#11	0.2176	0.0834	0.0179	H_0Reject
	#15	#13	0.2219	0.0552	1.1343E-6	H_0Reject
u_D	#15	#11	0.2571	0.0620	1.1775E-7	H_0Reject
	#13	#11	0.0578	0.0543	0.6529	H_0 Not Reject
	#15	#13	0.3435	0.0585	1.2852E-13	H_0Reject
l_B	#15	#11	0.4731	0.0682	9.1540E-11	H_0Reject
	#13	#11	0.1717	0.0834	0.1023	H_0 Not Reject
	#15	#13	0.1259	0.0552	0.0182	H_0Reject
l_D	#15	#11	0.1133	0.0620	0.0782	H_0 Not Reject
	#13	#11	0.0620	0.0543	0.5674	H_0 Not Reject
	#15	#13	0.3951	0.0585	7.5100E-18	H_0Reject
h_B	#15	#11	0.5903	0.0682	1.8156E-16	H_0Reject
	#13	#11	0.2764	0.0834	0.0011	H_0Reject
	#15	#13	0.2638	0.0552	3.1804E-9	H_0Reject
h_D	#15	#11	0.3642	0.0620	1.7857E-14	H_0Reject
	#13	#11	0.1301	0.0543	0.0104	H_0Reject
	#15	#13	0.2584	0.0585	6.3182E-8	H_0Reject
w_B	#15	#11	0.3514	0.0682	3.6861E-6	H_0Reject
	#13	#11	0.1450	0.0834	0.2345	H_0 Not Reject
	#15	#13	0.3016	0.0552	6.6448E-12	H_0Reject
w_D	#15	#11	0.3535	0.0620	1.1322E-13	H_0Reject
	#13	#11	0.0798	0.0543	0.2655	H_0 Not Reject

H_0: There are no significant difference between length frequency distribution (α=0.05, k=1.36).

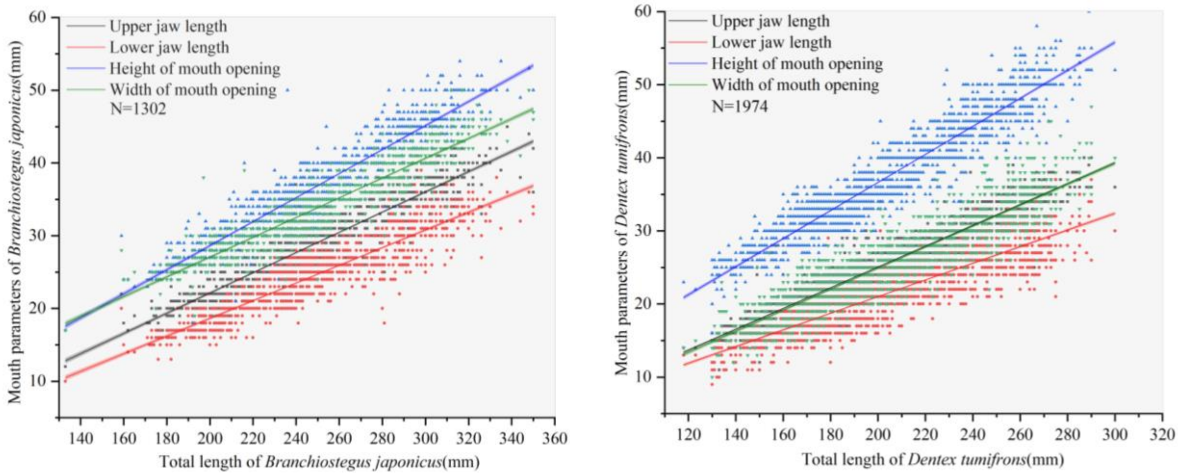

Figure 4. The relationship between total length and mouth parameters

Selectivity Model of *B. japonicus* and *D. tumifrons*

By comparing the AIC values of each model (Equal *p* and Estimated *p*), the estimated model was considered the best fit model with the minimum AIC value (Table 3). For hook sizes "J" #13 and "J" #11, the 50% selection length were 224.827 and 233.179 mm for *B. japonicus*; 201.461 and 202.603 mm for *D. tumifrons*, respectively (Table 3, Figure 5, Figure 6). For hook size "J" #15, because of the high proportion of *B. japonicus* juveniles caught (Figure S3), no selective analysis was conducted. According to Hayashi (1977), the minimum total lengths at maturity of *B. japonicus* were estimated at 175 mm for females and 225 mm for males. Therefore, when the total length of *B. japonicus* exceeds 225 mm, the reproduction of this particular individual is guaranteed at least once. For *D. tumifrons*, the minimum landing size was 130 mm. From the typical total length of the two species caught using the "J" #13 hooks, this hook size meets the minimum landing size requirements for *D. tumifrons* (L_{50}=201.461 mm) and the total length of *B. japonicus* reached 224.827 mm.

Hooking Mouth Rate of Different Hook Types

The height to width ratio of the mouth opening for *B. japonicus* ranged from 0.667 to 1.613, with an average of 1.089±0.087, whereas the height to width ratio of the mouth opening for *D. tumifrons* was 0.962–2.333, with an average of 1.489±0.195 (Figure S5). Using K–S test, this ratio was significantly different between the two species (D max=0.8799>Critical value=0.0238; P<0.05). This reflects the morphological differences in the mouth between the two species; indeed, the mouth shape of *B. japonicus* was nearly round, whereas that of *D. tumifrons* was elongated and oval.

The hooking mouth rate (the ratio of number of individuals hooked in the mouth to the total number of individuals caught) for *D. tumifrons* was higher than that for *B. japonicus* with every hook examined in this study ("J" #15: 21.21 % and 15.77 %, "J" #13: 7.16 % and 5.34 %, "J" #11: 28.40 % and 22.58 %, respectively). When "J" #13 hooks were used, both *B. japonicus* and *D. tumifrons* had the lowest hooking mouth rate (i.e., the highest rate of hook swallowing) (Figure S6).

Table 3. The estimation of parameters by selectivity models

	B. japonicus		*D. tumifrons*	
Hook sizes	#13	#11	#13	#11
Equal *p*:				
a(±SE)	-14.330(1.735)	-32.562(4.595)	-13.353(4.944)	-16.658(2.773)
b(±SE)	0.067(0.008)	0.137(0.020)	0.095(0.033)	0.094(0.016)
Split parameter *p*	0.5	0.5	0.5	0.5
L50(mm; ±SE)	215.391(1.887)	238.170(1.751)	140.224(5.230)	176.666(1.710)
MLL	-65.820	-47.450	-101.580	-80.800
AIC value	**135.643**	**98.899**	**207.159**	**165.590**
Estimated *p*:				
a(±SE)	-12.636(4.076)	-24.721(8.921)	-9.992(2.268)	-14.994(3.291)
b(±SE)	0.056(0.023)	0.106(0.044)	0.050(0.016)	0.074(0.020)
Split parameter *p*(±SE)	0.567(0.141)	0.340(0.148)	0.794(0.078)	0.731(0.076)
L50(mm; ±SE)	224.827(22.638)	233.179(15.229)	201.461(20.679)	202.603(12.136)
MLL	-64.470	-41.600	-64.680	-62.120
AIC value	**134.940**	**89.200**	**135.359**	**130.242**

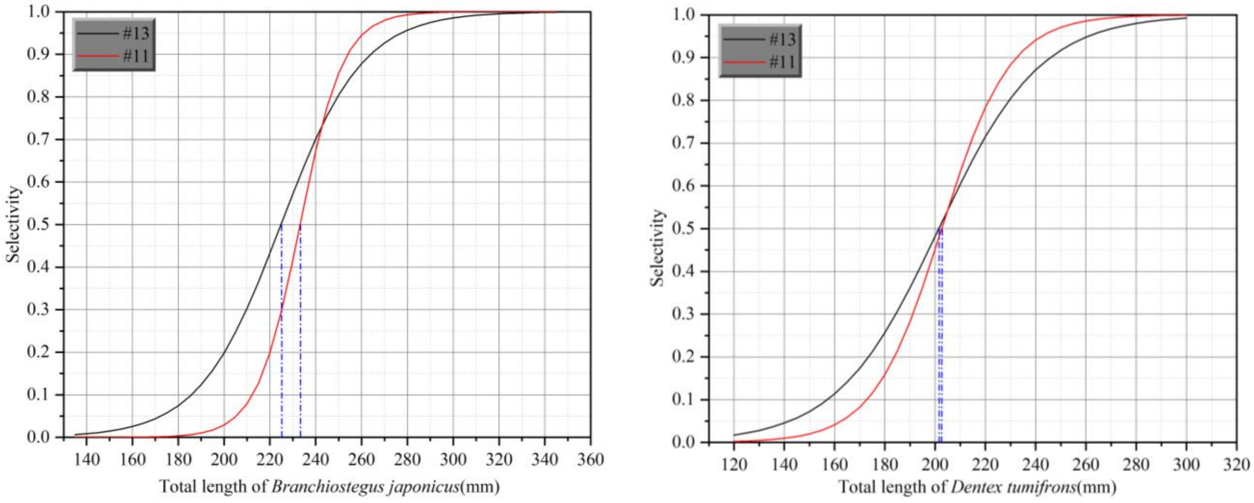

Figure 5. Selectivity curves of hook sizes by the best fit Estimated model for *B. japonicus* and *D. tumifrons*

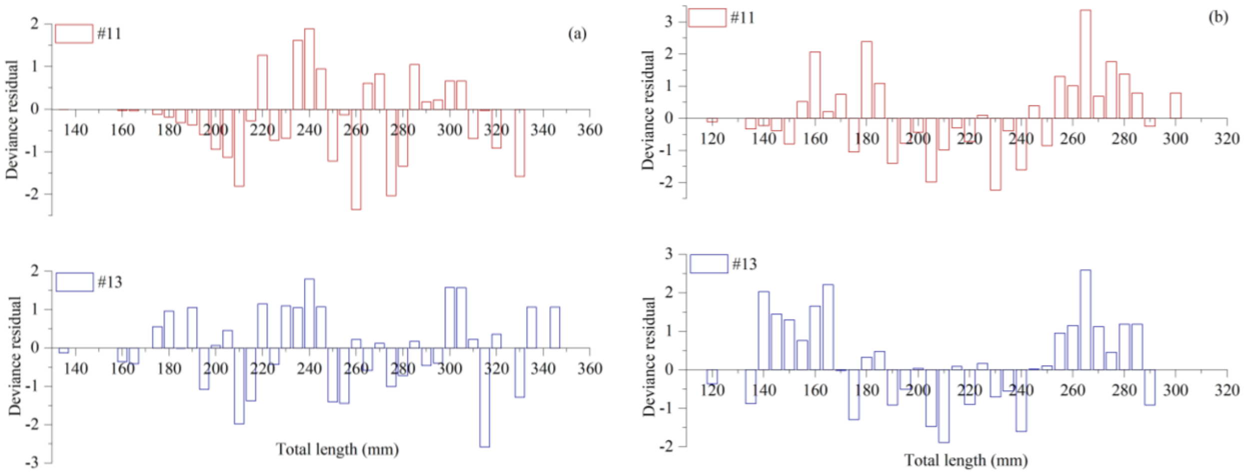

Figure 6. Deviance residuals of hook sizes for *B. japonicus* and *D. tumifrons*

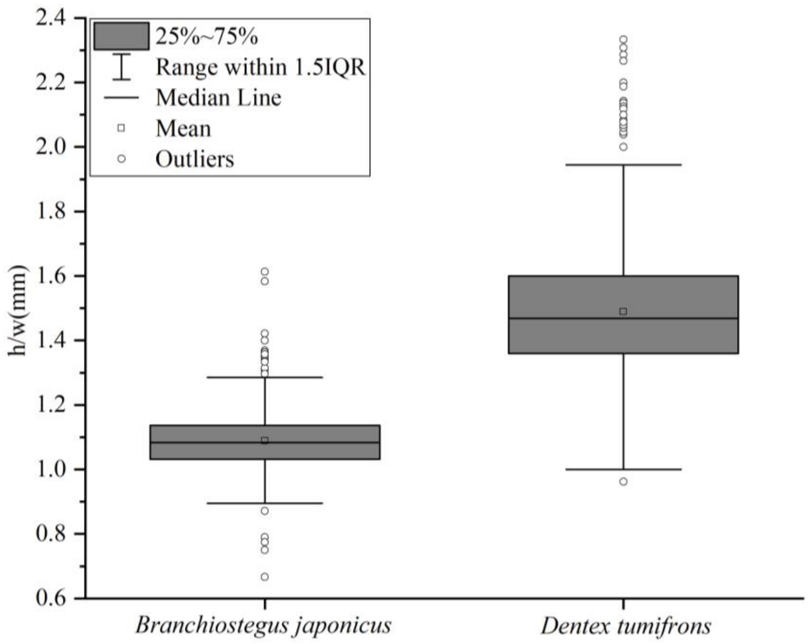

Figure S5. The ratio of height to width of mouth opening

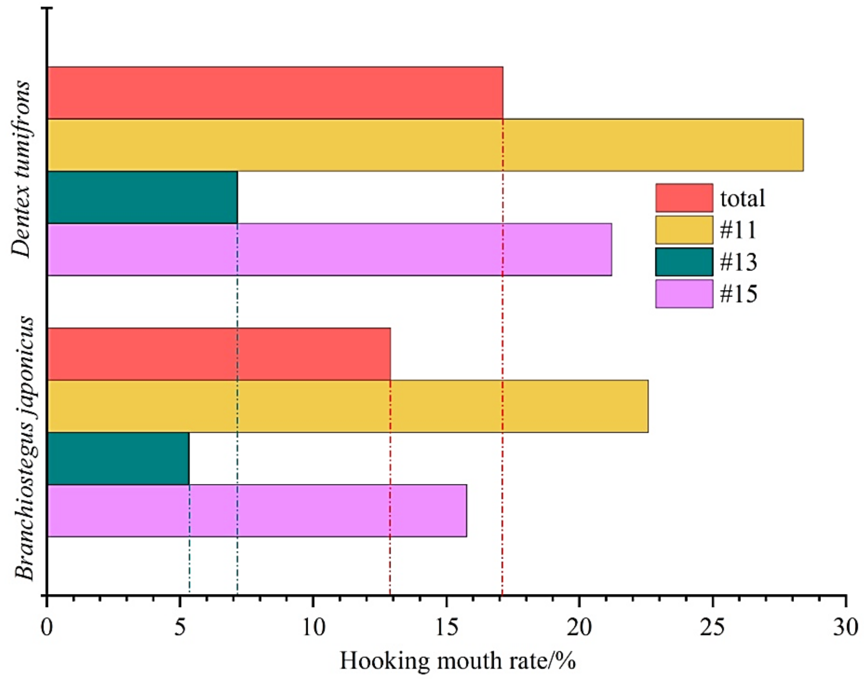

Figure S6. The hooking mouth rate of different hook sizes for *B. japonicus* and *D. tumifrons*

Discussion

Selectivity of Different Hooks

There was a significant difference between the three hook sizes used, but a high overlap of length distributions between hook sizes observed for both species in the current study. This high degree of overlap has also been observed with other selectivity studies (Erzini et al., 1996; Erzini et al., 1998; Czerwinski et al., 2009; Czerwinski et al., 2010). These studies have shown varying results because they relate to hook sizes utilized, subsequent catch length frequencies and selectivity. For instance, Kanda et al. (1978) have shown that a large differences in hook size (>200%) was required to detect selectivity; in studies by Erzini et al. (1998) and Stergiou and Erzini (2002), the limited range in hook size led to apparent lack of selectivity. However, not all species are selective in this case, some studies showed small differences between hook sizes but still demonstrated selectivity. In the study by Czerwinski et al. (2009), which hook size did not exceed 43.7 % of the overall size (width ×length) and also showed significant size selectivity in the black spot sea bream. In this study, although there was a high degree of overlap in catch size and the overall size of the largest hook used was over 104.08 % of the smallest hook, our K–S test showed that the two species had significantly different total lengths with three hook sizes (Table 1), which is an important reason for the differences in selectivity. This finding was consistent with those in the study by Czerwinski et al. (2009). In addition, the positive linear relationship between the total length and mouth size of both species also reveals the difference in size selectivity of three hook sizes.

Model Selection

Despite the number of studies on hook selectivity, the selectivity curves developed for the hook remains controversial. Although hook selectivity curves remain controversial, new in-depth studies have begun to yield some preliminary consensus. For instance, normal and log-normal selectivity curves can be used for recreational handline fishing (Kanda, Koike, Takeuchi, & Ogura, 1978; Cortez-Zaragoza, Dalzell, & Pauly, 1989; Tuncay Ateşşahin et al., 2015). Although there is no consensus on longline hook selectivity curves as of yet, many scholars have suggested that logistic curves are appropriate for small-sized species (Erzini et al., 1998; Stergiou & Erzini, 2002; Czerwinski et al., 2009; Yamashita et al., 2009; Czerwinski et al., 2010). *B. japonicus* and *D. tumifrons* are both small species, suggesting that similar logistic models might be applicable in this case (Erzini et al., 1998; Yamashita et al., 2009; Czerwinski et al., 2010). The SELECT model has been widely used in the selection of fish gear (Park, Millar, An, & Kim, 2007; Yamashita et al., 2009). However, studies have shown that using of maximum likelihood methods are advantageous to describe small Sparidae species (Sousa et al., 1999; Czerwinski et al., 2009). Therefore, using a logistic model with maximum likelihood methods is more appropriate for analyzing hook selectivity. We therefore selected the model with the lowest AIC value as the final model. Of course, many factors determine the model selection: the relationship with the hook size, with the catch length distribution or bait size (Sousa et al., 1999). For hooks, evaluating the relationship between the mouth size and fish size can be used as a shortcut for selecting the best model (Erzini et al., 1997). In this study, we demonstrated that there was a positive linear relationship between the total length and mouth size in the two species examined, which also provides a reference for the choice of logistic curves for the selectivity model (Figure 4). In this experiment, we also used standard squid bait selection to reduce the effort of baits for selecting the model. Unlike the size of the baits that can be easily controlled, the effect of population distribution on hooks model selection is often difficult to measure because the population structure can differ between experiments (Ralston, 1990; Czerwinski et al., 2009). For instance, because of the very different catch size distribution in two periods, Czerwinski et al. (2009) adopted different selection models with the same species. Similarly, some studies on sea breams (Sparidae) also adopted the skew-normal model (Erzini et al., 1996). In this study, we did not consider the difference in size distribution between periods in the current experiment, assuming that the length distributions of fish resources were the same in different months. Instead, this study mainly focused on controlling the bait size to select a more appropriate model.

Minimum Hook Size for Selecting Mature Individuals

In this study, the #13 hook showed the lowest hooking mouth rate in both species, suggesting that #13 hook is the most suitable hook size for swallowing among the three hook sizes in both species. Both species observed to swallow the hook as the main fishing practices in the trial. This phenomenon was also observed in other species (Oztekin, Ayaz, Ozekinci, & Kumova, 2018; Czerwinski et al., 2009). Yamashita et al. (2009) found that *B. japonicus* are likely to swallow the hook and bait whole without chewing and then to be hooked. Given the evidence presented in this study, *D. tumifrons* may have the same feeding behavior. The use of squid as bait in the experiment is associated with the feeding preferences of both species. Karpouzi and Stergiou (2003) suggested that carnivorous fish are often too efficient in their handing and consumption of large prey items. In this study, the smallest hook “J” #15 was small for the fish mouth; therefore, the rate of mouth hooking was higher during the hauling process. Conversely, the largest hook “J” #11 was too large and the small fish could not swallow it, leading to the highest hooking mouth rate. *B. japonicus* have a rounder mouth than *D. tumifrons*, which may be why they are more lip-hooked than *B. japonicus*. Furthermore, *B. japonicus* have a wider mouth area than *D. tumifrons*, making it easier to swallow the hooks, which may explain the lower hooking mouth rates in this species. Further research is warranted to understand the relationship between mouth area and coefficient of swallowing hooks of fish.

To ensure sustainable development in the fishing industry, it is important to ensure that fish can spawn at least once before they are caught (Oztekin et al., 2018). Yamashita et al. (2009) suggested that #16 hooks should be considered appropriate in terms of small *B. japonicus* protection. This hook size was based on the total length of 300 mm with high commercial value as the 50% selection length rather than the minimum total lengths at maturity. In this study, it was of practical significance to take the minimum length of sexual maturity of *B. japonicus* as the minimum total length to determine the minimum hook size. The use of the “J” #13 hook in this study meant that fewer illegal–sized *D. tumifrons* were caught. Meanwhile, the L_{50} of *B. japonicus* was 224.827 mm, which is also considered appropriate. In order to give the fish a chance to reproduce at least once, the size of “J” #13 hooks was selected as the minimum hook size for ensuring sustainable bottom longline fishing for *B. japonicus* and *D. tumifrons*. Besides, considering the hooking mouth rate, “J” #13 hooks provided the lowest escape rate and were more suitable for catching the two species when using bottom longlines.

Ethical Statement

Ethical committee approval was not required for this study as the study did not involve any live animal experiments.

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Author Contribution

GX: Experiment design, Investigation, Statistical analysis, Writing -original draft, Writing- review & editing. WZ: Experiment design, Writing- review & editing. YZ: Supervision. LX: Writing- review & editing.

All authors approved the submission and publication of this manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest regarding this manuscript.

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