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journal or publication title	Fisheries Science
volume	85
number	1
page range	19-32
year	2019-01
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科学研究費研究課題	底曳網の選択性パラメータにおける変動要因と資源管理におけるリスク評価 Factors affecting variation in selectivity parameters of trawl codend and risk evaluation for fisheries resource management
研究課題番号	16K07837
URL	http://id.nii.ac.jp/1342/00001811/

doi: 10.1007/s12562-018-1270-x

Codend selectivity of a trawl net with legal minimum mesh size in the East China Sea

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Abstract

Selectivity curves were obtained for 22 species from stock assessment research data in the East China Sea between 2001 and 2011, conducted using a cover net attached to the codend of a trawl net (Seikai National Fisheries Research Institute SS-RI type trawl net). The trawl net codend used was made of diamond mesh net with a legal minimum mesh opening size of 54 mm (mesh length of 66 mm). The cover net with a mesh opening of 18 mm (or 10.3 mm depending on the research year) was attached to the codend. For each of the 20 fish species and two squid species, we pooled data of hauls where body size for the whole catch was measured without subsampling to obtain the body size compositions of both of the codend and the cover net. The maximum likelihood method was performed for estimation of parameters in the logistic curve equation representing the codend selection curve. For 18 fish species (excluding *Trichiurus japonicus* and *Muraenesox cinereus*), we examined the relationship of the obtained selection parameters [l_{50}, length of 50% retention and SR, selection range (= l_{75} - l_{25})] to the fish body shape. We demonstrated that fish species with a smaller ratio of body height/width to body size (i.e. more slender body type) show a tendency of larger values of l_{50} and SR. Furthermore, by comparing the l_{50} of each fish species with the reproductive parameters such as minimum maturity length, we examined the sustainability of the resources based on the minimum mesh size regulation.

Key words: codend selectivity, fish community structure, maturity length

Introduction

Studies on mesh selectivity of trawl nets in the East China Sea were actively conducted in the 1950s by the Seikai National Fisheries Research Institute (e.g., Aoyama and Kitajima 1959, Aoyama 1961). Based on the results of these studies, Article 17 (operation restrictions) of designated fisheries (Ministry of Agriculture, Forestry and Fisheries Ordinance No. 5 of January 22, 1963) was enacted. According to Article 17, for trawl fishing in the East China Sea, the mesh opening (two bars and one knot in stretched mesh after soaking in water) of the codend and funnel-net should not be smaller than 54 mm, the mesh opening of other parts of the net should not be smaller than 65 mm, and any fishing operation using a net of non-suitable mesh size is prohibited (Aoyama 1965). The same minimum mesh size regulation with this mesh opening has also been implemented for South Korean and Chinese trawl fisheries in the East China Sea. The fishing grounds of the Japanese trawl fishery expanded throughout the East China Sea and the Yellow Sea in the 1960s, and then shrank to the continental shelf edge close to Japan because of competition with the development of South Korean and Chinese fisheries. Concurrently, fish species in catches changed to fish species distributed in the fishing grounds of the continental shelf edge, such as yellowback seabream *Dentex hypselosomus*, Pacific rudderfish *Psenopsis anomala*, squids, whitefin jack *Kaiwarinus equula*, red seabream *Pagrus major*, and blackthroat seaperch *Doederleinia berycoides*, from those distributed along the continental shelf and used for raw materials for processed fish products, such as yellow croaker *Larimichthys polyactis*, largehead hairtail *Trichiurus japonicus*, daggertooth pike conger *Muraenesox cinereus*, silver croaker *Pennahia argentata*, and lizardfishes *Saurida* spp. in the 1960s (Tokimura 2011). In addition, because of the extended period of fisheries pressure on these resources, both the fish stock levels and also the biological characteristics of the target species in the trawl fisheries have changed (Horikawa and Yamada 1999). Furthermore, Yamamoto and Nagasawa (2015) reported that the fish community structure for each sea area has changed, and pointed out that the pressure from fisheries capture is a contributing factor. The mesh size regulation is considered as a factor of the fisheries pressure affecting each fish species differently dependent on body morphology (shape). Therefore, it is necessary to specify in relation to the body shape the mesh selectivity for each fish species.

For the last three decades, the Seikai National Fisheries Research Institute in the National Research and Development Agency, Japan Fisheries Research and the Education Agency (FRA) have been conducting research on the geographical distribution and stock assessment of catch species, using research vessels with a trawl net (Seikai National Fisheries Research Institute SS-RI). In this survey, the mesh opening and mesh length (two bars and two knots in stretched mesh) of the codend were nominally 54 mm and 66 mm, respectively. For the purpose of catching small organisms, a cover net with a mesh opening of 18 mm (or 10.3 mm depending on the research year) was attached to the outside of the codend. Therefore, the codend mesh selectivity can be determined using the body size composition data of catches collected by the codend and by the cover net obtained in this survey. The codend of this trawl had a mesh opening of 54 mm, which satisfied the regulation. By analyzing the codend selectivity using the same mesh size as the legal minimum mesh size, this will enable clarification of the influence of mesh size regulations on the fisheries resources of each fish species and allow a more ecosystem approach to fisheries resource management.

In general, retention probability is known to increase from 0.0 to 1.0 for girth relative to mesh perimeter between 0.5 and 1.0 (girth / mesh perimeter) (Tokai et al 1994). Fish with a girth / mesh perimeter larger than one cannot pass through the mesh because these fishes have a larger girth than the inner mesh. Similar results have been confirmed for various fish species (Matsushita and Ali 1997, Liang et al 1999). As the body height (or body width) differs depending on the species of fish even if they have the same body length, it is conceivable that mesh selectivity differs between species and that the mechanism behind pressure resulting from fisheries capture also differs.

Therefore, in the present study, selectivity curves were obtained for as many fish species as possible from the data obtained in the present resource survey. Based on the parameters estimated for expressing the selection curve, the effects of body shape of fish species on the selection parameters (length of 50% retention, l_{50} and selection range, SR) were examined. Furthermore, by comparing the l_{50} value of each fish species with the reproduction parameters obtained in the past studies, such as minimum maturity length, we examined the sustainability of the fisheries resources of each species by implementing the regulation with the single minimum mesh size for trawl fisheries targeting multi-species resources.

Materials and Methods

Survey overview

The Seikai National Fisheries Research Institute (this research institute was affiliated to the Fisheries Agency until March 31, 2001 and then was affiliated to the Fisheries

Research Agency from April 2001) has conducted trawl surveys since the 1960s for the purpose of research on stock assessment in the sea area permitted for trawl fishing operation in the East China Sea (Mizutani et al 2005, Yamamoto et al 2010). The data used in the present study were obtained from the following trawl research ships: “Torishima” (426 ton) [of Tankai-senpaku Co. Ltd (Tokyo)] and “Kaiho-maru IV-generation” (499 ton) (of the Okinawa Prefectural Board of Education) in 2001; “Kumamoto-maru III-generation” (380 ton) (of the Kumamoto Prefectural Reiyou High School) in 2002; “Kaiyo-maru 7th” (499 ton) (of the Nippon Kaiyo Co. Ltd) in 2003–2009; and “Kumamoto-maru IV-generation” (443 ton) (of by the Kumamoto Prefectural Reiyou High School) in 2004–2011.

The trawl net used in these surveys is a net type called the Seikai National Fisheries Research Institute SS-RI type trawl net (Mizutani et al 2005). A 66-mm diamond mesh net with 54 mm mesh opening was used for its codend of 6.4 m length, outside of which the cover net of the diamond mesh net with a mesh size of 18 mm (or 10 mm in length depending on the year) was attached. The cover net was 5.6 m long, i.e. 0.8 m shorter than the codend length, but was attached at 1.7 m behind the forward end of the codend, and thus it was long enough to completely cover the codend. Moreover, the shape of cover net was rectangular while the side net of the codend was tapered, and thus this design formed enough room inside of the cover net to avoid any masking effect of the cover net. For the SS-RI type trawl net, which is the same net type as that belonging to Yoko-maru owned by Seikai National Fisheries Research Institute, the mesh opening of 50 meshes randomly selected from the codend was measured with digital calipers when moistened after towing on June 17, 2012. The average value (standard deviation) was 55.4 mm (1.00 mm) for the codend and 14.3 mm (0.41 mm) for the cover net.

The trawl survey was conducted between sunrise and sunset, and the trawl net was towed for 30 min at a towing speed of 3 knots in the ground speed after grounding on the sea floor. The total weight of fish catch obtained during each haul was measured for the codend and for the cover net. The whole catch was separated by species, and then the body size: body length, total length, fork length, preanal length, and mantle length depending on the species was measured at 5-mm intervals. When more than 50 specimens were collected in the codend or in the cover net, 50 specimens were randomly subsampled, and their body sizes were measured.

Handling of data

In the present study, using the body size composition data of specimens from the codend and cover net obtained by multiple operations, we identified a representative codend selectivity curve for each species. Generally, when body sizes are measured for all specimens in the codend and cover net, a selection curve can be obtained by pooling the body size compositions of each haul. However, as mentioned above, the body size of the subsampled specimens obtained from a haul was measured when the number of specimens was large. If subsampling was performed with different sampling fractions between the codend and the covernet, body size composition data obtained from multiple hauls cannot be directly pooled for analysis of codend selectivity. For such subsampled data, we need to analyze the data using the SELECT method (Millar 1994, Wileman et al 1996, Tokai 2012). For each of the species in these survey data, we thus excluded data collected by subsampling for either the codend or cover net. Data were extracted only from the hauls in which all the specimens were measured for both the codend and cover net without subsampling, and then the pooled data were used to obtain the body size compositions of the codend and cover net for analysis. Selection curves were determined with the body size compositions grouped at 5-mm intervals for 20 species of fish (*M. cinereus*, *Argentina kagoshimae*, *Glossanodon semifasciatus*, *Saurida umeyoshii*, *Saurida* *macrolepis*, *Zeus faber*, *D. berycoides*, *Priacanthus macracanthus*, *Branchiostegus japonicus*, *Trachurus japonicus*, *Decapterus maruadsi*, *K. equula*, *D. hypselosomus*, *P. argentata*, *P. anomala*, *Trichiurus japonicus*, *Scomber japonicus*, *Scomber australasicus*, *Pleuronichthys cornutus*, *Thamnaconus hypargyreus,* and two squid species (*Loligo edulis* and *Todarodes pacificus).* Basically, the fork length was used as the fish body size measurement. Besides, the preanal length was used for *M. cinereus* and *Trichurus japonicus*; the total length was used for *Z. faber*, *P. macracanthus*, *B. japonicus*, *P. argentata*, and *P. cornutus*; and the mantle length was used for *L. edulis* and *T. pacificus.*

Selection curve and its parameter estimation method

In the cover net method, fish collected by both the codend and cover net are considered to have entered the codend. The proportion retained in the codend without escaping through the mesh of the codend is defined as the retention probability. The selection curve, which represents the change in the retention probability with respect to the body size in the codend of this trawl, is represented by a logistic curve equation with the body size l as a variable (Millar 1994, Tokai 2009, 2012).

$$r(l) = \frac{\exp(a + bl)}{1 + \exp(a + bl)}$$

Here, a and b are parameters of the logistic curve equation. These parameters were obtained using the maximum likelihood estimation (Wileman et al 1996, Tokai 1997).

The fitness of the model was examined by likelihood ratio test (Millar 1994, Tokai 2009). Length of 50% retention, l_{50}, and selection range SR [$=l_{75}$ - l_{25}], which are selection parameters, were calculated using the following equation (Wileman et al 1996):

Length of 50% retention $\quad l_{50} = - a / b$

Selection range $\quad \mathrm{SR} = 2 \ln 3 / b$

The estimated error of these selection parameters, length of 50% retention l_{50} and selection range SR, were also determined according to Wileman et al (1996).

Generally, length of 50% retention l_{50} is used as a reference point of the body size caught by the fishery (Sparre and Venema 1998). However, in considering the impact of trawl fishing on resources, body size of fish that can hardly escape through the mesh and conversely that can mostly escape through the mesh are both important. Therefore, body sizes of 95%, 75%, 25%, and 5% retention were used as indicators and were calculated as follows:

body size of 95% retention $l_{95} = (-a + \ln 19) / b$

body size of 75% retention $l_{75} = (-a + \ln 3) / b$

body size of 25% retention $l_{25} = (-a - \ln 3) / b$

body size of 5% retention $l_{5} = (-a - \ln 19) / b$

Body shape of fish

It is well accepted that selectivity parameters (length of 50% retention l_{50} and selection range SR) are affected by the body shape (Liang et al 1999). In this study, fish species were divided into the following four categories based on the shape of the cross section and ratio of body height/width to the body size.

Slender type: The ratio of body height to body length was low and the cross section is round. Four fish species (*A. kagoshimae, G. semifasciatus, S. macrolepis*, and *S. umeyoshii*) were included.

Round type: The ratio of body height to body length was relatively high and the cross section is relatively round. Five fish species (*B. japonicus, Trachurus japonicus, D. maruadsi, S. australasicus,* and *S. japonicus*) belonged to this category.

Compressed type: The cross section was relatively narrow, and three fish species (*D.*

berycoides, P. macracanthus, and *P. argentata*) showed a compressed fish body shape of this type.

Extremely compressed or depressed type: The fish body was extremely compressed or depressed and flat, and five fish species (*Z. faber, K. equula, D. hypselosomus, P. anomala*, and *T. hypargyreus*) had such an extremely compressed body shape, and one flatfish *P. cornutus* had a depressed body shape.

We examined the length of 50% retention, l_{50} and selection range SR for each of these body shapes. For *M. cinereus* and *Trichiurus japonicus*, preanal length was measured, and thus the measurement site differed greatly from that of the other fish species. In addition, as Liang et al (1999) reported, these two species have an ability to pass through a narrow mesh space. Therefore, these fish species were excluded from our analysis. Moreover, because the body of squids was soft and completely different from fish body, the two squid species for the relationship of selection parameters with body shape were not analysed here.

Body size related with maturation and spawning

For females of each species, minimum maturity length, length at 50% and 100%

maturity, and first spawning length (age) were obtained from Yamada et al. (2007) and the previous studies listed in Table 1. However, for *A. kagoshimae*, we could not identify in the literature any body size information for the size at maturity or spawning.

Results

Estimated selection curve

Stacked histograms for expressing body size compositions caught in the codend and cover net were obtained for the 20 fish and two cephalopod species (Fig. 1). Logistic parameters (a and b) for expressing the selection curve of the trawl codend were estimated, and thus selection curve parameters, length of 50% retention l_{50} and selection range (SR) were calculated with their estimated errors (Table 2). The proportion retained in the codend from the observed data and the estimated selection curve for expressing retention probability were plotted versus body size (Fig. 2). The likelihood ratio test did not indicate a lack of curve fit in species other than five species: *G. semifasciatus*, *Trachurus japonicus*, *D. hypselosomus*, *T. hypargyreus*, and *T. pacificus* (Table 2). For these five species, even though a large enough number of specimens were caught and utilized for parameter estimation, the likelihood ratio test suggested that there were statistically significant differences between the estimated logistic selection curves and the proportion retained in the codend from the data with respect to body size. The plots of the proportion retained in relation to the body size appeared slightly unsymmetrical. This may be a reason for the lack of curve fit in the symmetrical logistic curve. Still, the estimated curves expressed clearly the plots for the retention probability.

Length of 50% retention, l_{50} and selection range, SR in relation to body shape

The length of 50% retention l_{50} and selection range SR are shown by fish body shape category in Figure 3. The value of l_{50} became higher as the body shape became slender, and became smaller as the body became flattened. Of fish whose girth is almost equivalent to the mesh perimeter of the mesh with 55.4 mm mesh opening, slender fish species have longer body sizes. In addition, although the same trend was shown in the selection range SR, the variation of the selection range was larger in slender and round fish species with a nearly round cross section. Thus, the codend selectivity tends to be less selective in body size for slender fish species compared with flat body fish species. In general, the wider the selection range, the greater the length of 50% retention. In fact, the ratio of the selection range to the length of 50% retention varied between 0.2 and 0.55, irrespective of the body shape category (Fig. 3). ANOVA test did not reveal any significant differences in the average value of this ratio between body shape categories (ANOVA test, $F = 0.73$, $P > 0.05$).

Comparison of codend selection parameters with body lengths at maturity and spawning

From the previous studies, we selected the minimum maturity length, length at 50% and 100% maturity, and first spawning length (age) as body size parameters related to maturity and spawning for females of each species, and compared them with lengths of 95%, 75%, 50%, 25%, and 5% retention in the codend from the logistic curve parameters representing codend selectivity (Fig. 4).

Because the minimum maturity length and first spawning length were smaller than the length of 50% retention, in *M. cinereus*, *G. semifasciatus*, and *S. macrolepis,* there remains a possibility that fish passing through the codend mesh can contribute to reproduction. *Argentina kagoshimae* had a l_{50} value of 18.9 cm which was large enough compared with the fork length of at largest 20 cm observed in the commercial catch (Okamura and Yamada 1986), and therefore, similar to *G. semifasciatus*, probably had a chance of avoiding the trawl fishing pressure by escaping out of the codend. The minimum maturity length was within the range between the 50% retention length and the 75% retention length in *Trichiurus japonicus*, and was within the range between the 75% retention length and the 95% retention length in *S. umeyoshii*, *Trachurus japonicus*, *D. maruadsi*, and *L. edulis*, which means that the matured individuals still had a small probability of escaping out of the codend. In *B. japonicus*, *P. argentata*, *S. japonicus* and *T. hypargyreus,* the minimum maturity length was similar to the length of 95% retention, and thus most of the fish that start maturation are largely unable to escape from the codend mesh when entering the net. In the other species, the minimum maturity length is larger than the length of 95% retention. This means that immature individuals which once entered a trawl codend were almost all retained in the codend without any chance of contributing to reproduction.

Discussion

Effectiveness of single mesh size regulation on fish resource conservation in the East China Sea

In the present study, we obtained the selection curve of trawl codend for 20 fish and two squid species. Since 1963, mesh size regulation have been implemented in the East

China Sea by setting a single minimum mesh size of 54 mm mesh opening for trawl fisheries in Japan, China, and South Korea. Among the species treated in the present study, the slender species, such as *A. kagoshimae*, *G. semifasciatus*, and *S. macrolepis* may be able to avoid fishing capture pressure with a high probability of escape from the mesh. In contrast, for the other species than *M. cinereus*, *A. kagoshimae*, *G. semifasciatus*, and *S. macrolepis*, we found that individuals larger than the minimum maturity length were largely unable to pass through the mesh. For fish with the same body length, the length of 50% retention is smaller in fish with an extremely flat body than in slender body fish. This suggests that these fish with extremely flat bodies are unlikely to escape from the codend mesh and therefore would be subject to the effect of fishing pressure at an earlier life stage than fish at a similar body length but with a slender body. As a result of analysis on annual variation in average density of each demersal fish species in the East China Sea and Yellow Sea from the same trawl data as the present study, Yamamoto and Nagasawa (2015) inferred that the proportion of species with resistance to the fishing pressure relatively increased among the dominant species, that is a change in the fish community structure. The information on codend selectivity for each species obtained in the present study indicated that differences occur between species in vulnerability to fishing capture pressure under the mesh size regulation with a single mesh size of 54 mm mesh opening, and were thus useful to examine the changes in the fish community structure under the mesh size regulation. In this study, fish body size at maturity and spawning was compared with the body size subject to fishing capture pressure, e.g. 50% retention length. In future analyses, the influence of fishing pressure under a single mesh size regulation should also be evaluated in terms of reproductive strategies of each species based on the life history parameters such as growth, fecundity and reproductive cycle.

We demonstrated here that the utility of mesh size regulation using only one mesh size for the trawl codend is marginal for resource management of multi-species fisheries such as the trawl fishery in the East China Sea. Thus, other measures for separating species should be combined to regulate the capture fish size of as many species as possible. For instance, it has been reported that there are seasonal and geographical variations in biological communities, that is, species composition varies with the marine environment in the East China Sea (e.g. Yamamoto et al 2010). This suggests that the number of species distributed in the fishing ground are limited to some extent when a trawl fisher decides a fishing ground according to his target species. In addition, selective fishing gears such as two-level trawl nets have been developed to separate fish species into the two codends on the base of the trawl gear used in the East China Sea (e.g. Nagamatsu et al 2006). Such a selective fishing gear, based on the behavior of the target species, can separate fish species into each codend. However, still many non-target fish are retained in the codend. Of fish species separated in the codend using the method described above, the most important species should be chosen in terms of conservation of biological resources and then the appropriate mesh size should be decided for each codend.

This study analyzed data from hauls without sub-sampling in the trawl surveys and thus estimated the selection curve of the codend with the legal minimum mesh size for limited 22 species. However, the original data derived from the trawl surveys also contain a large amount of trawl catch data obtained through sub-sampling. In future analyses, by using the SELECT method (Millar 1994), the total data set including sub-sampled data should be analyzed to improve the accuracy of estimation of the selection curve parameters and to estimate the selection curve for some more fish species.

Acknowledgments

We would like to extend our deep gratitude to the crew members of the following survey vessels: Torishima of Tankai-senpaku Co., Ltd.; Kaiho-maru, a fishing training vessel of the Okinawa Prefectural Board of Education; Kumamoto-maru, a fishing training vessel of the Kumamoto Prefectural Reiyou High School; and Kaiyo-maru 7th of the Nippon Kaiyo Co. Ltd for their cooperating with this survey. We also thank Mr. Kazunobu Minotani and Ms. Qian Yang, students of the Tokyo University of Marine Science and Technology at the time of the data analysis. Part of the survey was conducted by Marine Fisheries Research and Development Division and Marine Fisheries Research and Development Center, Fisheries Research Agency (formerly the Japan Marine Fishery Resources Research Center (JAMARC)). This study used data obtained in the research by the Research Fund of the Fisheries Agency of Japan for fisheries stock assessments. This study was partly supported by JSPS Grant-in-Aid for Scientific Research (C) 16K07837.

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Figure captions

Fig. 1. Length distributions of fishes and squids caught in the codend and in the covernet by species.

Fig. 2. Proportion retained in the codend and the estimated selection curve by species.

Fig. 3. Length of 50% retention, selection range, and ratio of the selection range to 50% retention length in the codend selection curve in relation to fish body shape.

Fig. 4. Comparison between maturity size parameters of female and codend selection lengths by species.