Mesh Size Selectivity of Tie-Down Gillnets for the Blackfin Flounder (Glyptocephalus stelleri) in Korea

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Abstract: Although gillnet fisheries are increasingly common in Korea, few studies have conducted sea trials using tie-down gillnets. Here, we analyzed the mesh size selectivity using tie-down gillnets with four different mesh sizes (84, 90, 105, and 120 mm) to catch blackfin flounders. A total of 10 sea trials were conducted at depths of 100–140 m in the waters of Yangyang County, Gangwon Province, Korea, and the catching efficiency and mesh size selectivity were comparatively analyzed. The net with a mesh size of 84 mm showed the highest number of catches (373), followed by the 90-mm (363) and 105-mm (307) meshes. The results of the master curve estimation showed that the larger the mesh size, the higher the total length representing the same retention probability. Therefore, the catch rate of small fish decreased with the increasing mesh size. For the 84-mm net, the 50% selection length for small fish (total length \( \leq 170 \) mm) was estimated at 186.9 mm, which was approximately 17 mm larger than the length limit. The results show that when using tie-down gillnets, the size of the fish caught changed according to the changes in the mesh size.

Keywords: blackfin flounder; tie-down; gillnet; selectivity; master curve; Kitahara’s method

1. Introduction

A gillnet is a type of fishing gear typically composed of a rectangular net with a float at the top and a sinker at the bottom that allow the net to extend vertically in water. In principle, the gillnets are placed in a certain water depth at locations where fish encounter the net and are trapped such that the gills or other parts of the body are held by the mesh size. Fish capture methods differ depending on the shape of the fish caught in the gillnet fisheries. Gillnets are generally used in research to estimate the abundance, ecological properties, catchability, diversity of species, diet of species, growth, maturity of the target species, and age structures of fish populations. Commonly, gillnets are one of the highly size selective gears in commercial fisheries [1–5]. In terms of research gear, different mesh sizes have been used simultaneously to observe the size frequencies for the effects of mesh size selectivity, ecological parameters, relative fishing efficiency, and conservational feasibility for sustainable utilization [6–10].

In Korea, the number of fishing vessels with gillnets accounts for approximately 30% of all coastal fishing vessels [11]. Among these, the gillnet fisheries on the east coast are more efficient than other fisheries because the target fish species are simple: snow crab (Chionoecetes opilio), sandfish (Arctoscopus japonicas), Pacific cod (Gadus macrocephalus), Okhostk atka mackerel (Pleuronichthys azonus), Korean sandeel (Hypoptychus dybowskii), Pacific herring (Clupea pallasii), and blackfin flounder (Glyptocephalus stelleri). The blackfin flounder is one of the representative fish species found along the east coastal area of Korea. Fisheries using a trawl or a seine haul significant catches of the blackfin flounder in Korean offshore fisheries, and most coastal fisheries use gillnets. Unlike herrings, Pacific cods, or snow crabs, the blackfin flounder is not a seasonal fish and is caught throughout the year.
In 2020, the total catch of the blackfin flounder was 1492 metric tons in Korea, of which approximately 49% (734 metric tons) was caught by coastal gillnet fisheries [11]. The blackfin flounder is sometimes caught by being held to the gillnet. However, because of its rounded and flat body shape, it is often caught by pocketing. Therefore, trammel nets are frequently used to increase the catching efficiency for the blackfin flounder. However, in Korea, trammel nets have a high bycatch ratio with high proportions of immature fish and pose the risk of overfishing. Thus, their use is strictly regulated by related law. Recently, tie-down gillnets have been used, in which the lines are tied vertically to a single gillnet at regular intervals so that the net extends to a lesser degree than its original height. The gillnet netting forms a large pocket in the water similar to that formed by a trammel net, and compared with a single gillnet, gillnet netting exhibits a higher catching efficiency for flounders [12–15].

Although there have been reported concerns regarding overfishing associated with the use of tie-down gillnets (as is the case for trammel nets), the risk has not yet been studied. There are few studies on tie-down gillnets comparing mesh selectivity, bycatch ratios, and catching efficiency, although some studies have investigated the effects of tie-down gillnets on reducing mortality [14–17]. The catching efficiency of gillnets has been reported to vary with the target fish species and the type of fishing gear (such as trammel nets and a single gillnet) [1,18]. Studies have also investigated the catch composition or catching selectivity of a single gillnet or trammel net [1,4,19,20]. Some non-Korean studies have investigated a method for adjusting the headline height using support lines to reduce the bycatch of marine animals (such as sea turtles) when fishing using gillnets [16,21,22]. However, studies conducting sea trials using tie-down gillnets are limited.

This study aimed to determine the catching efficiency of tie-down gillnets. To do this, we conducted sea trials using four types of tie-down gillnets with different mesh sizes for the blackfin flounders found along the east coast of Korea and comparatively analyzed the catch characteristics and selectivity for each mesh size. Our results can be used as a basic reference for establishing plans for the efficient use and management of blackfin flounder stocks.

2. Materials and Methods

2.1. Experimental Nets and Set-Up

The experimental gillnets used to conduct the sea trials were based on the blackfin flounder tie-down gillnets used in the waters off Gangwon Province and had the same area and composition. Experimental nets with four mesh sizes (84, 90, 105, and 120 mm) were used to investigate the selectivity of tie-down gillnets with differing mesh sizes. The height of the support line was 2.47 m, and the ratio of the height of the vertical dimension of the net to the height of the support line was approximately 55%. The length of the float line in the experimental net was 75.4 m, and that of the sink line was 93.3 m. A monofilament net was used, and the diameter of the netting thread was Ø0.286 mm. The support line was made of polyethylene (PE) with a thread diameter of Ø1.4 mm. Two strands of the support line were vertically hung from the float line to the sink line, and the middle portion of the support line was knotted with netting once. The internal diameter of the experimental net in each group was measured 20 times, and the average values were 83.8 ± 4, 90.2 ± 2, 104.3 ± 2, and 120.3 ± 4 mm, respectively. The float and sink lines had different lengths, and the hanging ratios were 40.0% and 49.5%, respectively. For each experimental net, the number of horizontal meshes was adjusted to maintain a constant hanging ratio. The compositions of each experimental net are listed in Table 1, and the basic structure of the experimental nets is shown in Figure 1. The experimental nets were arranged in groups of four in order of the mesh size, and 16 panels were assigned to one set for use in the experiment, as shown in Figure 2.
Table 1. Composition of the experimental gears to estimate mesh size selectivity in the sea trials.

| Mesh Size (mm) | Vertical Mesh (mesh) | Horizontal Mesh (mesh) | Hanging Ratio (% | Hanging Ratio | Length of Float Line (m) | Length of Sink Line (m) | Net Height (m) |
|----------------|----------------------|------------------------|-------------------|---------------|--------------------------|------------------------|----------------|
|                |                      |                        | Float Line        | Sink Line     |                          |                        |                |
| 84             | 50                   | 2244                   | 40.0              | 49.5          | 75.4                     | 93.3                   | 3.07 (support line 2.47) |
| 90             | 50                   | 2094                   | 40.0              | 49.5          |                          |                        |                |
| 105            | 50                   | 1795                   | 40.0              | 49.5          |                          |                        |                |
| 120            | 40                   | 1571                   | 40.0              | 49.5          |                          |                        |                |

Figure 1. Construction of the experimental tie-down gillnets used in the sea trials.

Figure 2. Arrangement of the experimental tie-down gillnets for the mesh size selectivity tests.
2.2. Sea Trial

The sea trial was conducted a total of seven times between February 2020 and December 2020 in the waters around Namae Port, Yangyang County, Gangwon Province by chartering a coastal gillnet fishing vessel (Gross tonnage: 4 tons, diesel engine: 264.6 W). The experimental gillnets were deployed at the start of the sail at 4:00 a.m. and hauled at the same time the next day. The fish caught in the experimental nets were transported to fish tanks on the deck and separated by panel types. The soaking time was set to 1 day (24 h), and the water depth was approximately 100–140 m. The sea trial location is shown in Figure 3. The catches were separated for each experimental net and classified by fish species for measurements. The length of each fish was measured in units of 1 mm, and the body weight was measured in units of 1 g using a digital scale (CAS SW-1, Yangju, Korea). The measurements were used for comparative analyses on mesh selectivity and catching efficiency. The Kolmogorov–Smirnov test was used to test the normality of the catch data for each trial using commercial software (SPSS statistics 26, Armonk, NY, USA).

Figure 3. Location of the sea trials’ site for the selectivity experiments.

2.3. Estimation of the Mesh Selectivity Curve

We used Kitahara’s (1968) method to estimate the mesh selectivity curve and the method developed by Fujimori et al. (1996) to estimate the master curve. Kitahara’s method of mesh selectivity curve estimation is based on the geometrical similarity theory proposed by Baranov (1914), which assumes that as the mesh size increases $k$ times, the length of the fish caught also increases $k$ times (Equation (1)). Based on this assumption, Kitahara used the relative length $(l/m)$—a normalization of the length $(l)$ to the mesh size $(m)$—as a variable to derive the selectivity curve $S(l/m_i)$ as follows [23–25]:

$$S(m, l) = s(l_j/m_i)S(km, kl) = s(kl_j/km_i) = s(l_j/m_i)$$

(1)

where $k$ is a proportional constant. The number of catches per unit effort ($c_{ij}$) can be expressed as follows:

$$c_{ij} = C_{ij}/X_i = s(l_j/m_i) \cdot q_i \cdot d_j$$

(2)
where $C_{ij}$ is the number of catches of fish with a length of $l_j$ in a net with a mesh size $m_i$ and $X_i$ is the catch effort of the net, while $q_i$ represents the catching efficiency, indicating the effect of fishing conditions such as the fishing gear structure and soaking time, and $d_j$ represents the relative stock density of fish with a length $l_j$. By taking the logarithms of both sides of Equation (2) and rearranging the equation, the following equation can be derived [26,27]:

$$\ln s \left( \frac{l_j}{m_i} \right) = \ln C_{ij} - \ln (q \cdot d_j)$$

In Equation (3), the second term on the right-hand side is the correction related to the catching efficiency or stock density. Kitahara’s method, similar to Ishida’s (1962) method, has a drawback in that it does not have a curve formula that can represent the selectivity curve. Therefore, in order to express the selectivity curve for the mesh as one master curve, Fujimori et al. (1996) applied the master curve formula of polynomials to Kitahara’s method as follows [24,28]:

$$\ln s (R) = a_n R^n + a_{n-1} R^{n-1} + a_{n-2} R^{n-2} + \cdots + a_0$$

where $R = l_j/m_i$. To estimate the selectivity curve, a symmetric quadratic polynomial and an asymmetric cubic polynomial are applied for estimation. However, for gillnets, the number of fish caught is often not in agreement with the theory of Baranov, and higher reliability has been reported when using asymmetric polynomials than symmetric ones [4,24,25]. Therefore, in this study, the selectivity curve formula was estimated by setting cubic polynomials. In addition, the relative efficiency $q$ was generally assumed to have a maximum value of 1, and the selectivity curve $s(R)$ can be expressed by the following equation:

$$s(R) = \exp \left( a_n R^n + a_{n-1} R^{n-1} + a_{n-2} R^{n-2} + \cdots + a_0 \right) - F_{\text{max}}$$

where $F_{\text{max}}$ is the maximum value of Equation (4) and can be obtained by differentiation [24,29]. Each parameter of the function was obtained using the least-squares method, and the fit of the model was determined by obtaining the unbiased estimator ($\rho$) of the error.

3. Results

3.1. Results of the Sea Trials

A total of 10 sea trials was performed using 4 types of tie-down gillnets, and the results of 7 trials were comparatively analyzed. Three trials were excluded because of gillnet breakage, lost gillnets, and so on. A total of 18 species were caught. The total number of catches was 2466 (526,363 g), of which blackfin flounder accounted for the highest proportion of individuals (1144; 122,302 g), followed by red halibut (306; 31,241 g) and black-edged sculpin (289; 93,478 g). The catches and catch rates for each experimental net are listed in Table 2. The statistical analysis, Kolmogorov–Smirnov test, and results for normality of the catches had a normal distribution ($p$-value > 0.05) for the seven successful trials.

The catches of the experimental nets with each mesh size were as follows: 682 fish (104,411 g) were caught with the 84-mm mesh, 643 (113,843 g) with the 90-mm mesh, 673 (166,014 g) with the 105-mm mesh, and 475 (142,230 g) with the 120-mm mesh. The 84-mm mesh had the largest catch in terms of total number of catches, and the 105-mm and 120-mm meshes had the largest catch in terms of catch weight. This was because there was a relatively high proportion of cod in the 105-mm and 120-mm meshes (Table 2).
**Table 2. Catch rates of each species of fish caught by the experimental nets.**

| Species Name                        | Scientific Name          | 84 mm | 90 mm | 105 mm | 120 mm | 110 mm | 120 mm |
|-------------------------------------|--------------------------|-------|-------|--------|--------|--------|--------|
|                                     | Number of Catches | Weight (g) | Catch Rate (%) | Number of Catches | Weight (g) | Catch Rate (%) | Number of Catches | Weight (g) | Catch Rate (%) | Number of Catches | Weight (g) | Catch Rate (%) |
| Flounders                           |                         |       |       |        |        |        |        |        |        |        |        |        |
| Blackfin flounder                   | Glyptocephalus stelleri | 373   | 33,594 | 32.14  | 1198.36 | 307    | 36,520 | 22.00  | 1304.29 | 101    | 14,549 | 10.23   |
| Red halibut                         | Hippoglossoides dubius   | 21    | 3,965  | 5.80   | 141.01  | 29     | 6426   | 9.64   | 229.50  | 45     | 11,788 | 7.10    |
| Littleneck flounder                 | Paralichthys breviceps   | 0     | 0.00   | 0.00   | 0.00    | 0      | 0.00   | 0.00   | 0.00    | 7      | 1758   | 1.06    |
| Scad-eye flounder                   | Asobutus ocellatus       | 3     | 491    | 0.43   | 16.11   | 5      | 493    | 0.43   | 17.84   | 3      | 446    | 0.27    |
| Hake                                |                         |       |       |        |        |        |        |        |        |        |        |        |
| Blackcod                            | Gadus macrocephalus     | 3     | 373    | 3.73   | 10.45   | 1      | 10.45  | 1.00   | 1.00    | 0      | 0.00   | 0.00    |
| Whiting                             | Atheresthes stomias     | 1     | 549    | 0.54   | 19.61   | 1      | 962    | 0.85   | 34.36   | 0      | 0.00   | 0.00    |
| Sandhills                           | Atheresthes stomias     | 0     | 0.00   | 0.00   | 0.00    | 0      | 0.00   | 0.00   | 2      | 2300   | 1.42   | 84.29   |
| Alaska pollack                      | Pseudoscopelus alaska   | 1     | 449    | 0.44   | 14.61   | 1      | 962    | 0.85   | 34.36   | 0      | 0.00   | 0.00    |
| Cod                                 | Gadus macrocephalus     | 45    | 6022   | 6.02   | 17.68   | 45     | 40,023 | 36.16  | 2143.60 | 32     | 63,390 | 58.63   |
| Skate                               | Atheresthes stomias     | 1     | 547    | 0.54   | 19.61   | 1      | 962    | 0.85   | 34.36   | 0      | 0.00   | 0.00    |
| Pollock                             | Atheresthes stomias     | 0     | 0.00   | 0.00   | 0.00    | 0      | 0.00   | 0.00   | 2      | 98     | 0.06   | 5.50    |
| Golden rockfish                     | Sebastes kinkuna        | 1     | 160    | 1.60   | 5.71    | 0      | 0.00   | 0.00   | 0.00    | 0      | 0.00   | 0.00    |
| Anchovy                             | Exocoeta japonicas     | 0     | 0.00   | 0.00   | 0.00    | 1      | 12     | 0.12   | 0.45    | 0      | 0.00   | 0.00    |
| Mollusks                            |                         |       |       |        |        |        |        |        |        |        |        |        |
| Schoolmaster gonate squid          | Bathyteuthis loquax    | 2     | 729    | 0.72   | 26.04   | 1      | 195    | 0.17   | 6.89    | 0      | 0.00   | 0.00    |
| Gastropods                          |                         |       |       |        |        |        |        |        |        |        |        |        |
| Whelk                               | Nucella assessa         | 2     | 405    | 0.40   | 14.46   | 0      | 0.00   | 0.00   | 0.00    | 1      | 124    | 0.12   |
| Bayans                              | Nucella assessa         | 1     | 25     | 0.25   | 0.82    | 0      | 0.00   | 0.00   | 1      | 74     | 0.04   | 2.44   |
| Fanshula                            | Nucella assessa         | 0     | 0.00   | 0.00   | 0.00    | 1      | 37     | 0.37   | 1.32    | 0      | 0.00   | 0.00    |
| Crustaceans                         |                         |       |       |        |        |        |        |        |        |        |        |        |
| Snow crab                           | Chionoecetes opilio     | 51    | 6266   | 6.26   | 226.29  | 72     | 7749   | 6.63   | 279.75  | 96     | 12,960 | 7.13    |
| Snow crab                           | Chionoecetes opilio     | 56    | 7482   | 7.48   | 267.21  | 32     | 3582   | 3.55   | 127.63  | 79     | 9768   | 5.85   |
| Kuro shrimp                         | Caprella lar           | 2     | 36     | 0.36   | 1.36    | 4      | 28     | 0.28   | 1.00    | 0      | 0.00   | 0.00    |
| Shrimps                             | Caprella lar           | 0     | 0.00   | 0.00   | 0.00    | 0      | 0.00   | 0.00   | 0.00    | 1      | 30     | 0.02   |
| Total                               |                         | 682   | 104,411| 104    | 3729    | 643    | 113,843| 100    | 4066    | 672    | 166,014| 100    |
| Species                             |                         | 14    | 13     | 8      | 10     | 18     |        |        |        |        |        |        |

1 Catch rate = Weight of species/Total weight. 2 CPUE = Weight of species/(panels × deployment times).
The blackfin flounder was the main target fish in this study. Our sea trial results showed that with an increase in the mesh size, the size of the caught fish increased, and the catch size decreased considerably. Among the experimental nets with 4 different mesh sizes, the net with the 84-mm mesh had the highest number of blackfin flounder catches (373 fish), followed by the 90-mm net (363 fish) and the 105-mm net (307 fish). However, the number of catches decreased sharply for the net with a mesh size of 120 mm (101 fish). The number of catches and the ranges of the fish’s total lengths for each mesh size are listed in Table 3, and the corresponding frequency distributions are depicted in Figure 4.

| Total Length (mm) | Mesh Size (Catch Number) | Total |
|-------------------|--------------------------|-------|
|                   | 84 mm  | 90 mm  | 105 mm | 120 mm |     |
| <160               | 0      | 0      | 0      | 0      | 0   |
| 160–170            | 13     | 4      | 0      | 0      | 17  |
| 170–180            | 19     | 8      | 4      | 3      | 34  |
| 180–190            | 34     | 15     | 15     | 2      | 66  |
| 190–200            | 59     | 29     | 23     | 7      | 118 |
| 200–210            | 77     | 57     | 31     | 11     | 176 |
| 210–220            | 68     | 83     | 44     | 16     | 211 |
| 220–240            | 48     | 72     | 37     | 11     | 168 |
| 230–240            | 16     | 41     | 51     | 17     | 125 |
| 240–250            | 6      | 16     | 37     | 8      | 67  |
| 250–260            | 7      | 12     | 29     | 5      | 19  |
| 260–270            | 0      | 1      | 9      | 9      | 14  |
| 270–280            | 0      | 3      | 6      | 5      | 9   |
| 280–290            | 3      | 0      | 2      | 2      | 7   |
| 290–300            | 0      | 0      | 1      | 2      | 3   |
| >320               | 0      | 0      | 1      | 2      | 3   |
| Total              | 373    | 363    | 307    | 101    | 1144 |

The mode of the total length showed a pattern of a slight increase with an increase in the mesh size. We considered small individuals as those with a total length ≤200 mm. Four small individuals were caught with the 120-mm net, which was a considerable decrease compared with the 42 small individuals caught with the 84-mm net (Table 3 and Figure 4).

3.2. Estimation of the Mesh Size Selectivity Curve

The selectivity of the four mesh sizes for blackfin flounders was analyzed using Kitahara’s and Fujimori’s methods using the catch data listed in Table 3. Each mesh size selectivity curve showed a shift to the right with an increase in the mesh size, and the length of the fish caught increased with the mesh size. The mesh size selectivity curves of the four groups of experimental nets are shown in Figure 5.

The parameters of the polynomial equation for the master curve were estimated using the least-squares method based on the catch data, and the results are shown in Table 4.

The estimated polynomial for the master curve can be expressed as follows, and the master curve is shown in Figure 6:

\[ s(R) \equiv s(l/m) = \exp \left\{ \left( -1.1275R^3 + 5.5905R^2 - 5.5255R + 0.6519 \right) - 4.9439 \right\} \quad (6) \]

In the master curve for mesh selectivity, the optimal length/mesh size \((l/m)\) value with a retention probability of 1 was 2.70, and the 50% selection range was 2.225–3.116 with an interval of 0.891. This suggests that with the increasing mesh size, the fish with longer total lengths exhibited the same retention probability. This confirmed that the catch rate of small fish decreased with an increase in the mesh size.
Table 5 outlines the 25% ($L_{25}$), 50% ($L_{50}$), and 75% ($L_{75}$) selection lengths and selection ranges—the criteria for selectivity evaluation—obtained from the master curve. The net with a mesh size of 84 mm showed the smallest selection range, and the larger the mesh size, the higher the selection range was.

Figure 4. Frequency distributions of the total lengths of blackfin flounders caught by the experimental nets with four different mesh sizes.

The relationship between the mesh size and selection length is presented in Figure 7. The fishing of blackfin flounder with a total length $\leq 170$ mm is currently prohibited by relevant laws and regulations. In the nets with a mesh size of 84 mm currently used for blackfin flounder fishing, the 50% selection length was estimated to be 186.9 mm, which was approximately 17 mm larger than the length limit.
Figure 5. Selectivity curve of each experimental net, as estimated using Kitahara’s and Fujimori’s methods.

Table 4. Selectivity parameters estimated with Kitahara’s and Fujimori’s methods.

| Model                        | Parameters          | $a_3$ | $a_2$ | $a_1$ | $a_0$ | $R$  | $\rho$ | $R_{\text{max}}$ |
|------------------------------|---------------------|-------|-------|-------|-------|------|-------|-----------------|
| Kitahara’s and Fujimori’s methods |                     | –1.1275 | 5.5905 | –5.5255 | 0.6519 | 2.7005 | 0.3562 | 4.9439          |

$a_3$–$a_0$: parameter of the polynomial for the master curve. $R$: variable, length/mesh (l/m). $\rho$: unbiased estimator. $R_{\text{max}}$: maximum value of the polynomial for logarithm selectivity.

Figure 6. Master curve of mesh size selectivity of the tie-down gillnets for blackfin flounders, estimated using Kitahara’s and Fujimori’s methods.

Table 5. The mesh sizes with 25%, 50%, and 75% selection of blackfin flounders and the selection ranges in each selection curve (unit: mm).

| Mesh Size (mm) | $L_{25}$ | $L_{50}$ | $L_{75}$ | SR $^2$ |
|----------------|----------|----------|----------|---------|
| 84             | 167.2    | 186.9    | 201.8    | 34.6    |
| 90             | 179.1    | 200.3    | 216.2    | 37.1    |
| 105            | 209.0    | 233.6    | 252.2    | 43.3    |
| 120            | 238.8    | 267.0    | 288.2    | 49.4    |

$^1 L_{25}, L_{50}, L_{75}$: 25%, 50%, and 75% selection lengths. $^2$ SR (selection range): $L_{75}$–$L_{25}$
4. Discussion

The gillnet technique is relatively simple and does not require special fishing equipment or facilities, compared with other types of fishing techniques for large fish. There are several gillnet fisheries actively operating in coastal waters. Gillnet fishing is characterized by the fish being caught by the gills or its body being held by the mesh. Therefore, the mesh size tends to be proportional to the size of the target fish [2,5,25,30,31]. Gillnets have a relatively high catching selectivity compared with the trawling and trap fishery techniques [25]. However, to increase the probability of catching fish in gillnet fisheries, the heads of the fish should be narrower, as in fusiform (spindle-shaped) fishes. Since flounders have wide bodies, they are sometimes caught by being held in the mesh, tangled in the net, or surrounded by the gillnet [32–36].

The number of fish species caught along the east coast of Korea is low, and flounder catches account for a large proportion of these, serving as an important source of income for fishermen. Flounders are mostly caught with gillnets in coastal waters and by trawling offshore. In the past, a single gillnet was primarily used in Korean gillnet fisheries, but target catches were frequently dropped during the hauling operations, and the catches were not landed [37,38]. Trammel nets have been used more recently; however, trammel nets can catch fish of various sizes, and their use is strictly regulated due to the risk of overfishing. The catching efficiency of the trammel net has been reported to be 1.4–2 times higher than that of a single gillnet [18,19,23,25,29,39].

Recently, tie-down gillnets have been widely used and adjusted to form wrinkles in the net by adjusting the height of the gillnet. This comprises a form of fishery intermediate between a trammel net and a single gillnet. However, the catching efficiency of this technique has not been quantitatively estimated due to the limited number of studies on the fishing performance and catch size selectivity of tie-down gillnets. In addition, tie-down gillnets have been suggested to pose a risk of overfishing similar to that posed by trammel nets, but this has not been established through research. Various types of support line installations have been developed recently, which increase the catching efficiency of gillnets. Therefore, a systematic study on the support lines of tie-down gillnets is needed.

This study aimed to investigate the size selectivity of nets with different mesh sizes. In the sea trial results from Table 2, the smallest mesh size (84 mm) had the highest catch number, and the length of the fish caught was also relatively small. In addition, the number of catches tended to decrease with the increasing mesh size. The average weight of the blackfin flounder increased as the mesh sizes of the tie-down gillnet increased. The total length (represented by the mode) showed a slight increase with an increase in the mesh size. Recently, fisheries regulations for the protection of fish stock have specified the length limits for several species of flounders, including the blackfin flounder, the main target fish of coastal gillnet fisheries in the waters of Yangyang County, Gangwon Province. The length limit for the blackfin flounder is currently set at 170 mm and will gradually increase. The mesh sizes currently used by most fishermen are 84 mm and 90 mm. The 50% selection length...
length ($L_{50}$) for the 84-mm net was 186.9 mm, which is approximately 17 mm longer than the length limit.

We suggest that continuous monitoring of these factors is necessary in the future, as well as an increase in the length limit of the blackfin flounder. In addition, the standards and regulations for the shape or design of tie-down gillnets have not yet been established. Therefore, precise investigation of the impact of gillnets on a fish stock is required for the quantification of fishing power and fisheries resource management according to changes in the composition of tie-down gillnets. The support line is particularly important, as the geometry of the gillnet changes depending on its height, and the reduction ratio changes with the support line. The shape of the gillnet also varies depending on the attachment spacing between the support lines, which contribute to changes in the catching efficiency of the tie-down gillnet. The results obtained in this study can be utilized as basic data for understanding the catch characteristics of tie-down gillnets used for flounder fisheries.

5. Conclusions

In this study, experiments on mesh size selectivity were performed on tie-down gillnets with four different mesh sizes (84, 90, 105, and 120 mm) used in a blackfin flounder fishery in Korea. In total, 2470 fish belonging to 18 species were caught, of which 1144 were blackfin flounders. The net with the 84-mm mesh showed the largest number of catches (373 fish), followed by the 90-mm net (363 fish) and the 105-mm net (307 fish). The number of catches decreased sharply for the net with a mesh size of 120 mm (101 fish). The selectivity analysis using the master curve showed that the larger the mesh size, the longer the total body length representing the same retention probability, indicating that the catch rate of small fish decreased with an increase in the mesh size.

In the net with the 84-mm mesh, the 50% selection length was estimated to be 186.9 mm, which was approximately 17 mm longer than the length limit. Our results indicate that when using tie-down gillnets, the length of the fish caught changed in accordance with the mesh sizes.

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