Mesh size selectivity of the gillnet in East China Sea

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Abstract. A production test using several gillnets with various mesh sizes was carried out to discover the selectivity of gillnets in the East China Sea. The result showed that the composition of the catch species was synthetically affected by panel height and mesh size. The bycatch species of the 10-m nets were more than those of the 6-m nets. For target species, the effect of panel height on juvenile fish was ambiguous, but the number of juvenile fish declined quickly with the increase in mesh size. According to model deviance (D) and Akaike’s information criterion, the bi-normal model provided the best fit for small yellow croaker (Larimichthy polyactis), and the relative retention was 0.2 and 1, respectively. For Chelidonichthys spinosus, the log-normal was the best model; the right tilt of the selectivity curve was obvious and well coincided with the original data. The contact population of small yellow croaker showed a bi-normal distribution, and body lengths ranged from 95 to 215 mm. The contact population of C. spinosus showed a normal distribution, and the body lengths ranged from 95 to 205 mm. These results can provide references for coastal fishery management.

1. Introduction

Gillnets have traditionally been used in offshore fisheries. The target species include small yellow croaker (Larimichthy polyactis), butterfish (Pampus argenteus) [1], spotted mackerel (Scomberomorus niphonius) [2], and so on. The annual output of gillnet is lower than trawl products only, and accounts for 20% of the total catches in offshore fishery. Gillnets are highly selective for those species captured mainly by gilling (i.e., captured behind the gill-cover) or wedged (being held by a mesh around their maximum body girth). Therefore, retention is supposed to increase with size up to a length of the maximum catch and decrease thereafter, and consequently the range of size-at-catch of a target species can be controlled with a careful choice of the mesh size [3]. It is a common method adopted by the management. The minimum mesh size regulation proposed the minimum mesh size (MMS) of gillnet in the offshore fishery to be 50 mm, but the selectivity of the 50-mm mesh gillnet has not been reported in the East China Sea and whether the regulation is reasonable was unknown. The limitation of MMS 50 mm mainly aimed for the gillnet targeted at small yellow croaker.

Small yellow croaker is an important economic species in coast fishery [4]. The annual catches have reached up to 10,000 tons in recent years, and are targeted by gillnet, trawl, stow net, and so on.
According to the fishery resources study, the fishery resources of the small yellow croaker have declined seriously, and the population structure is simple. The catch weight of the first age accounts for 90%. Early sexual maturity and individual miniaturization are obvious [6]. Most researches attributed the fishery resources decline to the higher fishing intensity and environmental pollution. The government has adopted a series of policies, including prohibited fishing in summer, the MMS regulation for the fishing gear of marine fishery, and so on, to promote the sustainable development of the coast fishery.

Gillnet selectivity in the East China Sea (ECS) has been explored earlier [1, 2, 7, 8]. Some selectivity experiments on the gillnets for small yellow croaker were carried out in Korean waters [9, 10]. The optimal mesh size for 50% retention of yellow croaker (total length 191 mm) was estimated as 51.1 mm. The setting depth of the net, which is 4.6–13.8 m above the sea bottom, is the best to reduce bycatch and catch more large-size fishes [11]. However, no selectivity studies on the gillnet for small yellow croaker have been conducted in the East China Sea, and most of the size selectivity experiments have been carried out in trawl and stow net.

2. Materials and methods

2.1. Survey area and gears

The production tests were carried out from October 22 to November 5, 2011. The survey area was located in the traditional fishing ground in the north of East China Sea, 32°02′–33°16′N, 123°25′E–123°54′E’ (figure 1). The water depth was about 60 m; 73 valid hauls were finished.

A total of 10 different gillnets were used, including 2 heights (6- and 10-m panels) and 5 mesh sizes (35 mm, 40 mm, 45 mm, 50 mm, and 55 mm) in each height. Ten panels of each kind test net were used in the production trial. The test net structure and arrangement are shown in figure 2. The foot and upper ropes of each panel were 20 m long. The horizontal hang ratio was 0.6. The nets were made of nylon monofilament with diameter 0.2 mm. Gillnets sewn together were set on the bottom in appropriate depth zones. The time of net deployment depended on weather conditions and water temperature. The soak duration was between 120 and 300 min. The configuration and arrangement of the test nets are shown in figure 2.

2.2. Catch handling

After hauling, all species were sorted out and identified to the species level. The body length was
measured to the nearest millimeter and reduced to length frequency data, which was used for mesh size selectivity analysis. Sex was identified by anatomy. The catch data in different trials were accumulated by the same test net.

2.3. Selectivity estimation
Some assumptions were commonly adopted to simplify the model parameter estimation; the equal fishing efforts of all test nets and the selection curves of the gillnets followed the “principle of geometric similarity” [12]. According to the assumption, the catch process was only dependent on the relative geometry of the fish and the mesh size.

The selection method used all the advantageous properties of the maximum likelihood and allowed for the incorporation of between-haul variability [3, 13], further satisfying the uni-modal [14] and bi-normal selection curve parameter estimation [15] used herein.

According to the selection method, for a given length class $j$, the numbers of fish $N_{ij}$, which encountered the test net $i$, were assumed to be the independent poisson random variables, and $N_{ij}$ could be described as the product of the abundance of length class $j$ fish ($N_j$) and the relative fishing intensity of gillnet $I(q_i)$ [14]. The catch numbers of the length class $j$ in gillnet $i$ ($C_{ij}$) was distributed as follows:

$$C_{ij} \sim Po(q_iN_jS_{ij})$$

$S_{ij}$ was the retention probability of gillnet $i$ to length class $j$. The log-linear form was as follows:

$$lnP = \Sigma_{j} \Sigma_{i} (C_{ij}\ln(\lambda) - lnC_{ij}! - \lambda)$$

$C_{ij}$ was the number of catches. $\lambda = qN_jS_{ij}$ was the expected value if the selectivity curve was known. The selectivity curve parameters and the relative abundance of the given length class $j$ could be estimated simultaneously.

The commonly used selectivity curves (uni-normal and bi-normal models) [14, 16, 17] are shown in table 1, which were also used in this paper.

| Model      | Selection curve                                                                 | Note                                                                 |
|------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------|
| Normal     | $\exp\left(\frac{-\left(l_j - m_i\right)^2}{2\sigma^2}\right)$               | $l_j$ is the body length of the $j$ length group                      |
|            | $m_i$ is the mesh size of the $i$ kind test nets                                | $m_i$ is the mesh size of the $i$ kind test nets                      |
| Gamma      | $l_j^{\alpha-1} \exp\left(\frac{\alpha - 1 - l_j}{\beta}\right)$             | $R_0; R_{01}; R_{02}$ is the selectivity factor                      |
| Log-normal | $\exp\left[-\frac{\left(ln\left(\frac{l_j}{m_i}\right) - ln(R_0)\right)^2}{2\sigma^2}\right]$ | $\sigma; \sigma_1; \sigma_2$ is the model standard error             |
| Bi-normal  | $\exp\left[-\frac{\left(l_j - m_i - R_{01}\right)^2}{2\sigma^2}\right]$ + $\omega \exp\left[-\frac{\left(l_j - m_i - R_{02}\right)^2}{2\sigma^2}\right]$ | $\alpha$ and $\beta$ are model parameters                          |
|            |                                                                                 | $\omega$ is weight coefficient                                       |

3. Results

3.1. Effect of panel height and mesh size on catches
The species composition of the catch was affected synthetically by panel height and mesh size. Table 2 presents the composition of species that were captured by different panels. Altogether, 21 species were captured by the 6-m panels and 30 species by the 10-m panels. With the 6-m panels, the species number declined along with the increasing mesh size. However, with the 10-m panels, a peak number of the species were captured by the 45-mm mesh.

Table 2. Species composition and catch number by different test nets.

| Species                        | Panel height 6 m | Panel height 10 m |
|-------------------------------|------------------|-------------------|
|                               | 35 mm | 40 mm | 45 mm | 50 mm | 55 mm | 35 mm | 40 mm | 45 mm | 50 mm | 55 mm |
| Larimichthys polyactis       | 155    | 158    | 67    | 53    | 38    | 62    | 164   | 84    | 76    | 43    |
| Chelidonichthys spinosus     | 10     | 14     | 18    | 113   | 48    | 29    | 27    | 124   | 64    | 65    |
| Pneumatophorus japonicus     | 23     | 22     | 23    | 18    | 11    | 16    | 9     | 22    | 24    | 15    |
| Engraulis japonicas Temminck | 3      | 4      | 1     | 16    | 11    | 17    | 18    | 8     | 9     |       |
| Johnius belengerii           | 14     | 7      | 3     | 3     | 4     | 26    | 3     | 6     | 3     |       |
| Setipinna taty               | 10     | 7      | 2     | 4     | 3     | 7     | 17    | 2     | 2     |       |
| Decapterus maruadi           | 16     | 4      | 4     | 2     | 2     | 16    | 1     | 3     | 3     |       |
| Chaeturichthys stigmatias    | 1      | 2      | 1     | 1     | 1     | 6     | 6     | 10    | 7     | 6     |
| Richarson                     |        |        |       |       |       |       |       |       |       |       |
| Pennahia argentatus          | 4      | 7      | 1     | 2     | 5     | 4     | 5     | 4     | 1     | 3     |
| Liparis tanakae              | 1      | 2      | 5     | 1     | 1     | 1     | 1     |       |       |       |
| Cynoglossus joyneri Günther  | 2      | 3      | 2     | 2     | 1     |       |       |       |       |       |
| Scomberomorus niphonius      | 1      | 2      | 1     | 4     | 1     | 4     | 1     |       |       |       |
| Lophius litulon              | 1      | 1      | 2     | 2     |       |       |       |       |       |       |
| Caelorhynchus multispinulosus|       |        | 1     | 2     | 1     |       |       |       |       |       |
| Katayama                      |        |        |       |       |       |       |       |       |       |       |
| Trichiurus japonicus         |        |        |       |       |       |       |       |       |       |       |
| Psenopsis anomalus           |        |        |       |       |       |       |       |       |       |       |
| Cleisthenes herzensteini     |        |        |       |       |       |       |       |       |       |       |
| Miichthys miiny              |        |        |       |       |       |       |       |       |       |       |
| Cloupea pallasi Valencienies |        |        |       |       |       |       |       |       |       |       |
| Saurida elongata             |        |        |       |       |       |       |       |       |       |       |
| Pleuronectes platessa Linnaeus|        |        |       |       |       |       |       |       |       |       |
| Nibea albiflora              |        |        |       |       |       |       |       |       |       |       |
| Zoares gilli Jordan          |        |        |       |       |       |       |       |       |       |       |
| Colichthys lucidus           |        |        |       |       |       |       |       |       |       |       |
| Parapercis sxefasciata       |        |        |       |       |       |       |       |       |       |       |
| Gnathagnus elongatus         |        |        |       |       |       |       |       |       |       |       |
| Todorodes pacificus Steenstrup|        |        |       |       |       |       |       |       |       |       |
| Trachypenaeus curviostris    |        |        |       |       |       |       |       |       |       |       |
| Parapeneaus fissuroides Crosnier|          |        |       |       |       |       |       |       |       |       |
| Portunus trituberculatus     |        |        |       |       |       |       |       |       |       |       |
| Charybdis feriatus           |        |        |       |       |       |       |       |       |       |       |
| Oratosquilla nepa            |        |        |       |       |       |       |       |       |       |       |

4
The dominant species caught by the 6- and 10-m panels were the same. For the 6-m panels, 351 small yellow croaker and 203 *C. spinosus* accounted for 71.47% of total catches. For the 10-m panel, 327 small yellow croaker and 309 *C. spinosus* accounted for 66.67% of total catches. The body-length range of the dominant species was also similar between the 6- and 10-m panels. The majority of the small yellow croaker fish were concentrated within the range of 88–128 mm and 138–178 mm, and *C. spinosus* was concentrated within the range of 118–193 mm.

Table 3 presents the proportion and the catch number of small yellow croaker juvenile fish for different panels. Although the juvenile fish number and the proportion of the 10-m panels were slightly larger than those of the 6-m panels, the effect of panel height on juvenile fish composition was ambiguous for any single mesh size.

| Panel height | Juvenile fish number or proportion of different mesh sizes | Total proportion of juvenile fish |
|--------------|----------------------------------------------------------|----------------------------------|
|              | 35 mm | 40 mm | 45 mm | 50 mm | 55 mm |                 |
| 6 m Number   | 72    | 33    | 17    | 22    | 18    | 162              |
| Proportion   | 63.16%| 37.08%| 25.37%| 47.83%| 51.42%| 46.15%           |
| 10 m Number  | 38    | 67    | 32    | 22    | 20    | 179              |
| Proportion   | 71.70%| 59.82%| 48.48%| 39.29%| 50%   | 54.74%           |

Note: According to the allowable size of capture and juvenile proportion of key marine fishery resources of Zhejiang province, the minimum landing size of small yellow croaker is 145 mm.

*C. spinosus* was not an economic species, and the basic biological research was limited. No minimum allowed landing size (MALS) was currently reported; therefore, the proportion of juvenile fish was not calculated in the present study.

Along with the increasing mesh size, the number of juvenile fish declined quickly; however, the proportion first declined and then increased. This difference might be related to the lack of larger fish. The most efficient mesh size for small yellow croaker was 40 mm. The number of fish below the MALS notably decreased along with the increasing mesh size. The most efficient mesh size for *C. spinosus* was 50 mm, and 117 fishes were captured. The catches declined with changes in mesh size.

### 3.2. Selectivity estimation

The body-length range of the dominant species was similar between the 6- and 10-m panels, and the catches of single-height panels were not enough for selectivity analysis. Therefore, when the mesh size of 6- and 10-m panels was the same, the catch data were accumulated for the mesh size selectivity analysis. The length frequency distribution for the species analyzed is shown in figure 3 (dotted line). Small yellow croaker and *C. spinosus* were the only species for which sufficient data were available for selection curve estimation.

The length frequencies of small yellow croaker were distributed with a similar mode for different mesh sizes. Two visual peaks existed for each mesh size. Along with increasing mesh size, the length related to the first peak declined. However, the second peak showed the opposite response. For *C. spinosus*, the length frequency distribution was uni-modal, increased faster on the left side of the peak, and gradually declined on the right side.

Based on the length frequency distribution data, four types of selectivity models were used to fit the data. Table 4 presents the fitting results (three uni-models and one bi-normal model). According to the Akaike’s information criterion (AIC) and model deviance (D), for small yellow croaker, the bi-normal model provided the best fit, the AIC was the smallest, and \( P > 0.01 \). For *C. spinosus*, the log-normal was the best model, the AIC was the smallest, and \( P > 0.01 \).

Together with MALS (145 mm), the selection curve was plotted in figure 3 for small yellow croaker. Two separate peaks were present in the fitted bi-normal curves, and the relative retention was 0.2 and 1, respectively. This figure demonstrated that, except for the 50- and 55-mm mesh, the retention rates of the MALS were relatively higher for other mesh sizes.

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**Table 3.** Small yellow croaker juvenile fish proportion and number captured by different test nets.

| Panel height | Juvenile fish number or proportion of different mesh sizes | Total proportion of juvenile fish |
|--------------|----------------------------------------------------------|----------------------------------|
|              | 35 mm | 40 mm | 45 mm | 50 mm | 55 mm |                 |
| 6 m Number   | 72    | 33    | 17    | 22    | 18    | 162              |
| Proportion   | 63.16%| 37.08%| 25.37%| 47.83%| 51.42%| 46.15%           |
| 10 m Number  | 38    | 67    | 32    | 22    | 20    | 179              |
| Proportion   | 71.70%| 59.82%| 48.48%| 39.29%| 50%   | 54.74%           |
Figure 3. Body-length frequency distribution of *Larimichthys polyactis* and *Chelidonichthys spinosus* captured by test nets (dotted line) and the mesh size selection curve (solid line).

Table 4. Fitting result of different selectivity models.

| Species       | Model     | Parameters                          | Model deviance | df |
|---------------|-----------|-------------------------------------|----------------|----|
| *Larimichthys polyactis* | Normal    | \((R_0, \alpha) = (-4.17, 1.17)\) | 114.76         | 54  |
|               | Gamma     | \((\alpha, \beta) = (-6.69, 0.83)\) | 129.80         | 54  |
|               | Log-normal| \((R_0, \alpha) = (-5.83, 0.59)\)   | 134.40         | 54  |
|               | Bi-normal | \((R_{01}, R_{02}, \sigma_1, \sigma_2, \omega) = (3.96, 1.86, 0.61, 0.05, 0.19)\) | 71.16         | 51  |
| *Chelidonichthys spinosus* | Normal    | \((R_0, \alpha) = (2.88, 0.71)\)   | 68.75         | 46  |
|               | Gamma     | \((\alpha, \beta) = (-19.31, 0.16)\) | 88.04         | 46  |
|               | Log-normal| \((R_0, \alpha) = (3.00, 0.03)\)   | 51.89         | 46  |
|               | Bi-normal | \((R_{01}, R_{02}, \sigma_1, \sigma_1, \omega) = (2.88, 2, 0.71, 0.50, 0.70)\) | 65.30         | 43  |
For *C. spinosus*, the right tilt of the log-normal curve was obvious. The selectivity increased faster on the left side of the model peak, with a gradual decline on the right side; these coincided well with the original data.

3.3. Estimated relative abundance of fish contacting the nets

According to the best selectivity model, the contact population of small yellow croaker showed bi-normal distributions, and body length ranged from 95 to 215 mm (Figure 4). There were two frequency peaks at 100 and 160 mm body length, respectively, indicating two age groups. The biomass of juvenile fish accounted for 72.3%.

Figure 5 shows that the contact population of *Chelidonichthys spinosus* was normally distributed, and body length ranged from 95 to 205 mm. The frequency peak was at 155 mm. The right tilt of the abundance plot was obvious.

![Figure 4. Estimated population structure of small yellow croaker.](image1)

![Figure 5. Estimated population structure of *Chelidonichthys spinosus*.](image2)

4. Discussion

Previous studies on small yellow croaker in Korean waters showed [7,8] that a bi-normal model also provided the best fit; the relative total length at a maximum selectivity of the primary fishing modes was estimated to be 4.03, which was similar to that in the present study. However, the relative total length at a maximum selectivity of the secondary fishing modes was larger than the results of the present study and was estimated to be 4.62. The bi-normal model likely reflected the combined effects of several capture processes, where the primary mode would result from gilling or wedging and the secondary mode from other methods of capture. The majority of small yellow croaker were concentrated within the range of 88–128 mm for the secondary fishing modes in the present study. The size was significantly smaller than that of the catches in previous studies. Therefore, it was suggested that the capture modes were different for the secondary fishing modes and led to the estimation variance. The optimal mesh size for 50% retention for small yellow croaker (total length of 191 mm) was estimated as 51.1 mm. According to the selectivity curve used in the present study, the body length for 50% retention ($L_{0.5}$) of single drift nets with a mesh size of 51.1 mm was 156.5 mm and transfer to total length was 186.4 mm. Therefore, the two results were similar. An MMS of 50 mm was allowed in coastal gillnet fisheries. The $L_{0.5}$ of the 50-mm mesh size for small yellow croaker was 152 mm, which was larger than the minimum allowed landing size [18]. The regulation could satisfy fishery resources conservation.

Small yellow croaker is one of the main economic species targeted by trawling, stow nets, and gillnets in coastal fisheries. The MMS allowed for trawls in the East China Sea is 54 mm. According to studies in recent years, the $L_{0.5}$ of small yellow croaker caught by trawls with the MMS 54 mm was 113~130 mm [19, 20] and significantly less than the $L_{0.5}$ of small yellow croaker caught by gillnets with the similar mesh size. It could be concluded that, with similar MMS, gillnets were much more selective than trawls and stow nets.
Small yellow croaker is demersal fish. Along with the growth of juvenile fish, the habitat changed from demersal to semi-demersal water or pelagic water [21]. Therefore, the set depth of gillnet or the panel height was relative to catch composition. Taeg [11] concluded that a setting depth of 4.6–13.8 m above the sea floor was the best to reduce bycatch and catch larger fish in Korea coastal water. The lower the setting depth above the sea floor, the more the bycatch species captured. In this study, although the number and proportion of small yellow croaker juvenile fish for the 10-m panels were greater than those for the 6-m panels, the difference was not obvious. Further, the dominant species was the same, and the bycatch species increased with the filtering area of the nets; 22 and 30 species were captured by the 6- and 10-m panel, respectively.

Gillnetting is less limited by external factors (e.g., rough bottom) and has been widely used for fishery resource investigation [22-24]. However, according to the high selectivity of gillnets for target species, the gillnetting as a sampling method has been debated. The gillnet selectivity is usually defined as a product of the contact ratio and retention ratio. The probability of a fish to encounter and retain in a net increases with swimming speed, body size, and so on. Therefore, the bigger fish will be captured more effectively, and the biomass may be overestimated [22-24]. The population structure of fish contacting nets was estimated in this study based on the better selectivity model; the contact population of small yellow croaker showed bi-normal distributions, and the juvenile fishes accounted for 72.3%. This value was significantly smaller than that in the previous study based on trawling, and the population structure was normal distribution [5, 18]. It is doubtless that trawling cannot provide a nonbiased result for fishery resource estimation. Trawl catchability can be relatively low for large fishes, avoiding the trawl but not gillnets [24]. Hence, a good strategy is to use several sampling methods and cover the shortage [23]. For juvenile fish, the biomass estimation from gillnetting can be used as the lower limit, and the result from trawling can be used as the upper limit. Therefore, it can be concluded that the proportion of small yellow croaker juvenile fish should be more than 72.3%. The population structure is simple, and the stock in Chinese coastal waters has been overexploited. For C. spinosus, the population structure distribution is normal and the right tilt is obvious.

As the basic biological research on C. spinosus is limited, it is not possible to estimate the influence of the test nets on the resource population of this species. The selectivity analysis can provide a reference for future research.

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