Doctoral Dissertation

STUDIES ON EVALUATION OF FACTORS AFFECTING EFFICIENCY OF MOHT NETS FOR SAMPLING FISH JUVENILES

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Graduate School of Marine Science and Technology
Tokyo University of Marine Science and Technology
Doctoral Course of Applied Marine Biosciences

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Abstract

Research on fish juveniles plays an important role in estimating the abundance of recruitment in fish stock assessment. In order to obtain accurate information about young fish, various sampling trawl gears are widely used. However, estimation of biomass from sampling trawl gear was often underestimated because all of mesopelagic fishes were not captured. For example, Isaacs-Kidd midwater trawls (IKMT), one of the most popularly used fishing gears had disadvantages that net mouth shape and towing depth were variable due to towing speed, which cause net avoidance of larger juvenile. To overcome these disadvantages of the sampling trawl gears, Matsuda-Oozeki-Hu Trawl (MOHT) were developed for quantitative catching. It has a rigid square frame net mouth and a cambered V-shaped depressor, which allow to be towed at high speed of 4 knot and to keep towing depth stable, irrespective of variation of towing speed. Based on MOHT, a new multi-layer quantitative sampling trawl gear with a net mouth opening/closing control system (MOC-MOHT) and with a codend opening/closing control system (COC-MOHT) were also developed. Catching efficiency is defined as the ratio of the number of caught fish to the number of fish existing in front of the net. This study assumed two hypothesis: before entering the net larger individuals to evade due to their faster swimming speed, that is, net avoidance; after young fish entering the trawl net, fish with enough small body escape through the mesh space of the net, which is called mesh selectivity. In this study, we attempted to clarify factors affecting the catching efficiency such as fish size associated with swimming ability, net mouth dimension, and towing speed, and through established models for mesh retention and net avoidance, evaluate the effect of net avoidance on fish stock assessment in comparison of fish density with acoustics survey results.

Comparative experiments were carried out to analyze mesh selectivity of the MOHT polyethylene net and size selectivity of net avoidance for small MOHT and IKMT nets. Four types of trawl net were used as follows: two size MOHT (standard and small one) with net of 1.59 mm-mesh polyethylene (PE) material, and two types of IKMT (one with net of 1.59 mm-mesh PE material and the other for plankton with net of 1.00 mm-mesh nylon material, hereafter IKPT). Of the four nets, selected two or three nets were alternatively towed: standard and small MOHTs and IKPT in Sagami Bay in 2003; standard and small MOHTs off Ibaraki and Iwate Prefecture in 2005; and standard MOHT, small MOHT and IKMT off Fukushima Prefecture in 2007, Pacific. Larvae and juveniles of Japanese anchovy *Engraulis japonicas* caught during the trials were sorted for measurement of body length in millimeter. Five models expressing net avoidance in small MOHT and two IKMTs and mesh selectivity of 1.59 mm-mesh net were performed, on the two assumptions: no net avoidance in standard MOHT with enough large net mouth to prevent fish evading in front of net mouth during towing; and no mesh selection in IKPT with 1.00 mm-mesh codend, i.e. enough small mesh to retain all larval and juvenile fish in the codend. The SELECT approach was applied to estimate model parameters from body length data of the successive two hauls for estimating the model parameters. The model which small MOHT and two IKMTs had different size selection for net avoidance was selected as an optimal model by Akaike' information criterion (AIC). Length of 50% retention and selection range in mesh selectivity of 1.59 mm-mesh codend were 12.20 and 2.82 mm, respectively. Our result was in accord with earlier research (Saiura et al 2006). Net avoidance of juveniles was likely to occur in IKPT with fine mesh codend and small MOHT, compared with IKMT and standard MOHT, respectively.

Effect of towing speed on net avoidance was tested by using the MOHT nets in each sea trials. These trials included standard MOHT sampling in the East China Sea in August 2016, MOC-MOHT sampling in Sagami Bay in July 2015, and COC-MOHT sampling in Sagami Bay in October 2014. In each trial, the net was casted for targeting depth where fish aggregation was observed by acoustics, and towing speeds were changed into the three stages of 4, 3, and 2 knot in this order. Compared with alternative experiment of standard MOHT, multi-layer sampling MOC-MOHT and COC-MOHT with five codends have advantages on catching the same fish school at speed of 2, 3 and 4 knot in one cast. All lantern fish were picked out for body length measurement and grouped into 5mm standard length intervals. They were identified into species level as follows: *Diaphus Kuroshio, Diaphus* spp, *Ceratoscopelus warmingii, Myctophum asperum, Myctophum nitidulum, Diogenichthys atlanticus, Lampanyctus alatus, Lampanyctus* sp, *Myctophidae* spp. Length distribution of each species showed that the catch number of large fish decreased at lower towing speed. Here, several models were assumed with linear functions of towing speed V to express logistic parameters α and β. In addition, the split parameters p in two hauls (4 and 3 knot, 4 and 2knot) was estimated by log-likelihood method or calculated with practical filtered water volume in the experiments. Total of six models were tested to examine the effect of towing speed on net avoidance. Through AIC model selection, net avoidance curve of 4, 3 and 2 knot for *Diaphus Kuroshio* and *Diaphus* spp was successfully obtained. It indicated that there was a linear relationship between net avoidance and towing speed, lesser speed resulting in more obvious net avoidance, and also suggested that net avoidance occurred even at high speed of 4 knot in MOHT sampling.

Catching efficiency for lantern fish by MOC-MOHT sampling was evaluated in comparing densities with acoustics survey. In Sagami Bay in July 2015, Sonic KFS-3000 echo-sounder system, operating at 38 kHz frequency, was also used to record acoustic data during all tows of MOC-MOHT. The area backscattering strength (SV) for the water column swept by MOC-MOHT was recorded automatically at Echoview® software. In order to calculate the mean TS for all the lantern fish, we made two assumptions: all the lantern fishes had a swim bladder; and for all the lantern fish, the same formula for *Diaphus garmani* estimated at 38 kHz between target strength and standard length was applicable. Meanwhile, lantern fish densities estimated by MOC-MOHT net sampling were calculated based on the actual fish number and filtered water in each haul. Without considering net avoidance in MOC-MOHT sampling, densities estimated by MOC-MOHT sampling was about 2 orders of magnitudes lower than acoustics. Net avoidance caused underestimation of catch number for larger fish in MOC-MOHT samples, which means underestimation not only in density estimation by MOC-MOHT but also in SV leading to density overestimation of the acoustics. With compensating length distributions for net avoidance with selection curve dependent of towing speed, the difference between the two methods reduced to be about one order of magnitude.

In this study, we established evaluation model of main factors affecting fishing efficiency, including fish size, net mouth dimension, mesh size and towing speed of several sampling trawl gear, and evaluated the effect of net avoidance on fish stock assessment in comparison with the acoustics. The methods and approaches established in this study are useful for many other species to obtain better estimation of fish stock from sampling trawl gear survey.

Chapter 1. General Introduction

1.1 larval fish sampling gear

In order to maintain sustainable development and the rational use of fishery resources, Total Allowable Catches (TAC) and Total Allowable Effort (TAE) system were established. Japan also introduced these control treaties and established rights to manage the fishery resources in Exclusive Economic Zone (EEZ) in 1996. According to the regulations of TAC, Allowable Biological Catch (ABC) was essential to presume the biomass of fisheries resources in EEZ waters correctly and promptly. On the statistics of fishery resources, one of the ways to presume spawned fish was based on biomass of eggs and larvae fish (Oozeki, 2000). Also, the cumulative mortality through the larval stage has great effect on the variation of the year class strength of these pelagic fishes. Therefore, quantitative sampling gears for catching larvae fish have been noted to obtain information on the early life stages of pelagic fish.

Among several sampling gears, the widely used Isaacs-Kidd midwater trawl (IKMT) was designed to sample at fast speeds of 2-3 m/s. However, four bridles in front of the net and unfixed net opening, also the fluctuation of the towing depth depending on towing speed lead to inappropriate quantitative sampling.

Because the young fish is sparse in distribution, efficient quantitative collection of fishing gear must meet the following conditions: ①The fixed net frame showed no deformation during the towing speed changed, so the accurate filtered water could be calculated. ②Net is made up of the same mesh size and the target fish will not escape from the net. ③Clogging phenomenon will not happen in the process of towing, meaning the sampling gear has full ability of filtering water. ④No obstruction in the front of net, efficiently leading all fish toward the net. According to the speed of the target species, high speed and stable target depth are required.

Framed trawl Methot-Isaacs-Kidd trawl (MIKT) was used to study the small-scale distribution of pelagic fish larvae. Although sampling using the MIKT was successfully controlled, several test trials revealed that the frame of the MIKT was not robust enough under rough sea conditions. Also, the towing depth was not easily controlled because of fluctuations of the towing speed.

In order to overcome the disadvantages of these sampling trawls, Hu et al. (2004) designed a new midwater trawl with a 5 m^2 rigid square frame and a cambered V-type depressor which was named as Matsuda, Oozeki and Hu Midwater Trawl (MOHT). The MOHT trawl is able to perform with the required depth stability in the ocean by adjusting the warp length. Smith et al. (1968) stated that when the ratio of filtering area to mouth area was above 5, the filtration efficiency was considered to be more than 95%. The ratio of MOHT was 9.91, so the filtration efficiency can be regarded as almost 100%.

Yamamura et al. compared the sampling efficiency of the MOHT and IKMT nets in Eastern Bering Sea during September 21–22, 2007. The result showed that MOHT had a higher sampling efficiency in both abundance and biomass compared to the IKMT. This ratio could have been even higher if the MOHT had been towed at higher speed. MOHT net is a suitable sampling gear for larvae and juveniles of pelagic fish under rough sea conditions. Although avoidance behavior and escapement lead to under-sampling with any net system, the MOHT has recently been found to outperform other systems in its capture efficiency (Pakhomov and Yamamura, 2010).

MOHT net has been gradually recognized and applied to sea investigations worldwide. A 5 m^2 mouth opening MOHT has been used in dominant pelagic fish to obtain clear ecological information like the biomass, food habits, distribution and so on (Tanimata et al., 2008; Pakhomov and Yamamura, 2010; Itoh et al., 2011; Matsuura et al., 2012; Davison et al., 2013; Netburn and Koslow, 2014; Davison et al., 2015; Ariza et al., 2015).

However, it's difficult for conventional sampling trawl with single net to sample young fishes because they are sparsely distributed and have sufficient swimming capability to evade nets. Therefore, high-speed stratified layer sampling nets, with large fixed mouth opening and uniform size of mesh, are required for quantitative assessment of the density of young fishes.

The MOCNESS (multiple opening/closing net and environmental sensing system, Wiebe et al., 1976, 1985) has been widely used for zooplankton and micronekton sampling. However, the effective mouth area was fluctuated as the towing speed changed due to the towing position in relation to the position of the attached bridles. Mouth shape of RMT (rectangular midwater trawl, Baker et al., 1973; Roe and Shale, 1979; Dimmler and Klindt, 1990) is also unstable because the flexibility of the side wires are connected to the upper and lower sections of the frame and the attachment of the bridles to the top of the frame. The LOCHNESS (large opening-closing high speed net and environmental sampling system, Dunn et al., 1993) has a large frame appropriate for fish sampling, while the weight of the whole system exceeds 2 t and heavy dropping bars each weighing 100 kg which needs a crane to set up.

Based on MOHT, the new multi-layer quantitative sampling gear with an autonomous net opening/closing control system (MOC-MOHT) and with a codend opening/closing control system (COC-MOHT) were developed and used for ocean investigation. These sampling gears are easy to operate on research vessels without any special facilities, and have the same net-depth stability as the MOHT under rough sea conditions. The MOC-MOHT has a rigid-frame 3.3 m high and 2.35 m wide and five nets of 11.0 m length with a rectangular mouth of 2.22×1.81m. A cambered V-shape depressor is hung below the frame and two bridles are attached at the midpoint of the side frames. The COC-MOHT has a rigid frame with a mouth of 5 m^2. The multiple codend opening/closing system has the same opening/closing mechanism as the MOC-MOHT and is 1.28 m high and 0.75 m wide.

Sampling gear	Advantage	Disadvantage
IKMT	fast speeds of 2-3 m/s.	four bridles in front of the net, unfixed net opening
MIKT	fixed frame net mouth	no robust net frame, towing depth not easily controlled
MOCNESS	multiple opening/closing net, numerous codend	effective mouth area changed as the changing towing speed
RMT	multiple opening/closing net, deep operating water depth	unstable mouth shape
LOCHNESS	multiple opening/closing net, a large frame net	heavy whole system (weight exceeds 2 tonne)

1.2 Trawl avoidance

The ideal sampling gear for micronekton is considered to be able to capture all the target young fishes on the way. As far as we know, for the same species of fish, with the increase of body length, those larger fish will have much difficulty to escape through the net mesh, while at the same time they will be much easier to escape ahead of the net. Mesopelagic fishes occur in all the world's oceans, but their abundance and ecological significance remains uncertain. The current global estimate based on net sampling prior to 1980 suggests a global abundance of one gigatonne (109 t) wet weight (Gjøsæter and Kawaguchi, 1980; Lam and Pauly, 2005). However, it is likely an underestimate (Gjøsæter and Kawaguchi, 1980) of mesopelagic fishes because they are not quantitative captured by sampling gear. Therefore, it is beneficially important for us to understand the net avoidance of fish larvae when evaluating the fishery resources accurately in the future.

Murphy and Clutter (1972) did research on avoidance during day time and night. They pointed out that the day-night difference in avoidance is only a small part of the total avoidance problem, the most of the avoidance being performed as well as in the dark as in the light. Barkley (1964, 1972) described the relative capacities of larvae to avoid when given early warning of the approach of the sampler. He indicated that the response starts three to four mouth diameters ahead of the net. Avoidance behavior of mesopelagic fish from a pelagic trawl was similar to the escaping potential predatory fishes (Stein et al., 2012). Fish can use several sensory stimuli to detect a moving trawl (Handegard and Tjøstheim, 2005; Jamieson et al., 2006), which including visual detection (Jamieson et al., 2006; Heino et al., 2011). For example, catches of myctophids have been considered to be more quantitative at night (Collins et al., 2012). However, trawls will stimulate bioluminescent flashes (Jamieson et al., 2006) and thereby also make a marked visual signal at night. Myctophids have eyes that are very sensitive to light, and bioluminescent flashes may be detected at a range of tens of meters (Warrant and Locket, 2004).

Fishing gear contrast experiment have revealed marked differences in catch efficiency of mesopelagic fish between different trawl types, due to various influences from extrusion through meshes and net avoidance behavior (Pakhomov and Yamamura, 2010; Heino et al., 2011). Although MOHT has advantage over the other gears, it still appeared to underestimate micronekton biomass when compared with the estimates using an echosounder with multiple frequency transducers. This indicated that regardless of trawl type, acoustic abundance estimates always appear to be consistently higher than the net-based estimates (Koslow et al., 1997; Kloser et al., 2009; Pakhomov and Yamamura, 2010).

1.3 Fishing gear selectivity

Selectivity is the feature of fishing gear to capture the target fish in fishing grounds and specific size of the fish. Therefore, fishing gear selectivity is composed of the size selectivity and species selectivity (Matsuoka, 2001). However, the selectivity of fishing gear is not absolute, so except the capturing a lot of other fish incidentally, besides the target fish. In addition, jettison phenomenon occurred during fishing operation. Selectivity estimates are primarily of importance because mesh selectivity is not constant for all gears but is dependent on many gear design parameters, the most important of which is mesh size. Especially in recent years, for the sake of resource conservation and environmental protection, fishing gear selectivity study becoming more and more essential.

As a quantitative sampling gear, we expect it to collect larval and juvenile fish ahead of its net as much as possible. However, small sized fish have the possibility to escape through the net mesh, which is termed as mesh selectivity. Meanwhile, fish with enough small body have the possibility of escaping through the mesh space of the net, which is called mesh selectivity (Smith and Richardson, 1977). For larger individuals, it is much easier for them to escape before entering the net with faster swimming speed, that is, net avoidance (Clutter and Anraku, 1968). Particularly, net avoidance is much obvious in smaller mouth area and high swimming speed of fish.

Selection curve is used to describe the possibility of target fish that a fish of a given length being retained in codend. The horizontal axis represents the fish length, while the vertical axis the proportion of fish that have been retained in the codend. Two parameters are widely used to describe the selection of fishing gear. The first is the 50% retention length which is the length of fish that has a 50% probability of being retained or escaped before entering the codend. The second is the selection range which is the difference in length between the fish that has a 75% probability of retention and that with a 25% probability of retention. This is a measure of the sharpness of selection i.e. the shape of the selection curve. A gear with a large selection range will start to retain fish of a smaller length and fail to retain fish at larger lengths than a gear with the same 50% retention length but shorter selection range.

1.4 Diel vertical migration of Myctophid fishes

Myctophids are mesopelagic fishes belonging to family Myctophidae. They are represented by 246 species in 33 genera, and are found in oceans worldwide. They typically have a slender, compressed body covered in small, silvery deciduous cycloid scales , a large bluntly rounded head, large elliptical to round lateral eyes, and a large terminal mouth with jaws closely set with rows of small teeth. They are an important link in the food chain of many local ecosystems, being as a major source of food for many marine animals. Myctophids are well-known for exhibiting adaptations to oxygen minimum zones and also performing diel vertical migration behavior. Changes in the resource of myctophids will bring great influence to changes in competitors and predators, and therefore the evaluation of myctophid resource trend is important to predict and protect marine biological resources.

Vertical migration at night usually starts about one hour prior to sunset and completes between a-half and one hour after sunset. Smaller individuals travel a distance of 10-170 m/h while larger individuals travel a distance of 100-200 m/h single-pass. Myctophid larvae remain in the epipelagic zone (< 200 m) and then move to relatively deeper depth to adapt to their later adult life in the mesopelagic zones, after which most species start diel vertical migration (Sassa, 2004). Knowledge of diel vertical migration pattern of common species is essential to understanding species distribution of water depth, as well as quantitative evaluation of their resources. Prior study carried out by Watanabe et al. (1999) inferred that myctophids have four kinds of migrational patterns. ①Migrants showing clear day-night habitat separation with peak abundance above 200 m at night: *Symbolophorus californiensis, Tarletonbeania* *taylori, Notoscopelus japonicus, Diaphus theta, Ceratoscopelus warmingi,* and *Diaphus gigas*. ②Semi-migrants, in which part of the population often remains in the daytime habitat at night. The distribution depths of migratory and nonmigratory individuals do not overlap: *Stenobrachius leucopsarus*. ③ Passive-migrants, in which there is no separation of day-night habitats, but the upper limit of daytime distribution depth shifts to a shallower layer at night, probably as the fish follow migratory prey: *Lampanyctus jordani*. ④Nonmigrants: *Stenobrachius nannochir, Lampanyctus regalis* (>140 mm SL), and *Protomyctophum thompsoni.*

Ropke (1993) and Sassa et al. (2004) considered that vertical distribution of potential prey is more important than just physical stratification in determining the vertical distribution of most mesopelagic larvae in subtropical-tropical region. This daily vertical migration is connected with nutrition and energy exchange between lower and higher trophic levels (Tsarin, 2002). Therefore, it is important to understand their prey items like copepods, euphausiids through gut content analyses which in turn will highlight their feeding ecology and community structure. Further, vertical migration is also controlled by light intensity, for e.g. an experiment carried out by Gjøsæter (1984) onboard RV 'Dr. Fridtjof Nansen', inferred that maximum lanternfishes are sensitive to bright light. This could be because they are adapted to low light conditions in deep waters and yet could be another reason for their migration to the surface after dusk. The scientist used the fish's migratory behavior as an advantage for catching near surface concentrated fish during trawling.

1.5 Acoustical biomass estimation of myctophid fishes

The biomass of mesopelagic fish was under estimated because conventional methods of biomass estimation using sampling gear have highly inherent bias associated with net avoidance (Holliday and Pieper, 1995; Medwin and Clay, 1998). Acoustical technology is one of the important means to estimate fish resources and distribution structure widely used in sea trial in recent years. With the rapid development of acoustical engineering technology, many research vessels are equipped with quantitative echo sounder.

In acoustic surveys, fish target strength (TS) of individual fish is used to convert the measured backscattered energy into estimates of fish biomass. TS value is measured directly with split- or dual-beam echo-sounders for many fish species (Ehrenberg, 1983; Foote, 1991). However, experimental and theoretical research on lantern fish TS are very limited, the main reasons are as follows. One most important reason is that in the lantern fish, some species have swim bladders while others have no swim bladders, and difference in status of swim bladders in the same species, even some airbladder form unknown species exist (Marshall, 1960; Capen, 1967; Butler and Pearcy, 1972). Another reason is that many adverse conditions for acoustic measurement including deep water living, small individual and unique ecological habits of diel vertical migration (Hamano, 1993). Estimation methods of TS can be divided into two types: experimental and theoretical methods. In experimental methods, natural way refers to the direct measurement of TS of target fish in natural state. But for lantern fish, those small individual who live in the deep layer, individual echo detection is difficult (Hamano, 1993). Suspension method refers to a measure TS values of dead or narcotic fish hung on echo sounder transducer by adjusting the fish body tilt. Theoretical models approximate the target organism as a geometric configuration, and many useful approximate methods have been developed to date (Ye, 1997). Theoretical models including the prolate-spheroid model (PSM; Furusawa, 1988) and the deformed-cylinder model (DCM; Ye et al., 1997).

1.6 The objective of the study

Research on juvenile fish plays an important role in estimating the abundance of recruitment in fisheries management. In order to obtain accurate information about young fish, various fishing gears are widely used. However, fishing gear result in an underestimated biomass because mesopelagic fishes are not captured quantitatively. For example, as one of the most popular used fishing gears, Isaacs-Kidd midwater trawls (IKMT) has disadvantages in changing of net mouth shape and unsteady in depth due to towing speed, which causes avoidance of larger juvenile. To overcome these disadvantages of those fishing gears, Matsuda-Oozeki-Hu Trawl (MOHT) has been developed for quantitative fishing. It has a rigid square frame net mouth and a cambered V-shaped depressor, which is able to perform at high speeds of up to 4 knot and keep stability at required towing depth. Based on MOHT, a new multi-layer quantitative sampling gear with an autonomous net opening/closing control system (MOC-MOHT) and with a codend opening/closing control system (COC-MOHT) were also developed. Catching efficiency is defined as the ratio of the number of caught fish to the number of fish existing in front of the net. The entering and the mesh retention affect the catch efficiency of towed net gear. This study assumed two hypothesis: before entering the net larger individuals to evade due to their faster swimming speed, that is, net avoidance; after young fish entering the trawl net, fish with enough small body escape through the mesh space of the net, which is called mesh selectivity. The factors effecting mesh selectivity such as mesh size, mesh shape, codend diameter and so on have been analyzed (Millar and Walsh, 1992; O'Neill and Kynoch, 1996; Reeves et al., 1992; Tokai and Saiura, 2002). Theoretical studies of net avoidance (Barkley, 1964; Clutter and Anraku, 1968; Murphy and Clutter, 1972; Laval, 1974) elaborated factors such as fish size, swimming ability of fish, net mouth dimension, towing speed have effect on collection efficiency. However, there were no studies using actual sea experimental data on factors affecting the net avoidance.

In this study, firstly, we applied comparative trials to analyze mesh selectivity of the MOHT polyethylene net and size selectivity of net avoidance for small MOHT and IKMT nets. In previous research papers, MOHT trawl showed better catching efficiency than other sampling gear under the same towing conditions. Hence, it is very suitable and meaningful that we choose MOHT trawls as experimental sampling gears. Secondly, we analyzed the effect of towing speed and fish body size on net avoidance. The same MOHT net were conducted to catch the same fish target at various towing speed at a specific depth layer. Finally, catching efficiency of MOC-MOHT was evaluated by comparing lantern fish densities with acoustics method. In conclusion, we attempted to clarify factors affecting the catching efficiency such as fish size associated with swimming ability, net mouth dimension, and towing speed, and through established models for mesh retention and net avoidance, evaluate the effect of net avoidance on fish stock assessment in comparison of fish density with acoustics survey results.

Chapter 2. Mesh selectivity of MOHT and net avoidance of IKMT and small MOHT

2.1 Introduction

Research on larva and juvenile of pelagic fish plays an important role in estimating abundance of recruitment for fisheries management. Several types of midwater trawls have been applied to catch larvae and juveniles in the oceanographic research (Oozeki et al., 2004). One of the popular sampling midwater trawls for targeting fish larvae and juvenile was the Isaacs-Kidd midwater trawl (IKMT) which was designed to be towed at high speeds of 2-3 m/s with a V-shaped depressor of 3m width, and the 10-foot IKMT has a mouth area of about 5 m^2 (Miya and Nielsen, 1991; Filippova and Pakhomov, 1994; Flynn and Klepadlo, 2012). However, the IKMT has a disadvantage of change in net mouth shape and unstable depth due to towing speed, which could cause net avoidance of larger juvenile. Specifically, quantitative sampling gears for larvae and juvenile require several conditions: net mouth fixed with frame and stable towing depth as well as high towing speed. To satisfy the conditions, a midwater frame trawl named Matsuda-Oozeki-Hu Trawl (MOHT) was developed for sampling young pelagic fish (Hu et al., 2001; Hu et al., 2002; Oozeki et al., 2004). The MOHT trawl (Fig. 2.1) has a net mouth of rigid square frame and can be towed at high speeds of 2-3 m/s with a cambered V-shaped depressor hung below the net frame. Another advantage of MOHT trawl was that towing depth of the trawl was easily controlled to be stable by adjusting the warp length, regardless of variation in the towing speed under rough sea condition.

After the standard MOHT with a mouth area of 5 m^2 was put into practical use, another small MOHT with a mouth area of 2 m^2 was developed for utilization on small research vessel. As a quantitative sampling gear, the two MOHTs are expected to collect larval and juvenile fish ahead of the net as much as possible. Still, larger fish with the larger body size have the higher swimming ability and thus are likely to escape more easily before entering the net, that is, net avoidance (Clutter and Anraku, 1968). Particularly, net avoidance would be remarkable in smaller mouth area of the net and higher swimming speed of larger fish (Barkley, 1964; Barkley, 1972). Because the small MOHT has a mouth area of smaller than the standard MOHT, the net avoidance of larvae and juveniles against the small MOHT maybe more likely to occur. Similarly, the disadvantage of the IKMT mentioned above also may cause net avoidance of larger juvenile.

Fish larvae and juvenile with enough small body have the possibility of escaping through the mesh space of the net (Smith and Richardson, 1977), that is mesh selectivity. Nets of the two MOHTs were constructed of square mesh consisting of a bar length of 1.95 mm and a twine diameter 0.36 mm (1.59 mm pores) knotless ultra-high-strength polyethylene (Toyobo, Japan; Dyneema SK60). Minnow netting with 1.41, 1.55 and 1.80 pores used in Japanese seine net fishery have mesh selectivity for Japanese anchovy larvae, which suggest mesh selectivity of MOHT net. Meanwhile, IKPT (Isaacs-Kidd plankton trawl) was a kind of IKMT, and its net was constructed of nylon material of 1.00 mm mesh space (1.33 mm bar length and 0.33 m twin diameter)(Kubodera, 1989; Williamson and Mcgowan, 2010), and thus may be able to retain smaller larvae, compared with the net of 1.59 mm mesh in the MOHTs and IKMT.

In this study, a total of 4 types of sampling gears: the two MOHT nets (standard and small), IKMT and IKPT were prepared and three series of alternative haul experiments were conducted with using two or three gears. From the test result, we evaluated mesh selectivity of the MOHT polyethylene net and size selectivity of net avoidance of Japanese anchovy larvae and juvenile for small MOHT, IKMT and IKPT.

2.2 Material and methods

2.2.1 Sampling gears

The specifications of the four sampling gears tested in this study were shown in Table 2.1 and Fig. 2.2. First, the standard MOHT had a mouth area of 5.03 m^2 and a total length of 12.8 m. The cambered V-shape depressor was hung below the net mouth, which was connected by two bridles from both sides of the mouth frame. To maintain the attack angle of the depressor constant, the depressor had a wing with area of 0.99 m^2 aspect ratio of 6.0 camber ratio of 15 %, and dihedral angle of 20 degrees. The mass of the depressor was 62 kg and the total mass of the frame was 230 kg. Meanwhile, the small MOHT which was developed for operation on small research vessel has a mouth area of 2.04 m^2 and total length of 8.3 m, and the wing area and mass of its depressor was 0.41 m^2 and 15 kg with the same aspect ratio, camber ratio and dihedral angle as the standard MOHT. The total mass of the small MOHT frame was 50 kg, about 1/5 of the standard MOHT's. For both of standard and small MOHT, the nets were constructed of knotless ultra-high strength polyethylene with the square mesh of 1.95 mm bar length and 0.36 mm twine diameter. The open area ratio (porosity × filtration area / mouth area) of the net was 8.78 for standard MOHT, and 9.91 for small MOHT, respectively.

Both of 10-ft IKMT and IKPT used in this study had the same net mouth construction with a 2.25 m steel bar at the upper part of the net mouth and a V-shaped depressor below the net mouth. The wing of the depressor was a wing width of 3.0 m, a wing area of 1.86 m^2 an aspect ratio of 4.8, and a dihedral angle of 20 degrees. The total lengths of the 10-ft IKMT and IKPT were both 12.6 m. The mass of the 10-ft IKMT including upper steel bar was about 88.9 kg. While the net of the 10-ft IKMT was made of knotless ultra-high strength polyethylene of the same twine as MOHT, that of IKPT was constructed of nylon twine with square mesh of 1.33 mm bar length and 0.33 mm twine diameter. The total mass of the IKPT including steel bar was 88.9 kg.

2.2.2 Alternate operation test

Three series of alternative haul experiments were carried out with the RV *Soyo-maru* (892 t) in September 2003, in May and June 2005, and in May and June 2007 (Table 2.2-2.7). The details of deployed sampling gears and towing conditions were as follows.

In September 2003, alternative towing of standard and small MOHT and IKPT were conducted totally 16 times (9 hauls at nighttime and 7 hauls at daytime) by oblique tows from the surface to 50 m depth in Sagami Bay. The winch speeds for wire-out and wire-in were set at 0.25 m/s, and the vessel speed was 4.5 knot at wire-out and 3.5 knot at wire-in, respectively.

In May and June 2005, standard and small MOHT were towed alternately under step-oblique tows at 30 m, 20 m, and 10 m depth: four hauls off Ibaraki prefecture and six hauls off Iwate prefecture. In step-oblique tows at target depth of 30, 20, and 10 m, warp length were set at 100, 70, 45 m for standard MOHT and 140, 100, 60 m for small MOHT, respectively. The winch speeds were set at 0.25 m/s during wire-out and 0.2 m/s during wire-in, and the vessel speed was set at the same way as the 2003 experiments. In June 2005, alternative tows of standard and small MOHT were conducted alternately by oblique tows from the surface to 100 m depth: six hauls off Ibaraki prefecture and six hauls off Iwate Prefecture. The winch speeds of wire-out and wire-in were set at 0.25 m/s, although the vessel speed was 4.5 knot at wire-out and 3.5 knot at wire-in, respectively.

In May and June 2007, three nets (standard and small MOHT, and IKMT of which nets were the same polyethylene material and mesh size) were alternatively towed by oblique tows from the surface to 25 m or 90 m depth off Fukushima Prefecture. It is the prerequisite that each haul target the same juvenile school during a series of alternative hauls experiment, and therefore in the 2007 experiments we detected Japanese anchovy juvenile school with quantitative echo sounder, and then put floating buoy with drogue into the sea to track the juvenile school during the series of alternative hauls. Each sampling gear was equipped with net depth sensor. While the vessel speed was 4 knot during towing, the winch speeds of wire-out and wire-in were set at 0.5 m/s and 0.1 m/s, respectively.

2.2.3 Measurement of the net depth and filter volume

During towing, the net depth was monitored with a net depth sensor (Scanmar, Norway) attached on the sampling gear: at the top center of the mouth frame of the MOHT and at the depressor of the IKMT (Fig. 2.2). For the IKMT, another small-sized depth logger (JFE Advantech Co., Ltd, Tokyo, Japan; MTS-TD, 85 mm × Φ50 mm, 40 g weight in air, and 5.0 cm resolution) was assembled at the steel bar of the net mouth. Flowmeters were located at the top center of the frame for MOHT trawl and at the center of the IKMT net mouth. Filtered water volume was usually calculated from the speed of flowmeter, towing duration and inner mouth area. The mouth areas of the standard and small MOHTs are fixed at 5.03 m^2 and 2.04 m^2, respectively. However, the net mouth of the IKMT was not fixed and the mouth area was changed. From the height of the IKMT net mouth obtained as difference in depth between the depth logger attached at the top bar and the depth sensor at the depressor, the inner net mouth of the IKMT was estimated on the assumption that the shape of the IKMT net mouth was pentagon-shaped with the fixed three sides: upper bar and two wing of the depressor. In addition, according to Smith et al. (1968) the filtration efficiency was considered to be more than 95% when the ratio of filtering area to mouth area was above 5. The ratios of standard and small MOHTs and two IKMTs used in the experiment were all larger than 8 (Table 1), which suggested the filtration efficiencies of the nets were enough large.

Specimens collected in each haul were preserved in 10% formalin. Japanese anchovy larvae and juvenile were sorted, and then 200 – 800 of the fish were randomly chosen for length measurement when the catch number was too large. Standard length (SL) was measured to the nearest 0.1 mm. Fish length data were grouped into 1mm interval for further analysis.

2.2.4 Analytic method

Three nets: standard and small MOHT with a mesh size of 1.59 mm and IKPT with a mesh size of 1.00 mm were alternatively towed in the 2003 experiments. In 2005 and 2007, three trawls (standard and small MOHTs and IKMT) which had the net of the same mesh size 1.59 mm and of polyethylene materials. Since IKPT with small mesh net could retain smaller fish than MOHT, we considered it as a control gear when analyzing the mesh selectivity of MOHT trawl. Moreover, the mouth shapes of IKPT and IKMT were changeable because of the unfixed net mouth, which may lead to net avoidance of larger fish. Similarly, net avoidance of larger fish may occur in small MOHT of which mouth area was about 40% of the standard one. This study modeled net avoidance of IKPT, IKMT and small MOHT trawl as size selectivity for fish body on the assumptions that standard MOHT could capture all the fish of enough larger body size in front of the sampling gear, that is, no net avoidance. And simultaneously, mesh selectivity of the net with 1.59 mm mesh size was also evaluated on the assumption that IKPT with a mesh size of 1.00 mm could retain fish of enough small size.

Mesh selectivity of towed net is usually expressed by monotonically increased logistic function of fish body size (Wileman et al., 1996), and thus this study denote the probability of *l*-length fish being retained in the mesh of 1.59 mm by monotonically increased logistic function $r(l)$ of body length l with the parameters α_r and β_r as follow,

$$r(l) = \exp(\alpha_r + \beta_r l) / [1+(\exp(\alpha_r + \beta_r l))] \quad (1)$$

Likewise, the net avoidance of small MOHT, IKPT and IKMT was expressed by the monotonically decreased logistic function $a(l)$ of body length l with parameters α_a and β_a as follows,

$$a(l) = \exp(\alpha_a + \beta_a l) / [1+(\exp(\alpha_a + \beta_a l))] \qquad (2)$$

From the logistic parameter estimates of α and β, the length of 50% retention, l_{50} and the selection range S.R. (= l_{75} - l_{25}, difference in fish length between 75% and 25% retention) was calculated with the following two equations.

$$l_{50} = -\alpha / \beta \qquad (3)$$

$$\text{S.R.} = 2\ln(3) / \beta \qquad (4)$$

Then, catch numbers $C_{t,\,l}$ of l-length fish in t-th haul can be expressed as the follow equation:

$$C_{t,\,l} = f_t\, r(l)\, a(l)\, q_t\, E_t\, d_l \qquad (5)$$

Here, q_t times E_t and f_t are catchability times catching effort deployed (e.g. filtered water volume), and sampling fraction at the t-th haul. In addition, d_l is density of fish encountering the net, and this study assumed that there was no difference in density of fish encountering the net between the successive two hauls.

In this study, the SELECT method was applied to estimate parameters of mesh selectivity and net avoidance from body length data of the catch in the successive two hauls. According to the SELECT method, the proportion of *l*-length fish retained in the net of *t*-th haul relative to the total of the two hauls is described by the following equation:

$$\phi_{t,\,l} = C_{t,\,l} \,/\, (C_{t,\,l} + C_{t\text{-}1,\,\mathrm{l}}) \qquad (6)$$

Here, $C_{t,\,l}$ and $C_{t\text{-}1,\,l}$ denote catch number of fish with body length *l* in the successive two hauls of towing number *t* and *t*-1. Subscribing equation (5) into equation (6), as a function of *l*, $\phi_t(l)$ is described by the following equation:

$$\phi_t(l) = p_t\, r_t(l)\, a_t(l) \,/\, (p_t\, r_t(l)\, a_t(l) + (1\text{-}p_t)\, r_{t\text{-}1}(l)\, a_{t\text{-}1}(l)) \qquad (7)$$

where $p_t = f_t\, q_t\, E_t \,/\, (f_t\, q_t\, E_t + f_{t\text{-}1}\, q_{t\text{-}1}\, E_{t\text{-}1})$. The equation (7) is the numerical model for which all parameters of mesh selectivity and net avoidance are actualized. As described above, $r_t\,(l)$ = 1 for the IKPT on the assumption of no mesh selectivity, and likewise. $a_t(l)$ = 1 for the standard MOHT on the assumption of no net avoidance. When the same net was deployed in the two successive hauls, $\phi_t(l) = p_t$, constant for fish body size.

In this study, while mesh selectivity of the net with is common for the three nets (the standard and small MOHTs and IKMT) in which nets were constructed with 1.59 mm mesh knotless ultra-high-strength polyethylene twine, five models with different parameter set which provide variation in net avoidance among the three nets (small MOHT, IKPT, and IKMT) for net avoidance were performed as follows.

Model A: on the assumption that the three nets (small MOHT, IKPT, and IKMT) have significantly different net avoidance from each other, the net avoidance of each net is defined as $a_s(l)$ with parameters α_s and b_s, $a_P(l)$ with parameters α_P and b_P, and $a_M(l)$ with parameters α_M and b_M, respectively.

Model B: The net avoidance of small MOHT, IKPT, and IKMT is assumed to be totally the same, and thus the parameters α_a and β_a of net avoidance are common in the three nets.

Model C groups assume that one of the three nets indicate different net avoidance from the other two.

Model Cs: net avoidance of small MOHT is assumed to be different from the other two (IKPT and IKMT), and thus $a_s(l)$ with parameters α_s and b_s for small MOHT and $a(l)$ with parameters α_a and b_a , for the other two nets are activated.

Model C_P: net avoidance of IKPT is assumed to be different from the other two (small MOHT and IKMT), and thus $a_P(l)$ with parameters α_P and b_P for IKPT and $a(l)$ with parameters α_a and b_a for the other two nets are activated.

Model C_M: net avoidance of IKMT is assumed to be different from the other two (small MOHT and IKPT), and thus $a_M(l)$ with parameters α_M and b_M for IKMT and $a(l)$ with parameters α_a and b_a for the other two nets are activated.

In this study, the model that produced a curve mostly closely resembling the plots in the catch data was selected from the proposed models by the Akaike Information Criterion (AIC) model selection. The log likelihood function to be maximized for parameter estimation is as follows:

$$\ln L\,(\alpha_r, b_r,;\ \alpha_s, b_s;\ \alpha_P, b_P;\ \alpha_M, b_M;\ p_1, p_2, p_3, \ldots\ p_{T\text{-}1})$$

$$= \sum_t^T \sum_l^T \left[C_{t,l} \ln\varphi(l) + C_{t-1,l}(1 - \ln\varphi(l))\right] \qquad (8)$$

where T denoted total number of the successive two hauls.

The Solver function in Microsoft Excel (Microsoft, Redwood, WA) was used to maximize the log-likelihood function.

2.3 Results

2.3.1 Length distributions of Japanese anchovy

In the experiment 2003, the standard length of Japanese anchovy collected at night time towing of no. A1~A9 ranged from 8 to 25 mm, while majority of the anchovy at daytime towing of no. A10~A16 were smaller than 15mm in SL (Fig. 2.3). At night time towing of no. A1~A9, the SL distributions of the anchovy caught by IKPT were bimodal with two peaks of 10mm and 17mm, but no mode around 10 mm was found in the SL distribution of the anchovy caught by standard and small MOHTs. Similarly, in daytime towing of no. A10~A16, IKPT caught a large amount of anchovy with SL around 10 mm while catch numbers of the anchovy caught by standard and small MOHTs were small. These suggested that catching efficiency of standard and small MOHTs was low for the anchovy with SL smaller than 15 mm, compared with IKPT. In contrast, the catch number of the anchovy with SL larger than 20 mm by IKPT seemed to be lower than standard and small MOHTs. Moreover, in the MOHT samples in which almost all of the caught anchovy were within the SL range of 10~25 mm, there seemed to be no distinct difference in the SL distributions between standard and small MOHTs.

In the experiment 2005, standard and small MOHTs were alternatively towed in waters off Ibaraki Prefecture and off Iwate Prefecture (Fig. 2.4-Fig. 2.5). In no. B1~B4 by step-oblique towing and in no. B17-B22 by oblique towing for 100 m depth off Ibaraki Prefecture, the SL distributions ranged predominantly from 10 to 25 mm and from 8 to 25 mm, respectively. In these tows, there seemed to be no distinct difference in the SL distribution between standard and small MOHTs. In contrast, in no. B5–B16 tows off Ibaraki Prefecture, the SL ranges of the caught anchovy were from 5 to 50 mm, and we observed some Japanese anchovy (SL > 35 mm) in the standard MOHT catch whereas very few anchovy of this size were captured by the small MOHT. This implied net avoidance of larger anchovy against the small MOHT.

In the experiment 2007, anchovies were collected off Fukushima coastal area (Fig. 2.6-Fig. 2.8). In station C1, standard length of larvae collected by standard MOHT, small MOHT and IKMT are 13.0~39.3 mm, 10.7~41.7 mm, 11.8~37.1 mm, respectively. Three trawls were effectively in collecting larvae between 20~23 mm. Compared to other two trawls, the standard MOHT collected the most larvae exceed 30 mm. In station C2, larvae collected by standard MOHT, small MOHT and IKMT are 4.6~40 mm, 6.4~31.5 mm, 6.4~37.5 mm, respectively. Particularly, no larvae exceed 32 mm was captured by small MOHT. In each haul, three trawls were effectively in collecting larvae between 17~23 mm. Larvae exceed 30 mm was mostly collected in standard MOHT compared to other two trawls. In station C3, larvae collected by standard MOHT, small MOHT and IKMT are 5.2~36.2 mm, 5.2~36.2 mm, 5.7~35.5 mm, respectively. Three trawls were effectively in collecting larvae between 15~30 mm. In station C4, larvae collected by standard MOHT, small MOHT and IKMT are 6.9~35.4 mm, 5.0~35.1 mm, 7.9~28.8 mm, respectively. The peak values in two standard MOHT hauls were 22 and 16 mm, in two small MOHT hauls were 20 mm, in two IKMT (Dyneema) hauls are 22 and 19 mm. In station C4, larvae collected in standard MOHT, small MOHT and IKMT are 11.9~51.9 mm, 9.6~36.4 mm, 12.3~46.2 mm, respectively. The peak values in two standard MOHT hauls were 19~22 mm, in two small MOHT hauls were 19 and 20 mm, in two IKMT (Dyneema) hauls are 20 and 22 mm. Among them, quantity of larvae in C8-8 and C8-9 hauls was only 50 and 14, which was obviously less than other hauls.

2.3.2 Parameter estimation and model selection

In this study, two continuous trawls, including 5 combination of IKPT vs small MOHT, 11 combination of small MOHT vs IKMT, 27 combination of small MOHT vs standard MOHT, 2 combination of IKPT vs IKPT, 4 combination of IKMT vs IKMT, 6 combination of standard MOHT vs standard MOHT, 4 combination of small MOHT vs small MOHT.

Model A has a smallest AIC value of 6221.7, in which size selectivity of net avoidance was differed from each other, was thought to be the optimal model in this study (Table 2.8).

In 2003, at night-time, four kinds of combinations were conducted in experiments, including small MOHT & IKPT, standard MOHT & small MOHT, standard MOHT & standard MOHT and IKPT & IKPT. The standard length was mainly gathered in 8~20mm (Fig. 2.3). In small MOHT & IKPT combinations, as the standard length of Japanese anchovy increased, the percentage of small MOHT in whole was also increased. While in standard MOHT & small MOHT, the proportion of samples remained stable with the increase of standard length. In addition, slight changes were observed in the same trawl combinations in standard MOHT & standard MOHT and IKPT & IKPT. In the daytime operations, four kinds of combinations the same as night-time were conducted. The length distribution was mainly gathered in 7~14mm for each combination. In small MOHT & IKPT combinations, larvae fishes with a length below 10mm were almost 0 in small MOHT, and the proportion of small MOHT increased as standard length increased. We can infer that, compared with the small MOHT with larger PE mesh size, IKPT with smaller mesh size can collect smaller larvae individuals.

In 2005, both step-oblique and oblique experiment methods were carried out off Ibaraki and Iwate coastal area. In step-oblique tows, two kinds of combinations were conducted in experiments around Ibaraki coastal area, standard MOHT & small MOHT and small MOHT & small MOHT. The standard length of anchovy fishes collected were mainly gathered in 12~23mm (Fig. 2.4-Fig. 2.5). In standard MOHT & small MOHT combination, the proportion of catch numbers in standard MOHT was maintained stable as length increased. Less larvae fish in length 27,28mm were caught, and the proportion in standard MOHT was higher. In Iwate coastal area, three kinds combinations of standard MOHT and small MOHT, and anchovies were mainly gathered in 12~28mm. In standard MOHT & small MOHT combination, the proportion of catch numbers in standard MOHT was increased with the increasing of fish length. Then, in oblique tows, three combinations were conducted off Iwate coastal area, and anchovies were mainly gathered in 12~24 mm. In standard MOHT & small MOHT combination, proportion of fishes in standard MOHT was remain a certain value at the range of 12~24 mm. But when the length was over 25 mm, especially more than 35 mm in less quantity, the proportion in standard MOHT was higher. In oblique tows off Ibaraki coastal area, also the three kinds of combinations, and anchovies were mainly gathered in 7~18 mm. For all combinations, the proportion was basically remained the same.

In 2007, a total of four kinds of combinations, including standard MOHT & small MOHT, small MOHT & IKMT, IKMT & IKMT and standard MOHT & standard MOHT, were carried out at five stations (C1, C2, C3, C4, C8) at night-time off Fukushima coastal area. These results indicate that the length distributions were mainly gathered in 13~29mm at station C1, 10~28mm at station C2, 12~28mm at station C3, 10~25mm at station C4 and 14~27mm at station C8. In standard MOHT & small MOHT combination, proportion in standard MOHT increased as the fish length increased, and it was more obvious in the length over 30 mm. In small MOHT & IKMT combination, proportion in small MOHT decreased with the increase of body length. In IKMT & IKMT and standard MOHT & standard MOHT combinations, there was still some fluctuations occurred in the proportion despite of the same trawl net.

2.3.3 Selection curve for mesh size and net avoidance

In five hypothetical models, according to the AIC model selection, the net avoidance of small MOHT, IKPT and IKMT completely different model was the optimal model (Table 2.9).

According to the selection curve of mesh size, anchovies with standard length smaller than 17mm could escape from the mesh. For selectivity of polyethylene mesh, 50% retention length and selection range were 12.20 and 2.82 mm, respectively. We can indicate that the polyethylene net can almost completely capture Japanese anchovy with standard length larger than 20 mm.

The selection curve of net avoidance was monotonous decreased. When compared to standard MOHT, it's obviously that other pelagic trawls were not efficient in collecting large size fishes. In this selection curve, standard lengths of anchovies were increased in sequence of IKPT, small MOHT, IKMT. 50% retention length and selection range were 18.55 and -4.11 mm in IKPT, 27.99 and -8.17 mm in small MOHT, 36.27 and -5.17 mm in IKMT (Dyneema), respectively. Between the same net structure of IKPT and IKMT, there were no anchovies larger than 25 mm collected in IKPT, which indicated net avoidance phenomenon of IKPT was more obvious than IKMT. Furthermore, between the same polyethylene material of small MOHT and IKMT, more obvious net avoidance was caused in small MOHT with smaller mouth area.

2.4 Discussion

2.4.1 Mesh selectivity of polyethylene net

50% retention length and selection range were 12.20 and 2.82 mm in the polyethylene net. MOHT trawl can collected almost all anchovies larger than 15 mm. Saiura et al. (2006) illuminate that in seine fisheries, mesh size of minnow netting was1.56mm, the similar mesh size as MOHT trawl (1.59 mm), which has 50% retention length of 8.34~12.54 mm and selection range of 2.40~2.76 mm. Moreover, clogging phenomenon would occur under the situation of heavy samples, which lead to smaller l_{50}. In this study, values of l_{50} and S.R. were in accord with minnow netting that under no clogging situation. Although the net materials used were different, our results of mesh selectivity were reasonable to the actual situation.

In general, mesh selectivity of larval and juvenile can be analyzed through diagonal rule (Smith et al. 1968), and the diagonal of MOHT net was 2.25 mm in this study. Hino (2006) analyzed the relationship on standard length corresponding to the high head, head width, body height, body width of fish, respectively. The result showed that the standard length was 22 mm when the maximum cross-section was the same as diagonal of net. Based on the diagonal rule, standard length in 22 mm was considered as 100% retention length, and anchovies with standard length smaller than 22 mm could also be collected in this study.

2.4.2Factors affecting net avoidance: net mouth construction and dimension, and net mesh size

The mouth area of the small MOHT was 2.04 m^2, 40% of that in the standard MOHT. According to length distribution of anchovies in 2005, because there were adequate samples at the range of 9~25 mm, the difference of mesh selectivity below 25 mm for two MOHT trawls can clearly be identified. Anchovies larger than 25 mm in standard length were less collected in small MOHT, indicating low collection efficiency of net small MOHT. It was mainly because net avoidance phenomenon was occurred in small MOHT.

Furthermore, between the same polyethylene net of small MOHT and IKMT, the small MOHT with smaller mouth opening had larger net avoidance than IKMT.

In this study, we assume that there was no net avoidance occurred in standard MOHT. However, large fishes had possibility to escape in front of standard MOHT, in other words, net avoidance might also occurred in standard MOHT. If net avoidance was also occurred in standard MOHT, the estimating of net avoidance on other fishing gears were underestimated. A bar length of square frame in MOHT was 1.43 m, while in the standard MOHT was 2.24 m. In regard to net avoidance, assume that fish body length has geometric similarity relationship with mesh size, so 50% retention length in small MOHT was 27.99 mm. From it, we can conclude that 50% retention length in standard MOHT was 43.84 mm (=27.99×2.24 / 1.43). The maximum length of Japanese anchovies in this study was about 40 mm, so the assumption that no net avoidance occurred in standard MOHT was valid in these length distributions.

50% retention length and selection range of IKPT (nylon) and IKMT (polyethylene) were 18.55 and -4.11 mm, 36.27 and -5.17 mm, respectively. Between IKPT and IKMT of the same frame structure and mouth opening, IKPT with smaller mesh size was affected larger net avoidance, because almost no anchovies larger than 25 mm were collected. When mesh size is smaller, the filter efficiency may also be lower, so we need to discuss the influence of filter water on different mesh size in future.

2.4.3 Difficulties in alternative haul experiment

Difference in sampling locations, trawling period, towing method, towing depth and experiment time in daytime or night time, each of them might had influence on standard length of Japanese anchovies being collected. In Iwate coastal area (2005), anchovies collected there had a length ranged from 10 to 45 mm. In Ibaraki coastal area (2005) and Fukushima coastal area (2007), anchovies were ranged from 10 to 30 mm. In contrast, anchovies collected off Ibaraki coastal area (2003) were mainly ranged from 10 to 20 mm. Therefore, when analyzing the effect of net avoidance phenomenon, we need to obtain sufficient data covering a wide range of standard length.

In addition, there was obvious difference in standard length of anchovies in the daytime and nighttime. For example, anchovies were gathered in 10~20mm in nigh-time while 8~15mm in the daytime in 2003. The reason of the difference in standard length was probably because of the vertical distribution movement for Japanese anchovies, or probably because anchovies can better identify trawl nets and escape successfully during daytime, which we need further validation in future research.

Even using the same sampling gear in continuous hauls, the ratio of standard length in two hauls had a tendency to up and down. In sea trial 2007, in order to collect the same fish school, we use fish finder to detect the fish school and then put buoy into the waters, carrying out the experiment at the same time. However, to collect the fish larvae of the same length distribution was very difficult. Suzuki (2010) used the same buoy tracking method in experiments to analyze the influence on net avoidance of standard MOHT. However the data was insufficient to get the ideal result because the collected anchovies were not come from the same fish school.

Nowadays, multiple layer sampling trawls have been developed to collect larvae and juveniles. When using multiple layer sampling trawls, we don't need to cast and raise the net during continuous trawl operations. Therefore, it can reduce the differences between the trawl operations to improve the possibility to collect the same fish school.

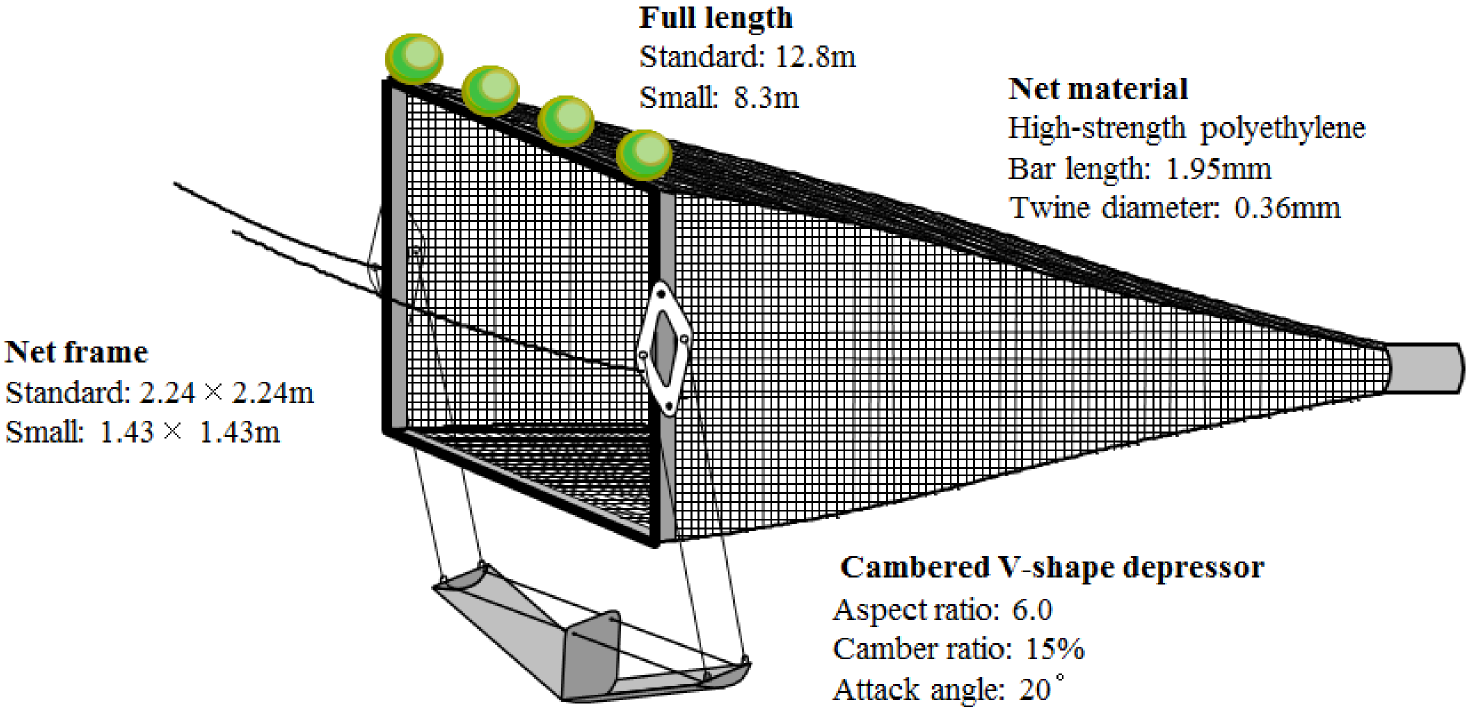

Fig. 2.1 Details of standard/small MOHT net

33

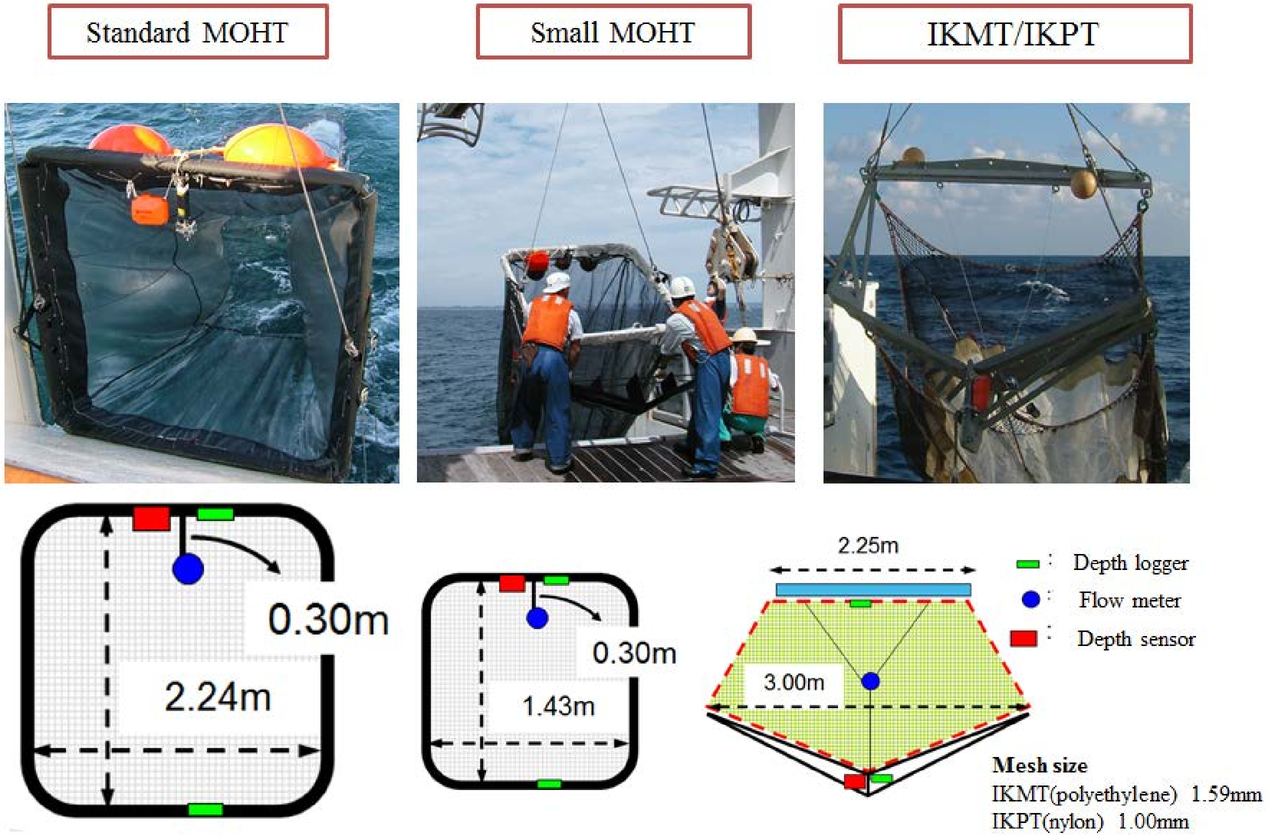

Fig. 2.2 The photo and mouth shape of each sampling gear

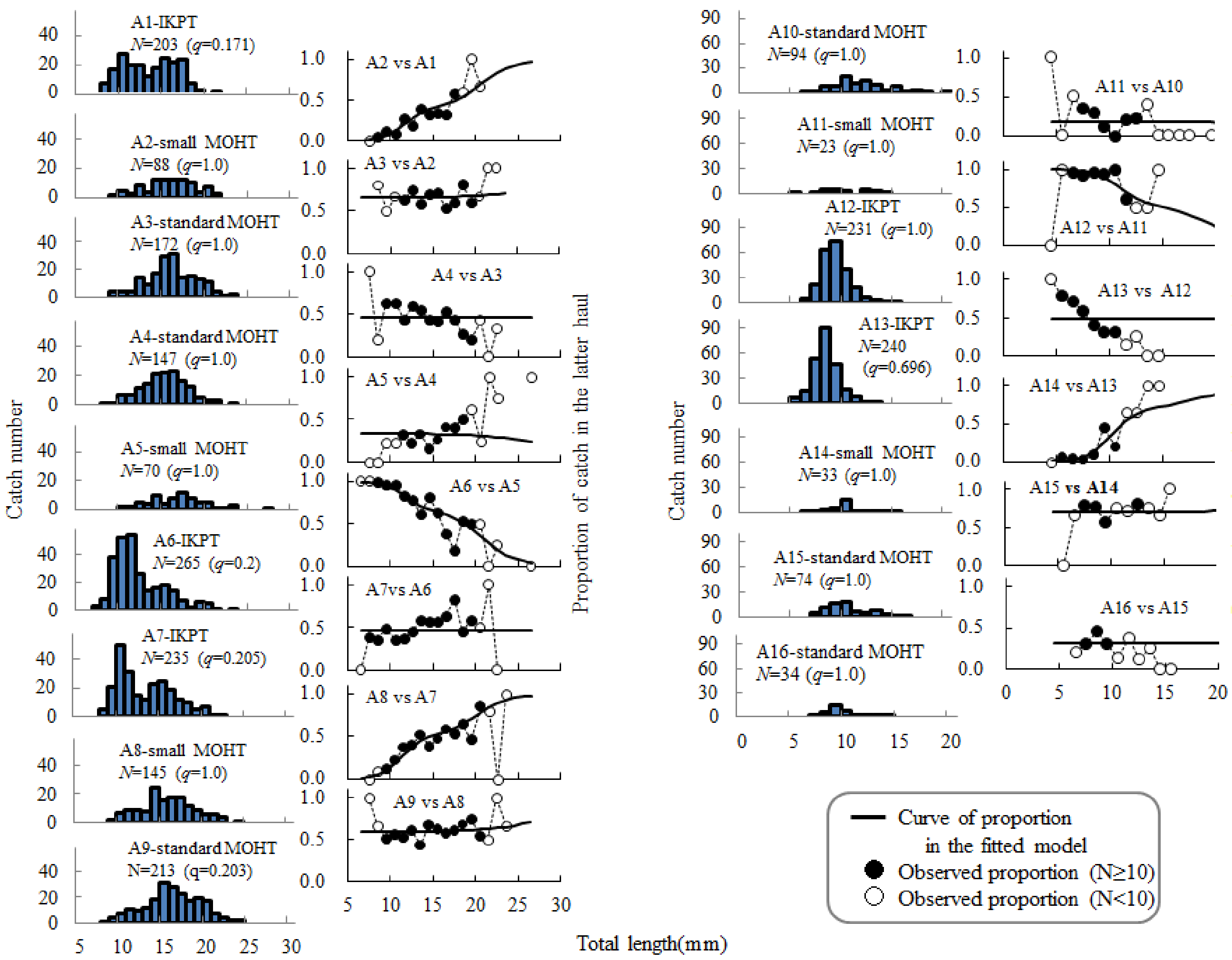

Fig. 2.3 Length distributions of Japanese anchovy in IKPT, small MOHT and standard MOHT, and the proportion of catch in the latter haul

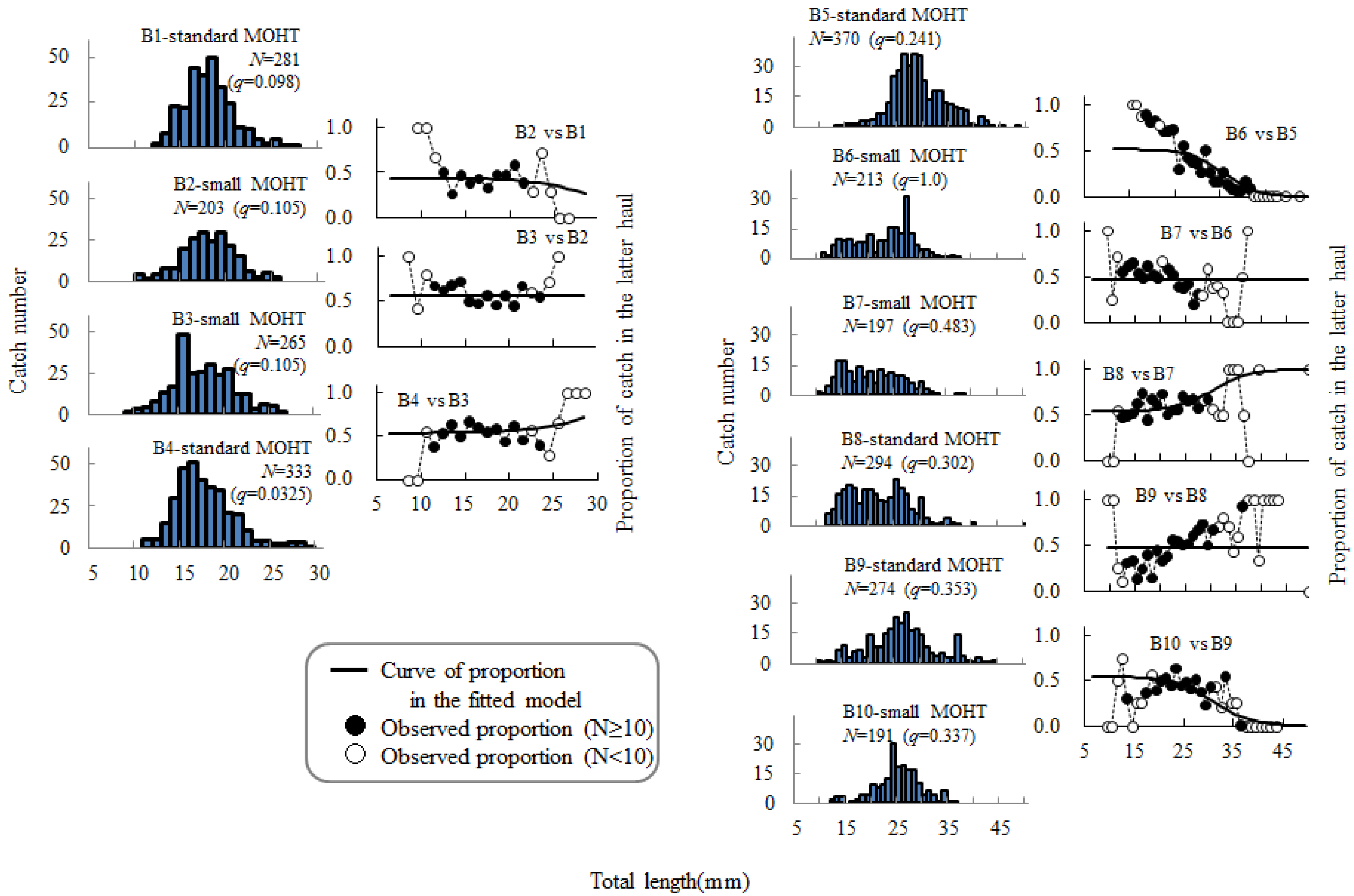

Fig. 2.4 Length distributions of Japanese anchovy in small MOHT and standard MOHT, and the proportion of catch in the latter haul

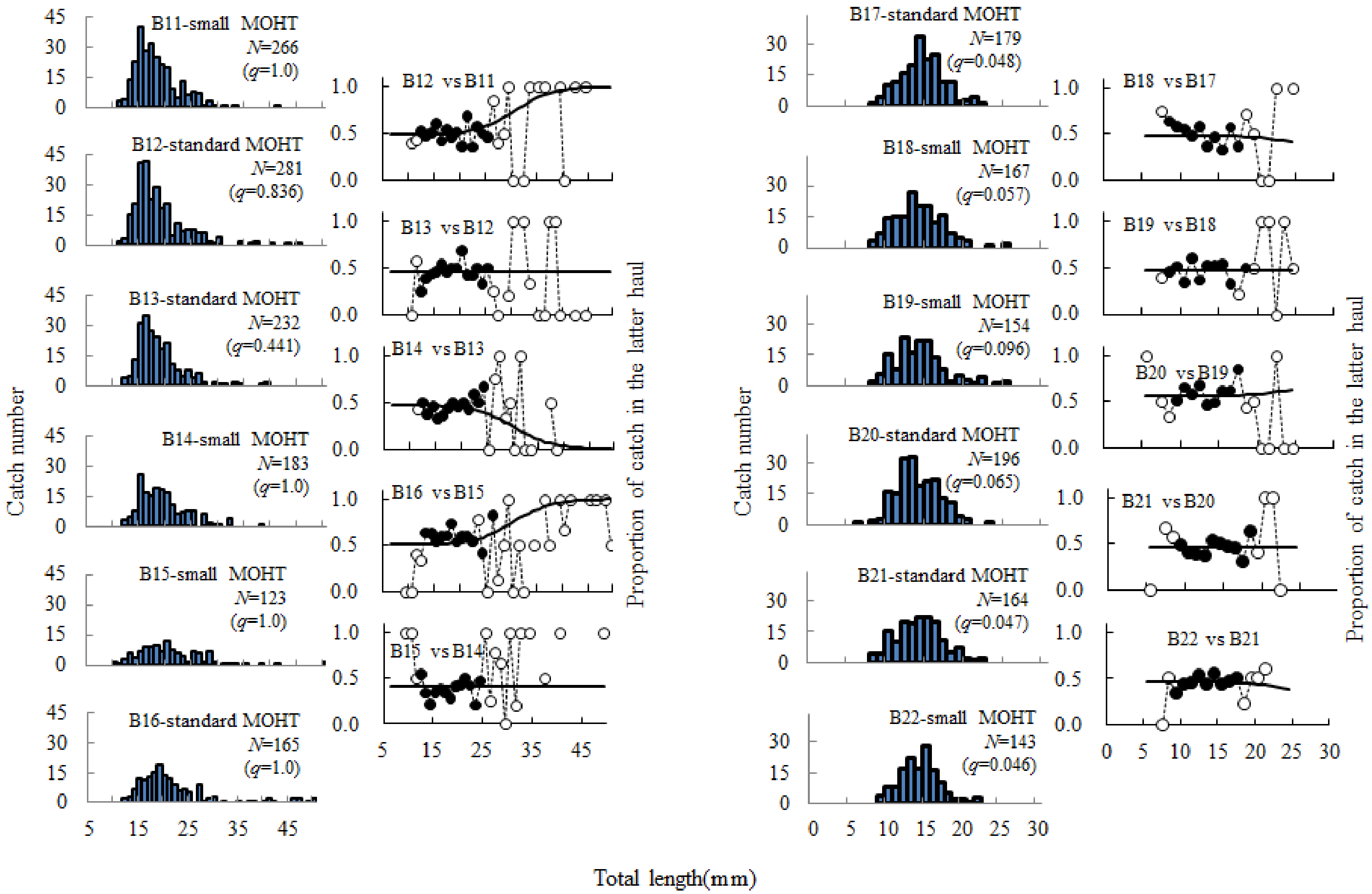

Fig. 2.5 Length distributions of Japanese anchovy in small MOHT and standard MOHT, and the proportion of catch in the latter haul (continued)

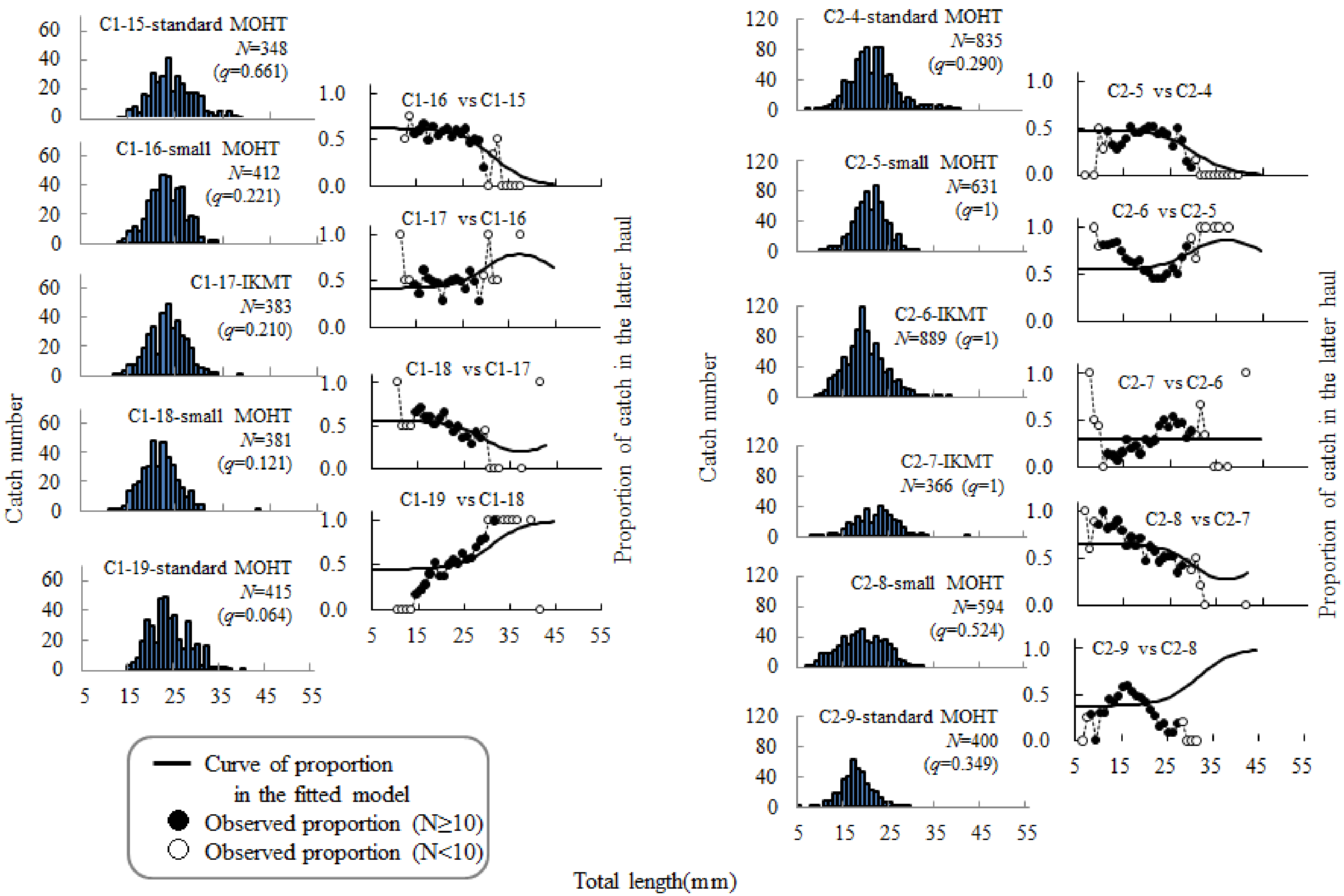

Fig. 2.6 Length distributions of Japanese anchovy in IKPT, small MOHT and standard MOHT, and the proportion of catch in the latter haul

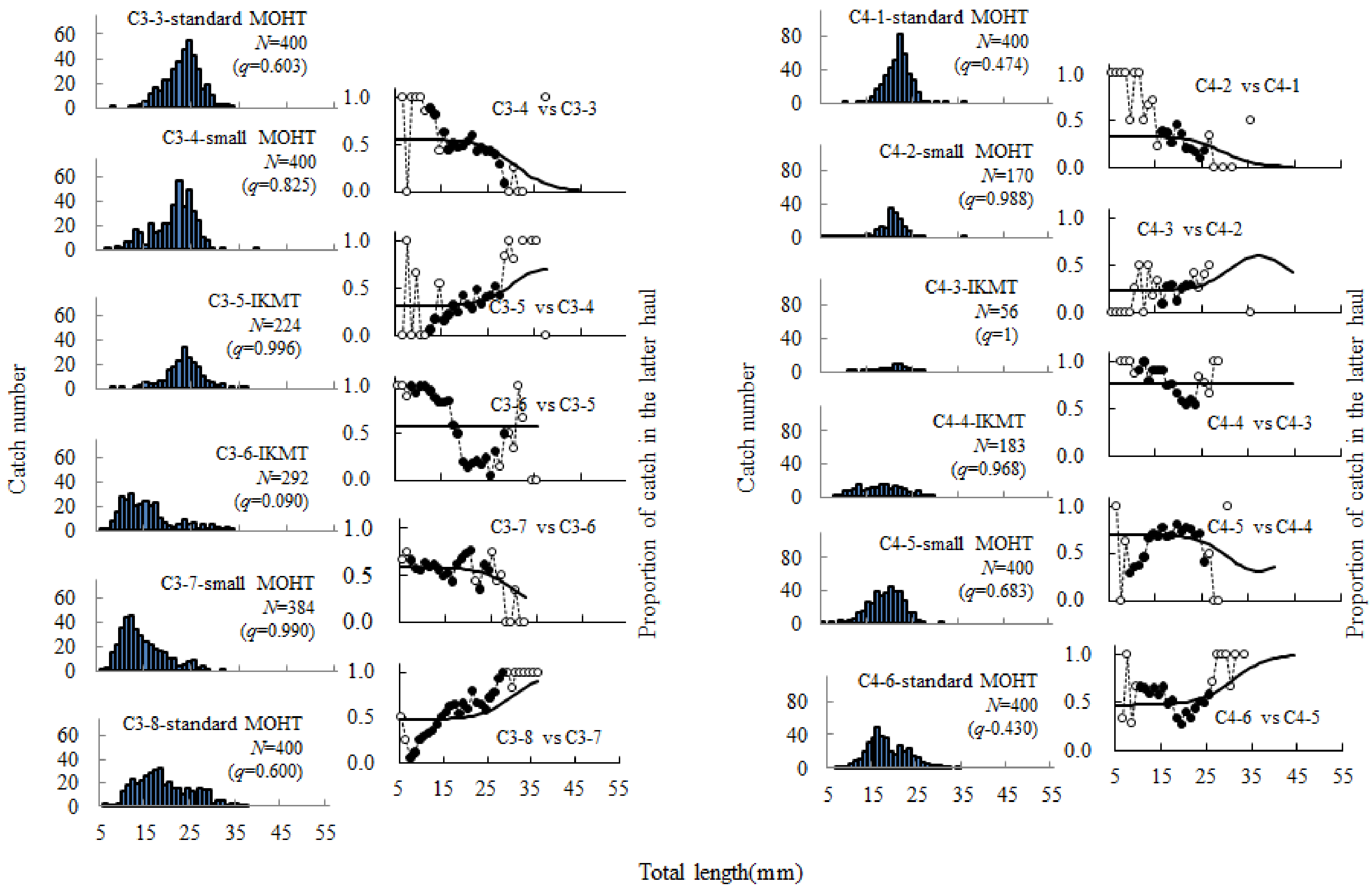

Fig. 2.7 Length distributions of Japanese anchovy in IKPT, small MOHT and standard MOHT, and the proportion of catch in the latter haul (continued)

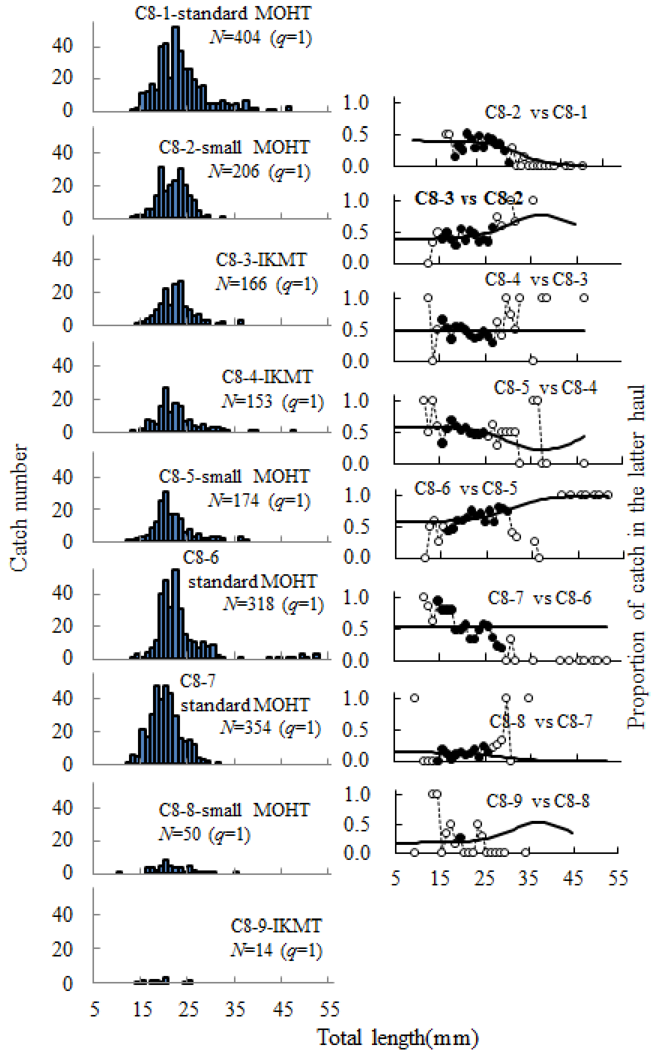

Fig. 2.8 Length distributions of Japanese anchovy in IKPT, small MOHT and standard MOHT, and the proportion of catch in the latter haul (continued)

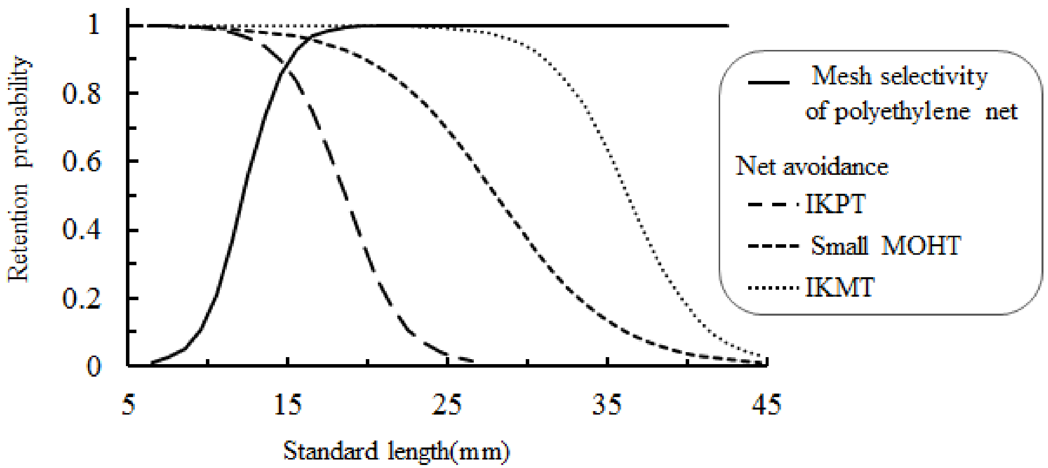

Fig. 2.9 Selection curves of mesh selectivity for polyethylene net and net avoidance for IKPT, small MOHT and IKMT

Table 2.1 Dimension of midwater sampling trawls used in this study

Gear type	Net length (m)	Net mouth dimension		Net material	Bar length of mesh (mm)	Twine diameter(mm)	Porosity	Open area ratio*
		Area (m^2)	Size					
Standard MOHT	12.8	5.03	2.24×2.24[a]	PE [c]	1.59	0.36	0.665	8.78
Small MOHT	8.3	2.04	1.43×1.43[a]	PE [c]	1.59	0.36	0.665	9.91
IKPT	12.6	About 5	2.25[b]	PA [d]	1	0.33	0.565	9.91～12.7
IKMT	12.6	About 5	2.25[b]	PE [d]	1.59	0.36	0.665	8.42～10.8

[a]: height and width

[b]: upper bar length

[c]: PE, polyethylene

[d]: PA, polyamide

*: Porosity × net area / mouth area

Table 2.2 Towing condition of alternative haul experiment in Sagami Bay (60m oblique tows)

Date	Towing no.	Gear type	Start time	Towing duration (min)	Start location		Filtered volume (m^3)	Maximum net depth(m)
					Latitude, N	Longitude, E		
9 Sep. 2003	A1	IKPT	19:05	35	35°15.13	139°22.18	15016	54.1
	A2	Small MOHT	20:12	35	35°15.06	139°22.00	10645	58.2
	A3	Standard MOHT	21:20	28	35°14.92	139°22.19	17752	58.5
	A4	Standard MOHT	22:15	25	35°14.72	139°21.86	15902	56.6
	A5	Small MOHT	23:07	28	35°14.63	139°21.88	8787	57.1
10 Sep. 2003	A6	IKPT	0:04	40	35°14.91	139°22.41	15327	56.0
	A7	IKPT	1:15	37	35°15.10	139°22.33	13562	54.5
	A8	Small MOHT	2:22	34	35°14.96	139°22.09	10448	59.8
	A9	Standard MOHT	3:20	29	35°14.76	139°22.27	16797	58.0
	A10	Standard MOHT	8:06	25	35°14.79	139°21.67	14077	56.7
	A11	Small MOHT	8:56	31	35°14.65	139°22.04	-	57.8
	A12	IKPT	9:53	30	35°14.83	139°22.02	11829	55.1
	A13	IKPT	10:49	36	35°15.07	139°21.98	15868	54.4
	A14	Small MOHT	12:17	36	35°15.47	139°22.41	10835	60.1
	A15	Standard MOHT	13:18	32	35°14.90	139°22.06	19443	56.3
	A16	Standard MOHT	14:16	34	35°15.11	139°22.06	21037	56.5

Table 2.3 Towing condition of step-oblique tows (target depth 30m, 20m, 10m) off Ibaraki prefecture, Pacific

Date	No.	Gear type	Start time	Towing duration (min)	Start location		Filtered volume (m^3)	Maximum net depth(m)
					Latitude, N	Longitude, E		
31 May 2005	B1	Standard MOHT	19:35	25	37°29.20	146°12.40	8611	-
	B2	Small MOHT	20:20	40	37°29.20	146°12.30	5636	-
	B3	Small MOHT	21:20	35	37°29.30	146°12.30	5353	-
	B4	Standard MOHT	22:25	30	37°29.20	146°12.30	11501	-

Table 2.4 Towing condition of step-oblique tows (target depth 30m, 20m, 10m) off Iwate prefecture, Pacific

Date	No.	Gear type	Start time	Towing duration (min)	Start location		Filtered volume (m^3)	Maximum net depth(m)
					Latitude, N	Longitude, E		
6 June 2005	B5	Standard MOHT	19:38	29	39°17.23	147°41.96	13598	30.7
	B6	Small MOHT	20:45	38	39°17.37	147°42.19	6958	37.57
	B7	Small MOHT	21:40	35	39°19.06	147°43.35	6667	33.45
	B8	Standard MOHT	22:29	30	39°18.24	147°42.43	13859	33.28
	B9	Standard MOHT	23:20	33	39°20.55	147°43.45	15127	36.63
7 June 2005	B10	Small MOHT	1:26	38	39°23.56	147°45.07	7535	38.88

Table 2.5 Towing condition of 100m oblique tows off Iwate prefecture, Pacific

Date	No.	Gear type	Start time	Towing duration (min)	Start location		Filtered volume (m^3)	Maximum net depth(m)
					Latitude, N	Longitude, E		
8 June 2005	B11	Small MOHT	19:43	51	40°04.14	149°11.36	9478	98.1
	B12	Standard MOHT	20:53	47	40°03.40	149°09.84	23871	95.7
	B13	Standard MOHT	21:52	44	40°04.71	149°16.70	21574	95.6
	B14	Small MOHT	22:48	54	40°02.56	149°20.22	10676	91.3
	B15	Small MOHT	23:53	54	40°06.15	149°22.31	10750	94.1
9 June 2005	B16	Standard MOHT	1:05	61	40°09.34	149°25.15	28903	91.9

Table 2.6 Towing condition of 100m oblique tows off Ibaraki prefecture, Pacific

Date	No.	Gear type	Start time	Towing duration (min)	Start location		Filtered volume (m^3)	Maximum net depth(m)
					Latitude, N	Longitude, E		
12 June 2005	B17	Standard MOHT	20:00	51	36°39.96	141°00.04	23883	94.6
	B18	Small MOHT	21:03	56	36°39.75	141°01.94	11450	93.6
	B19	Small MOHT	22:07	56	36°41.99	141°58.61	10537	98.5
	B20	Standard MOHT	23:16	55	36°38.66	141°59.78	31135	93.7
	B21	Standard MOHT	0:22	58	36°42.98	141°00.70	28010	95.6
13 June 2005	B22	Small MOHT	1:33	58	36°39.78	141°01.62	11691	98.1

Table 2.7 Towing condition of oblique tows (20m or 90m) off Fukushima prefecture, Pacific

Date	No.	Gear type	Start time	Towing duration (min)	Start location		Filtered volume (m^3)	Maximum net depth(m)
					Latitude, N	Longitude, E		
28 May 2007	C1-15	Standard MOHT	22:52	22	38°29.03	144°11.25	4532	26.60
	C1-16	Small MOHT	23:37	22	38°29.36	144°12.48	1445	27.40
29 May 2007	C1-17	IKMT	0:23	18	38°30.65	144°14.37	3927	28.70
	C1-18	Small MOHT	1:35	27	38°32.24	144°16.68	2186	25.20
	C1-19	Standard MOHT	2:26	23	38°33.72	144°18.86	3509	26.00
	C2-4	Standard MOHT	22:54	18	39°14.46	145°18.43	8734	22.30
	C2-5	Small MOHT	23:27	26	39°12.50	145°19.67	4584	22.00
30 May 2007	C2-6	IKMT	0:25	11	39°14.95	145°18.27	5072	21.60
	C2-7	IKMT	0:50	18	39°13.82	145°19.24	8711	22.00
	C2-8	Small MOHT	1:48	24	39°13.81	145°19.22	4842	23.60
	C2-9	Standard MOHT	2:21	17	39°12.77	145°20.04	7649	22.90
	C3-3	Standard MOHT	22:03	17	39°05.85	146°25.73	11451	25.50
	C3-4	Small MOHT	22:44	25	39°05.56	146°25.85	6245	23.40
	C3-5	IKMT	23:35	14	39°06.18	146°25.42	8575	24.40
31 May 2007	C3-6	IKMT	1:11	15	39°09.36	146°39.16	11310	25.20
	C3-7	Small MOHT	1:48	19	39°09.32	146°39.83	5576	21.90
	C3-8	Standard MOHT	2:20	20	39°08.72	146°42.55	14772	24.80
	C4-1	Standard MOHT	19:45	30	38°54.90	146°55.16	17792	86.90
	C4-2	Small MOHT	20:40	39	38°54.94	146°56.00	9649	92.00
	C4-3	IKMT	21:46	28	38°54.86	146°55.11	16648	87.00
	C4-4	IKMT	23:31	27	39°06.20	146°57.08	11149	87.60
1 June 2007	C4-5	Small MOHT	0:20	29	39°06.27	146°57.28	4516	90.00
	C4-6	Standard MOHT	1:10	27	39°06.30	146°57.16	11869	87.00
13 June 2007	C8-1	Standard MOHT	20:00	16	37°05.46	144°02.17	9581	22.40
	C8-2	Small MOHT	20:36	26	37°06.05	144°02.46	6032	21.50
	C8-3	IKMT	21:24	14	37°05.44	144°02.16	8266	22.90
	C8-4	IKMT	22:04	14	37°05.43	144°00.44	8195	22.90
	C8-5	Small MOHT	22:34	21	37°05.87	144°00.51	5389	20.10
	C8-6	Standard MOHT	23:15	19	37°05.65	144°00.46	11112	19.10
14 June 2007	C8-7	Standard MOHT	0:04	22	37°05.56	143°56.49	12237	20.20
	C8-8	Small MOHT	1:18	23	37°05.47	143°56.58	5253	19.50
	C8-9	IKMT	2:03	14	37°06.13	143°56.57	7690	22.20

Table 2.8 Logistic parameters for expressing size selectivity and the values of AIC

Model	Mesh selectivity				Net avoidance						MLL [a]	AIC [b]
	Large-scale MOHT		Small-scale MOHT		Small-scale MOHT		IKPT		IKMT			
	α_{RL}	β_{RL}	α_{RS}	β_{RS}	α_{AS}	β_{AS}	α_{AN}	β_{AN}	α_{AD}	β_{AD}		
Model A	-9.84	0.84	-9.84	0.84	7.53	-0.27	8.94	-0.50	15.41	-0.42	-3021.34	6176.70*
Model B	-8.46	0.62	-8.46	0.62	6.98	-0.25	6.98	-0.25	6.98	-0.25	-3070.46	6266.91
Model C_D	-8.28	0.58	-8.28	0.58	7.54	-0.27	15.22	-0.42	15.22	-0.42	-3027.92	6185.84
Model C_P	-8.46	0.62	-8.46	0.62	7.54	-0.27	7.54	-0.27	15.40	-0.42	-3027.71	6185.42
Model C_S	-9.84	0.84	-9.84	0.84	7.88	-0.28	9.00	-0.50	7.88	-0.28	-3039.43	6208.87

[a] MLL, Maximum log-likelihood.

[b] AIC, Akaike's information criterion

***** The best model with the smallest AIC value

Table 2.9 Selection parameters in the optimal Model A

Selectivity	Gear type	l_{50}	S.R.
Mesh selectivity	Polyethylene net	12.2	2.82
Net avoidance	Small MOHT	27.99	-8.17
	IKPT	18.55	-4.11
	IKMT	36.27	-5.17

Chapter 3. The collection characteristics of MOC-MOHT

3.1 Chapter introduction

Multiple layer sampling gears were developed to find out feeding behavior and diel vertical migration of young pelagic fish. They are composed of several codends that could be towed under various operating conditions. For example, specimen from multiple codends could not only be collected in different towing depth at the same towing speed, but also at different towing speed in same towing depth.

In general, fish with larger swimming speed are easier to escape in front of the net mouth. In order to capture juvenile fish efficiently, fishing gear is also required to operate at higher towing speed. Multi-layer MOC-MOHT has excellent performance the same as standard MOHT, with additional advantage of fixed frame mouth and stable operation at high towing speed of 4 knots. Moreover, it’s convenient for us to apply MOC-MOHT to capture the same fish school with multiple nets at various towing speeds in a single cast trial.

In this chapter, open sea trials of horizontal tows using multi-layer MOC-MOHT were carried out in Sagami Bay in July 2015. Towing speeds were changed into the three stages of 4, 3, and 2 knots in sequence. Then, standard lengths of the whole caught fish were measured for further analysis. Our objective was to make clear that whether net avoidance occur at high towing speed of 4 knots in MOHT nets, and build mathematical models to evaluate the relationship between length distribution of lantern fish and various towing speed.

3.2 Materials and methods

3.1.1 Sampling gear

The MOC-MOHT (Fig. 3.1) has a rigid frame of 3.3 m high and 2.35 m wide, five nets of 11 m long with a rectangular mouth of 1.81×2.22 m, which was conducted over a range of towing speeds (1.0-2.25 ms^{-1}). A cambered V-shape depressor (Hu et al., 2000) with an aspect ratio 6.0 and a camber ratio of 15% was hung below the frame attached by two 10 m-long bridles. The wingspread of the depressor was 2.44 m with a wing area of 0.99 m^2. Mass of the depressor was 50 kg in air, and the total mass of the frame without the depressor was approximately 490 kg in air. A net release mechanism was located at the center of the upper frame and a net-response was located inside the bottom of the left side frame for detecting closures of nets. A flowmeter was placed at the center of the lower frame and four floats were set inside the upper frame.

Nets were constructed of square mesh consisting of a bar length of 1.95 mm and a twine diameter 0.36 mm knotless ultra-high-strength polyethylene (Toyobo, Japan; Dyneema SK60). Five nets were attached to the frame with the nets numbered from the bottom to the top using black nylon canvas, of which the first net was different in shape from the other four nets. Pre-research showed that an approximately 10° tilt angle of the frame to the towing direction was necessary to ensure opening and closing operation. Net edge angles of MOC-MOHT were calculated as 15° (1^{st} net) and 2° (2^{nd} to 5^{th} nets). Codend bucket was connected to the end of each nets, stainless steel cylinder device with diameter 17.5 cm and height 45 cm. Specimen were collected in the buckets, in which the funnel type device was used to prevent the blowback of the sample.

The underwater control unit equipped with depth and temperature sensor was used to retrieve flowmeter count signals and net closing signals. A magnetic switch was equipped for starting/ending sampling data recording. Commands of net opening/closing were stored in the control unit via a Data read/write unit on deck. During the towing, data including depth, temperature, flowmeter counts, net releasing and closing time, were all stored in the control unit which can be obtained simply from the computer.

3.1.2 Open sea trial

Night sea trials were conducted on 19-20 July 2015, using MOC-MOHT carried out by Research vessel Kaiyou-maru (Fisheries Agency of Japan) in Sagami Bay, Pacific. MOC-MOHT has a 4 m^2 mouth opening and five nets with a mesh size of 1.59 mm. In 2015, MOC-MOHT was towed horizontally at a target depth of 50 m. On July 19, the autonomous opening/closing control system ran error so we removed four codend nets from experimental gear. Six hauls were all towed in 15 minutes, with towing speed of 4, 3 and 2 knot, respectively. On July 20, the autonomous opening/closing control system ran smoothly and the second, third and fourth nets were towed for 10 minutes at changed speeds of 4, 3 and 2 knot, respectively.

All hauls were conducted after sunset because of the diel vertical migration phenomenon of lantern fish. Simrad EK500 scientific echo sounder (38 kHz) was used to estimate acoustic abundance of myctophid fishes. Prior to trawling, the fish distribution can be identified in fish finder in which fish school is most focused at a depth of about 50 m. Therefore, we set the target depth around 50 m in horizontal tows to sample lantern fish. The net depth and speed was monitored in the vessel's laboratory and instructions were deliverd to the bridge to control the sampling gear.

Filter water in unit time was calculated through the flow velocity, towing period and mouth area of MOC-MOHT. Like MOHT, no mesh blocking phenomenon occurs in MOC-MOHT, so the filter water efficiency can be regarded as 100%. Flow velocity was presumed by counters in flow meter.

Specimens collected in each codend net were put in bottles with 10% formalin preserved for further analysis in laboratory. From all collected samples, 12 bottles of samples were carried out for species identification. The samples used for the identification analysis were as follows: ②, ③, ④, ⑤, ⑥, ⑦, 8-②, 8-③, 8-④, 9-②, 9-③, 9-④. Lantern fish species were classified as follows: *Diaphus Kuroshio, Diaphus garmani, Ceratoscopelus warmingii, Myctophum asperum, Myctophum nitidulum, Diogenichthys atlanticus, Lampanyctus alatus, Lampanyctus* spp, *Myctophidae* spp. All of the lantern fish were picked out for body length measurement and grouped into standard length in millimeters.

3.1.3 Data analysis

In experiments, MOC-MOHT was used to capture myctophid fishes at speeds of 2, 3 and 4 knots. Since high speed may has the possibility of collecting more larger fish than low speed, we considered 4 knot as a control towing speed when analyzing the towing speeds of 2 and 3 knot in this study. However, even in the case of towing speed at 4 knot, we can't confirm the phenomenon of net avoidance does not occur. Therefore, in our study, we predict the net avoidance caused by high speed of 4 knot, evaluating the net avoidance caused by low speed of 3 and 2 knots meanwhile.

SELECT method was applied in this study for continuous hauls, and parameters of net avoidance under various towing speeds were calculated. In general, fish with larger body length are more likely to escape in front of fishing gear. As avoidance phenomenon is associated with body length, the net avoidance of MOC-MOHT is expressed with monotonically decreased logistic function $a(l)$ with logistic parameters α and β.

$$a(l) = \frac{\exp(\alpha + \beta l)}{1 + \exp(\alpha + \beta l)} \quad (1)$$

From the logistic parameter estimates of α and β, the length of 50% retention l_{50} and the selection range S.R. can be calculated with the following two equations.

$$l_{50} = -\alpha / \beta \quad (2)$$

$$\text{S.R.} = 2\log_e(3)/\beta \quad (3)$$

When solving such selectivity, the parameters in test fishing gear were estimated through comparing to a corresponding control fishing gear. SELECT method (Millar, 1992; Wileman et al., 1996; Tokai and Mituhasi, 1998) is often used to solve such problems. However, the control fishing gear is not completely without selectivity. For example, in studies of Mituhasi *et al.* (2000) and Kitakado *et al.* (2002), when the size of cover net was not small enough, assuming that some catches can also escape from the mesh of cover net, so they solved the selectivity of the codend as well as selectivity of cover net. Likewise, in this study, net avoidance phenomenon also happened at 4 knot towing speed.

The diameter of the codend, catch weight in codend, towing speed and other factors, may have effect on calculating logistic parameters (Fryer, 1991; Reeves et al., 1992; O'Neill and Kynoch, 1996; Millar et al., 2004; Dahm et al., 2002; Miyajima et al., 2012). Therefore, logistic parameters α and β are expressed by linear equations of towing speed V in this study.

$$\alpha = a V + b \tag{4}$$

$$\beta = c V + d \tag{5}$$

Here, a, b, c, d are parameters.

According to the formula above, we can not only calculate logistic function of net avoidance at 2 and 3 knot, but also obtain logistic function at 4 knot. They are expressed with logistic function $a_4(l)$, $a_3(l)$ and $a_2(l)$.

Catch numbers of l-length fish at towing speeds of 4, 3 and 2 knots are C_4, C_3 and C_2, respectively. Two hauls of different towing speed, C_4 vs C_3, C_4 vs C_2, the proportion of catch at relatively low speed to the total catch is defined as follows:

$$\phi_{3vs4} = \frac{C_3}{C_3 + C_4} \tag{6}$$

$$\phi_{2vs4} = \frac{C_2}{C_2 + C_4} \tag{7}$$

Split parameter p_3 and p_2 are expressed by the following formula.

The proportion of catch $\phi_{(l)}$ expressed by logistic function $a_4(l)$, $a_3(l)$ and $a_2(l)$ are converted into follows.

$$\phi_{3vs4}(l) = \frac{p_3 \cdot a_3(l)}{(1-p_3)a_4(l) + p_3 \cdot a_3(l)} \tag{8}$$

$$\phi_{2vs4}(l) = \frac{p_2 \cdot a_2(l)}{(1-p_2)a_4(l) + p_2 \cdot a_2(l)} \tag{9}$$

In the formula, a, b, c, d, p_2, p_3 are parameters estimated.

According to whether towing speed influences the logistic parameters α and β, as well as split parameter or fixed parameter determined by the filter water, we formulated six models to examine variation in net avoidance.

The split parameters in two hauls p_2 and p_3 were estimated by log-likelihood method.

Model A: Towing speed had effects on both logistic parameters α and β, so the parameter $a \neq 0, c \neq 0$. A total of six parameters, *a*, *b*, *c*, *d*, *p2*, *p3*, were used in this model.

Model B: Towing speed had effect on logistic parameters α but had no effect on logistic parameter β, so parameter $a = 0, c \neq 0$. A total of five parameters, *b, c, d*, p_2, p_3, were used in this model.

Model C: Towing speed had no effect on logistic parameters α but had effect on logistic parameter β, so the parameter $a \neq 0, c = 0$. A total of five parameters, *a, b, d*, p_2, p_3, were used in this model.

The split parameters in two hauls p_2 and p_3 were determined by ratio of filter water in experiments, so p_2 and p_3 were fixed value.

Model D: Towing speed had effects on both logistic parameters α and β, so the parameter $a \neq 0, c \neq 0$. A total of four parameters, *a, b, c, d*, were used in this model.

Model E: Towing speed had effect on logistic parameters α but had no effect on logistic parameter β, so parameters $a = 0, c \neq 0$. A total of three parameters, *b, c, d*, were used in this model.

Model F: Towing speed had no effect on logistic parameters α but had effect on logistic parameter β, so parameters $a \neq 0, c = 0$. A total of three parameters, *a, b, d*, were used in this model.

Solver in Excel was implemented to maximize the functions. The AIC (Akaike's Information Criterion) model selection was performed for optimal model among these six models. π means number of parameters, and MLL means maximum log-likelihood.

$$\text{AIC} = -2 \times \text{MLL} + 2\pi \tag{10}$$

Within a reasonable range, the smallest AIC model was chosen as the optimal model.

3.2 The results

3.2.1Towing conditions (start time, maximum net depth, towing speed)

The towing condition in Sagami Bay from 19-20 July 2015 is shown in Table 3.1. The latitude and longitude of all trawling were obtained by GPS tracking, in which track of vessel is shown in Fig. 3.2. All trawling were carried out at night. On 19 July, six towing experiments were conducted in station 2~7. Towing durations were 21~26 minutes, and filtered volumes were 5350~10584 m^3. On 20 July, two towing experiments were conducted in station 8 and 9. Towing durations were 42 and 44 minutes, and filtered volumes were 21446 and 19356 m^3. In the process of horizontal tow, the length of warp was adjusted in order to maintain the fishing gear in a certain depth.

3.2.2 Towing performance

3.2.2.1 Towing depth in experiment

The towing depth was obtained from average values reading in four small water depth meter installed in the rigid frame of fishing gear. Towing depths of MOC-MOHT are shown in Fig. 3.3- Fig. 3.4. In haul 2, 3 and 4, the towing time were during 9~24 minutes, 6~21 minutes and 7~22 mintues at the towing speed of 3 knots after achieving 50 meters depth. Net depths of haul 2, 3 and 4 were 48~52 m, 47~53 m, 49~54 m, respectively. The water depth of three hauls were all around 50 m, which showed the fluctuation were very small. In haul 5, 6 and 7, the towing time were during 6~15.5 minutes, 4.5~17.5 minutes and 5~19.5 mintues at the towing speed of 3 knots after achieving 40 meters depth. However, the towing periods of three hauls were all less than 15 minutes. Among them, the towing period in haul 5 was a little shorter than other hauls. Net depths of haul 5, 6 and 7 were 34~41 m, 31~42 m and 34~44 m, respectively. The water depth of three hauls showed a slight fluctuation around 40 m. In the process of haul 8 and 9, the towing period of second, third and fourth interval were all about 10 minutes, and towing speed were set at 4, 3 and 2knots. The water depth of haul 8 was changed in 39~64 m, which indicated a drastic fluctuation around 50 m depth. For haul 8, the first bar dropped at a depth of 55 m, the second bar dropped at 39 m after 8 minutes, the third bar dropped at 46m after 9 minutes and then the fourth bar dropped at 63 m after 10 minutes. For haul 9, the first bar dropped at a depth of 41 m and then the following three bars were released at depths of 36, 37 and 46 m in 10 minutes interval. The water depth of haul 9 was changed in 33~47 m, which indicated a slight fluctuation around 40 m.

3.2.2.2 Tilt angle of net frame

Tilt angles of mouth frame are shown in Fig. 3.5- Fig. 3.6. At roll axis angle, positive direction expressed direction of rotation to the right, negative direction expressed direction of rotation to the left. At pitch axis angle, positive direction expressed lean forward, negative direction expressed backward tilt.

For 2^{nd} ~7^{th} hauls under the condition of single net, tilt angle of the frame decreased obviously with a decrease in the towing speed. The average tilt angles of 2nd ~4th hauls were 10.0°, 3.3°and 0.6°, respectively. Also, the average tilt angles of 5th ~7th hauls were 10.3°, 5.3°and 4.3°, respectively. Besides, the frame was temporarily inclined under the condition of wire-in and wire-out.

For 8th and 9th hauls, according to the tilt angle, the frame maintained almost the same tilt angle forward between the successive three nets. The frame inclined forward evidently when a slide-bar was released, and then moved to the previous inclination within 2-3 s. In haul 8, the average tilt angles were 24.1°, 27.2° and 26.7°, respectively. In haul 9, the average tilt angles were 31.8°, 29.0° and 27.1°, respectively.

3.2.2.3 Filtered water in each net

Accumulate filtered water for each codend in horizontal tows is shown in Fig. 3.7-Fig. 3.8. In haul 2, 3 and 4, the filter water was 5627, 5160 and 2304 m^3, respectively. Filter water at 3 knot was close to 4 knot, which was twice the filter water at 2 knot. In haul 2, 3 and 4, the filter water was 7843, 5830 and 4898 m^3, respectively. Filter water at 4 knot was the most and filter water at 2 knot was the least. In 8-②, 8-③ and 8-④ hauls, the filter water was 5566, 5587 and 4387 m^3, respectively. In 9-②, 9-③ and 9-④ hauls, the filter water was 5255, 5215 and 4206 m^3, respectively. Among them, filter water at 3 knot was close to 4 knot, more than filter water at 2 knot.

In 2nd ~7th hauls, the accumulated filtered water was reduced as towing speed became slower. In other words, filtered water was larger at the higher towing speed per unit of time. Growth rates of filtered water in 2nd ~7th hauls were relatively smooth, without obvious fluctuation. While in 8th and 9th hauls, when a net was closed/opened and the towing speed was changed, the growth rate of filtered water was fluctuated strongly.

3.2.3 Fish species composition

3.2.3.1 Species composition of specimen in each haul

Micronektons were identified into five species: Myctophidae, Cephalopoda, Euphausiidae, Sergestidae and other Ichthyoplankton. Proportion of individuals and weight for each specimen are shown in Table 3.2 and Fig. 3.9.

In mantissa ratio, proportion of Euphausiidae was the largest and accounted for 70% of specimen in each hauls except 6 and 7. Proportion of Cephalopoda was the least and accounted for less than 1% of specimen in each hauls. For Myctophidae, the numbers of lantern fish were 154 ~ 709 and the proportions were accounted for 0.6% ~ 15.8%. In weight ratio, proportion of Euphausiidae was also the largest and proportion of Cephalopoda was the least. For Myctophidae, the proportions were accounted for 2.8% ~ 33.4%.

3.2.3.2 Species composition of lantern fish in each haul

In total, 3738 lantern fish individuals were collected during the experiment 2015. According to the quantity, lantern fishes were sorted from most to least as follows: *Diaphus Kuroshio, Diaphus garmani, Lampanyctus sp, Ceratoscopelus warmingii, Myctophum asperum, Lampanyctus alatus, Diogenichthys atlanticus, Myctophum* *nitidulum.* Proportion of individuals/weight for myctophid fishes is shown in Fig. 3.10. Among them, *Diaphus Kuroshio* and *Diaphus garmani* were most important species since these two species of fish accounted for half of the total fishes. *Lampanyctus alatus, Diogenichthys atlanticus*, *Myctophum nitidulum* were seldom caught or not caught in each hauls. In 2~4 hauls, *Diaphus Kuroshio* fishes accounted for 23%~31%, and *Diaphus garmani fishes* accounted for 18%~23%. In 5~7 hauls, *Diaphus Kuroshio* fishes accounted for 45%~50%, and *Diaphus garmani fishes* accounted for 8%~12%. In 8 haul, very few lantern fishes were collected, so we didn't analyze the species composition. In 9 haul, *Diaphus Kuroshio* fishes accounted for 29%~35%, and *Diaphus garmani fishes* accounted for 34%~42%. Species composition of lantern fish were similar in haul 2~4, as well as in haul 5~7 and haul 9-②~9-④.

3.2.3.3 Catch numbers and length distributions of lantern fish in each haul

In the experiment 2015, five kinds of common lantern fish: *Diaphus Kuroshio, Diaphus garmani, Ceratoscopelus warmingii, Myctophum asperum, Lampanyctus sp* were measured the standard length to millimeter. Length distributions for each species of lantern fish are shown in Table 3.3~3.7 and Fig. 3.11-Fig. 3.15.

Length distributions of *Diaphus Kuroshio* were mainly ranged from 12~37 mm. The peak length was about 20~25 mm, almost the same in haul 2~4 and haul 5~7. While a little smaller peak length in haul 9-②~9-④ about 17~22 mm. At the towing speed of 2knot, almost no more than 26mm specimen was captured. Length distributions of *Diaphus garmani* were mainly ranged from 12~40 mm. In haul 2~4, there was no obvious peak value because less specimen was captured. Both in haul 5~7 and haul 9-②

~9-④, the peak length was about 17~22 mm. Length distributions of *Ceratoscopelus warmingii* were mainly ranged from 17~67 mm and no obvious peak value was obtained because the body length distribution is dispersed distributed. At the towing speed of 2 knot, almost no more than 50 mm specimen was captured. Length distributions of *Myctophum asperum* were mainly ranged from 25~61 mm with no obvious peak value. Length distributions of *Lampanyctus sp* were mainly ranged from 12~55mm and the peak length at the highest speed was about 20~30 mm.

3.2.3.4 The catch number in unit filtered water of Myctophidae

The CPUE (catch number in unit filter water) of lantern fish was shown in Fig. 3.16. In 2, 3 and 4 hauls, the values of CPUE were 0.05, 0.04, 0.07 ind/m^3, respectively. The values of CPUE were similar in 5, 6 and 7 hauls, respectively are 0.09, 0.08, 0.08 ind/m^3. In 9-②, 9-③ and 9-④ hauls, the values of CPUE were reduced as the towing speed decreased, respectively are 0.11, 0.08, 0.07 ind/m^3. In each series of speed changed experiments, the values of CPUE were largest at towing speed of 4 knots except haul 2.

3.2.4 Parameter estimation and model selection

Linear model was successfully obtained for *Diaphus Kuroshio* and *Diaphus* spp in haul 2~7 and 9. According to AIC model selection, the optimal model for *Diaphus Kuroshio* was model B with a smallest AIC value of 425.31. Similarly, the optimal model for *Diaphus spp* was model B with a smallest AIC value of 340.03. Further, the optimal model for both *Diaphus Kuroshio* and *Diaphus spp* was model C with a smallest AIC value of 761.94.

In optimal model B for *Diaphus Kuroshio*, the proportion of catch in slow speed haul is shown in Fig. 3.17. In the combination of haul 2 and 3, the standard length was mainly gathered in 12.5~28.5 mm. As the standard length increased, the percentage of catch in haul 3 was decreased. In the combination of haul 2 and 4, the standard length was mainly gathered in 12.5~29.5 mm. As the standard length increased, the percentage of catch in haul 2 was decreased. There was obvious fluctuation in standard length less than 19.5 mm. In the combination of haul 5 and 6, the standard length was mainly gathered in 12.5~28.5 mm. In the combination of haul 5 and 7, the standard length was mainly gathered in 12.5~29.5 mm. There was obvious fluctuation in standard length of 12.5 and 15.5 mm. In the combination of haul 9-② and 9-③, the standard length was mainly gathered in 13.5~24.5 mm. In the combination of haul 9-② and 9-④, the standard length was mainly gathered in 14.5~24.5 mm. There was no obvious fluctuation in the corresponding standard length.

In optimal model B for *Diaphus garmani*, the proportion of catch in slow speed haul is shown in Fig. 3.19. In the combination of 2 and 3, the standard length was mainly gathered in 15.5~23.5 mm. As the standard length increased, the percentage of catch in haul 3 was decreased. In the combination of 2 and 4, the standard length was mainly gathered in 13.5~23.5 mm. As the standard length increased, the percentage of catch in haul 4 was decreased. There was no obvious fluctuation in the corresponding standard length. In the combination of 5 and 6, the standard length was mainly gathered in 17.5~24.5 mm. In the combination of 5 and 7, the standard length was mainly gathered in 13.5~24.5 mm. In the combination of 9-② and 9-④, the standard length was mainly gathered in 14.5~24.5 mm. In the combination of 9-② and 9-③, the standard length was mainly gathered in 13.5~24.5 mm.

In optimal model B for *Diaphus Kuroshio* and *Diaphus* spp, the proportion of catch in slow speed haul is shown in Fig. 3.21- Fig. 3.22. The standard length was mainly gathered in 12.5~28.5 mm for *Diaphus Kuroshio* and 14.5~24.5 mm for *Diaphus* spp, respectively. Fluctuation was seen in the small number of standard length.

3.2.5 Selection curve for mesh size and net avoidance

Selection parameters and selection curve for *Diaphus Kuroshio* and *Diaphus spp* are shown in Table 3.8, 3.10 and 3.12, Fig. 3.18, 3.20 and 3.23.

For *Diaphus Kuroshio,* in six hypothetical models, according to the AIC model selection, the net avoidance model with estimated parameter *p* and linear parameter *a* equaled to zero was selected as the optimal model. The selection curve of net avoidance was monotonous decreased. When compared to towing speed of 4 knot, it is obviously that lantern fish were smaller in towing speed of 3 and 2 knot. In three selection curves, standard lengths of lantern fish were increased in sequence of 2, 3 and 4 knot. 50% retention length and selection range were 24.16 and -3.65 mm in 2knot, 27.24 and -4.11 mm in 3 knot, 31.22 and -4.71 mm in 4 knot, respectively. There were few lantern fish larger than 30 mm collected in 2 knot and few fish larger than 35mm in 3 knot, which indicated net avoidance phenomenon of slower net was more obvious than faster net.

For *Diaphus* spp, in six hypothetical models, according to the AIC model selection, the net avoidance model with estimated parameter *p* and linear parameter *a* equaled to zero was selected as the optimal model. When compared to towing speed of 4 knot, it is obviously that lantern fish were smaller in towing speed of 3 and 2 knot. In three selection curves, standard lengths of lantern fish were increased in sequence of 2, 3 and 4 knot. 50% retention length and selection range were 23.46 and -5.16 mm in 2knot, 30.46 and -6.69 mm in 3 knot, 40.38 and -9.53 mm in 4 knot, respectively. There were no lantern fish larger than 35 mm collected in 2 knot and no fish larger than 45 mm in 3 knot, which indicated net avoidance phenomenon of slower net was more obvious than faster net.

For *Diaphus Kuroshio* and *Diaphus* spp, according to the AIC model selection, the net avoidance model with estimated parameter *p* and linear parameter *a* equaled to zero was selected as the optimal model. In three selection curves, standard lengths of lantern fish were increased in sequence of 2, 3 and 4 knot. 50% retention length and selection range were 23.46 and -4.94 mm in 2knot, 29.06 and -6.12 mm in 3 knot, 38.19 and -8.05 mm in 4 knot, respectively. From the selection curve, we can draw the following conclusions: Fish with standard length smaller than 20 mm could be captured at towing speed of 2, 3 and 4 knots; Fish with standard length around 30 mm could not be captured at 2 knots, but is likely to be captured at 3 knots, and could be captured at 4 knots; Fish with standard length ranged between 40 and 50 mm could not be captured at 2 and 3 knots, but is likely to be captured at 4 knots.

3.3 Discussion

In the first test day, for single net, when the warp length was set at 150 m long in 2, 3 and 4 hauls, all the towing depths of the frame was stable at a range of 47~ 54 m. Also, when the warp length was set at 120 m long in 5, 6 and 7 hauls, towing depths of frame was all maintained between 31 to 44 m. It indicated that the depth of the water stability of the nets is very good. In the second test day, the frame had obvious rise for a short while after the opening/closing of nets in haul 8 and 9. Also, the warp length was adjusted to keep the net maintain a certain depth. However, towing depth was unstable in haul 8 than haul 9.

The species composition of lantern fish was similar in each set of trawl operations, and the experiment water layers were the same in one set of 4, 3 and 2 knots. So we think the difference in length distribution was caused by towing speed. In length distribution of *Diaphus Kuroshio, Diaphus* spp, two kinds of the largest number of lantern fish, we can see that large individuals were became less as towing speed became slower. In other kinds of lantern fish, the same trend was seen in length distributions when the towing speed was changed. Especially the trend was more obvious in *Ceratoscopelus warmingii,* which had a relatively wide range of body length.

In mean selection curves of *Diaphus Kuroshio*, 50% retention length of 4, 3 and 2 knots were 31, 27 and 24 mm, respectively. It indicated that fish length increased 3 or 4 mm as each additional one knot in towing speed. While in mean selection curves of *Diaphus garmani*, 50% retention length were 43, 30 and 23 mm, respectively. An increase of about 10mm difference was seen as the increase of one knot in towing speed. Compared with *Diaphus Kuroshio, Diaphus garmani* had obvious difference in fish length as the change of towing speed. Referring to length distribution of *Diaphus Kuroshio* and *Diaphus garmani,* length range of *Diaphus garmani* was relatively larger, especially in haul 2.

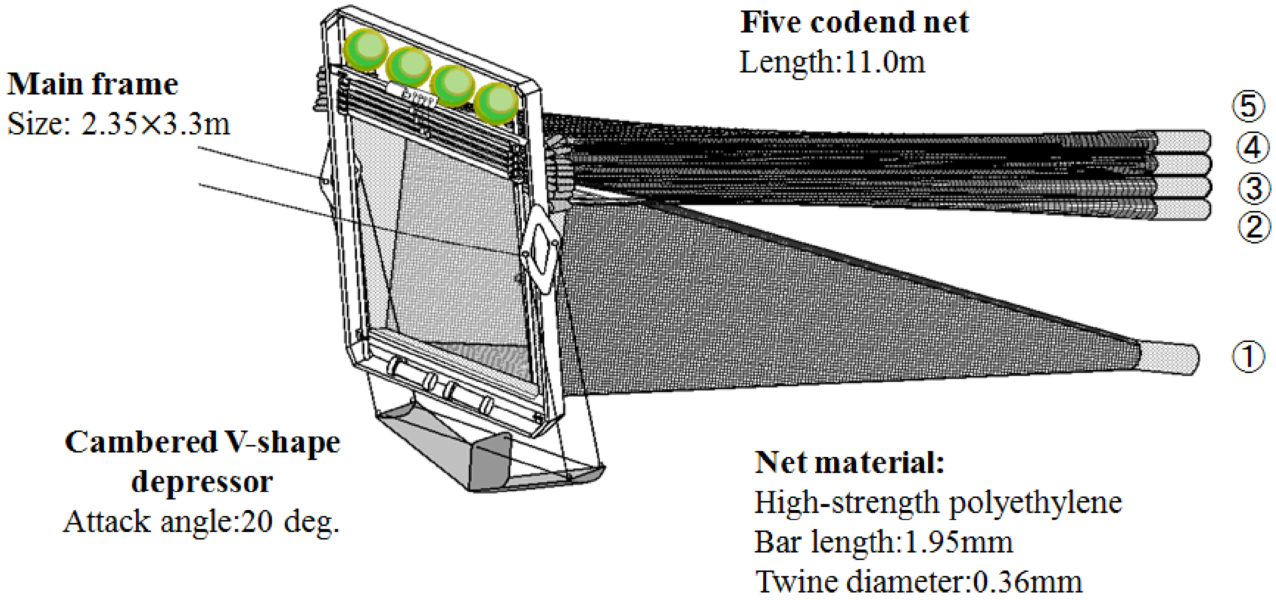

Fig. 3.1 Details of MOC-MOHT sampling gear

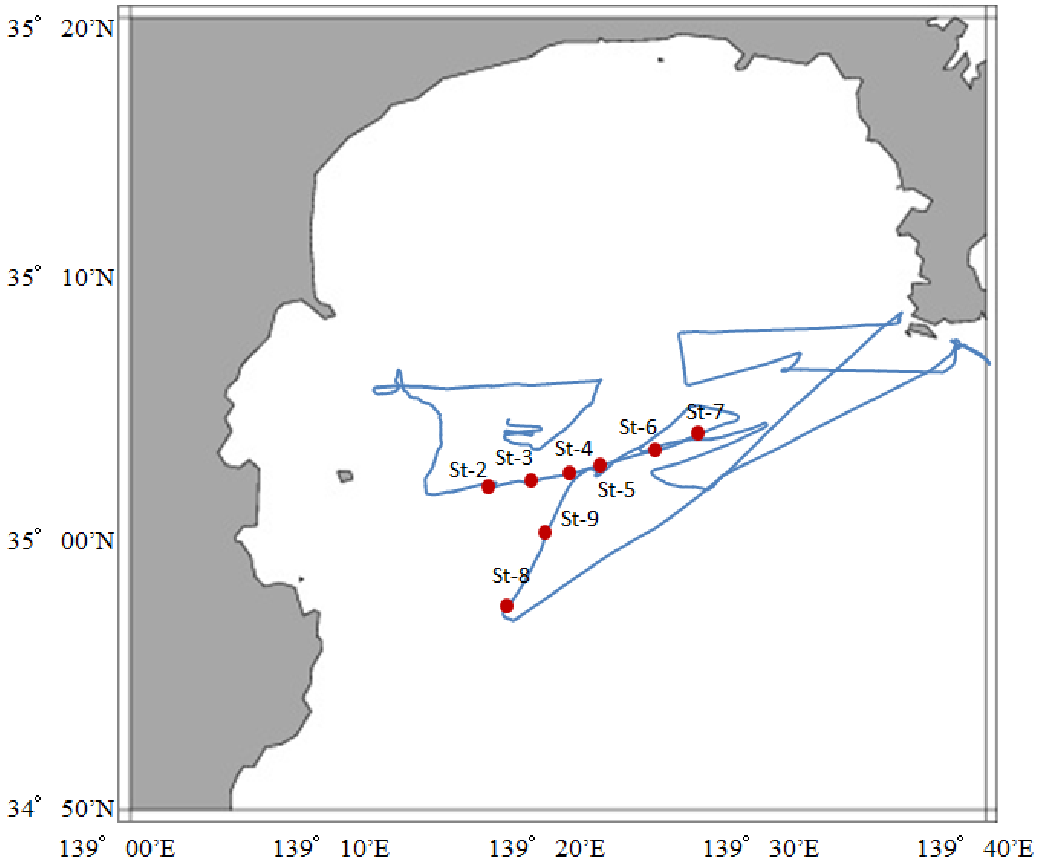

Fig. 3.2 The experimental area of MOC-MOHT sea trials

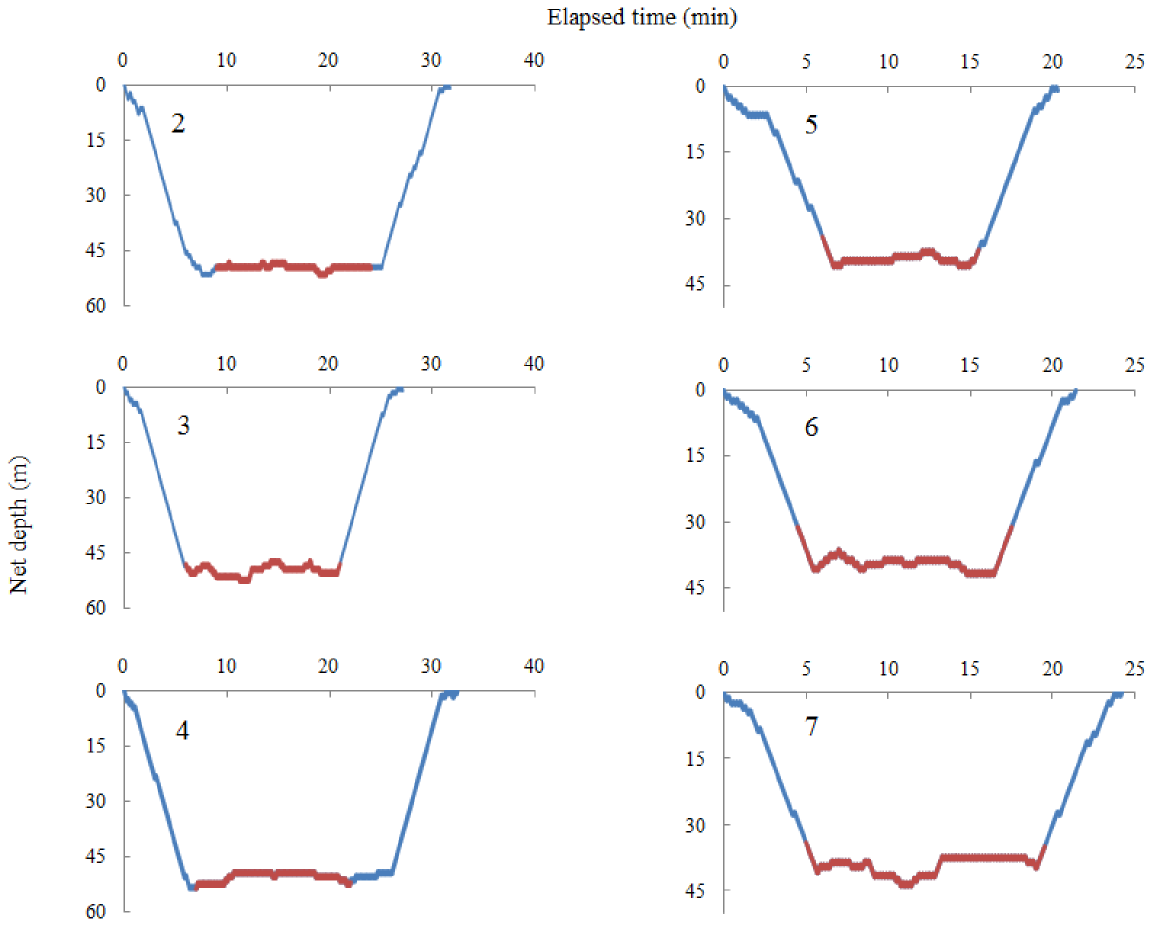

Fig. 3.3 Towing depth of MOC-MOHT in horizontal tows in haul 2~7

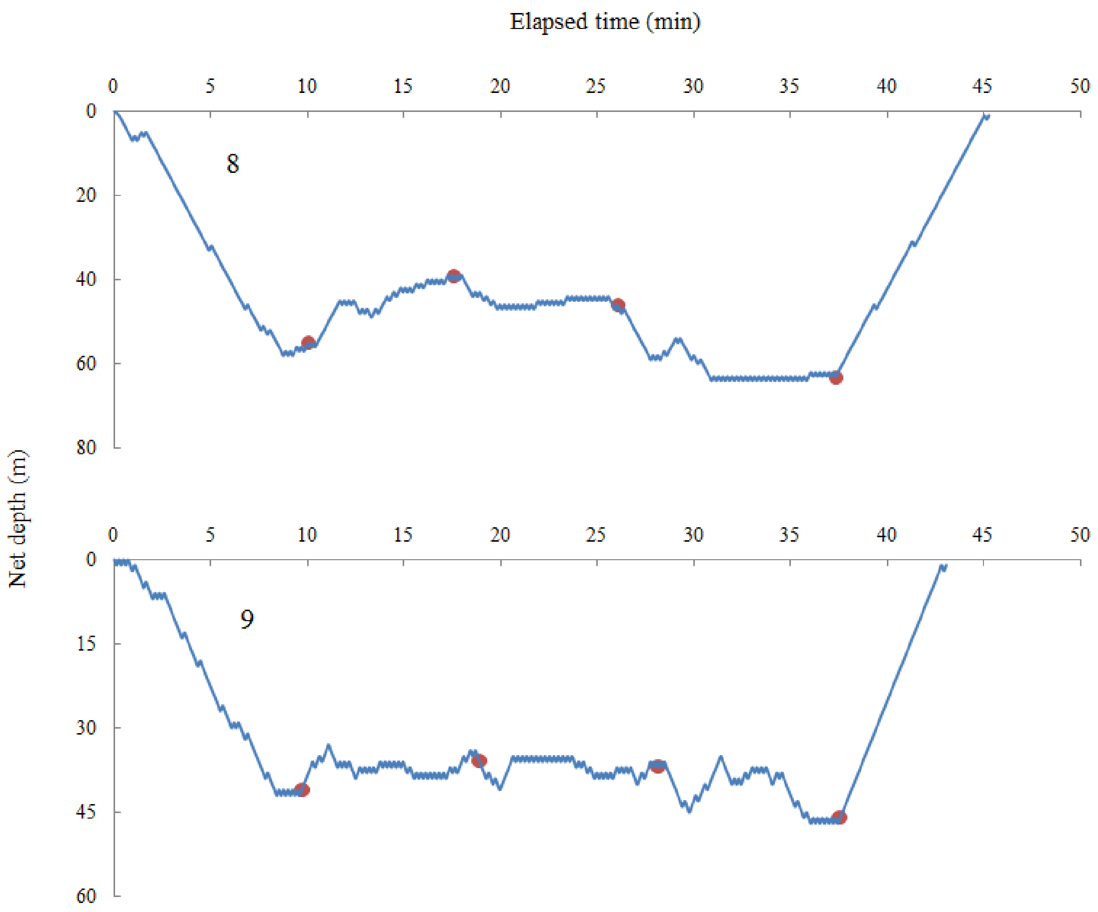

Fig. 3.4 Towing depth of MOC-MOHT in horizontal tows in haul 8 and 9

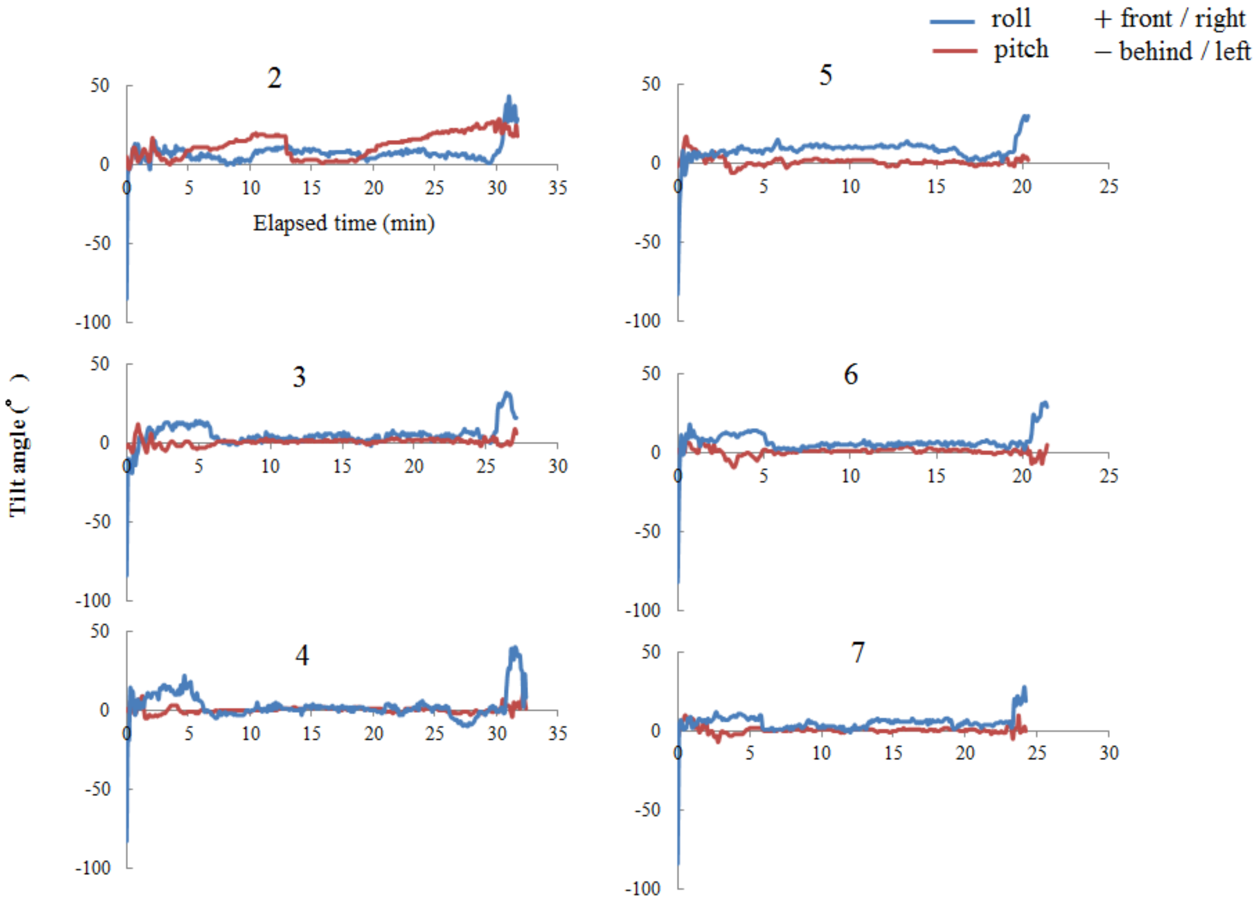

Fig. 3.5 Tilt angle of frame in horizontal tows in haul 2~7

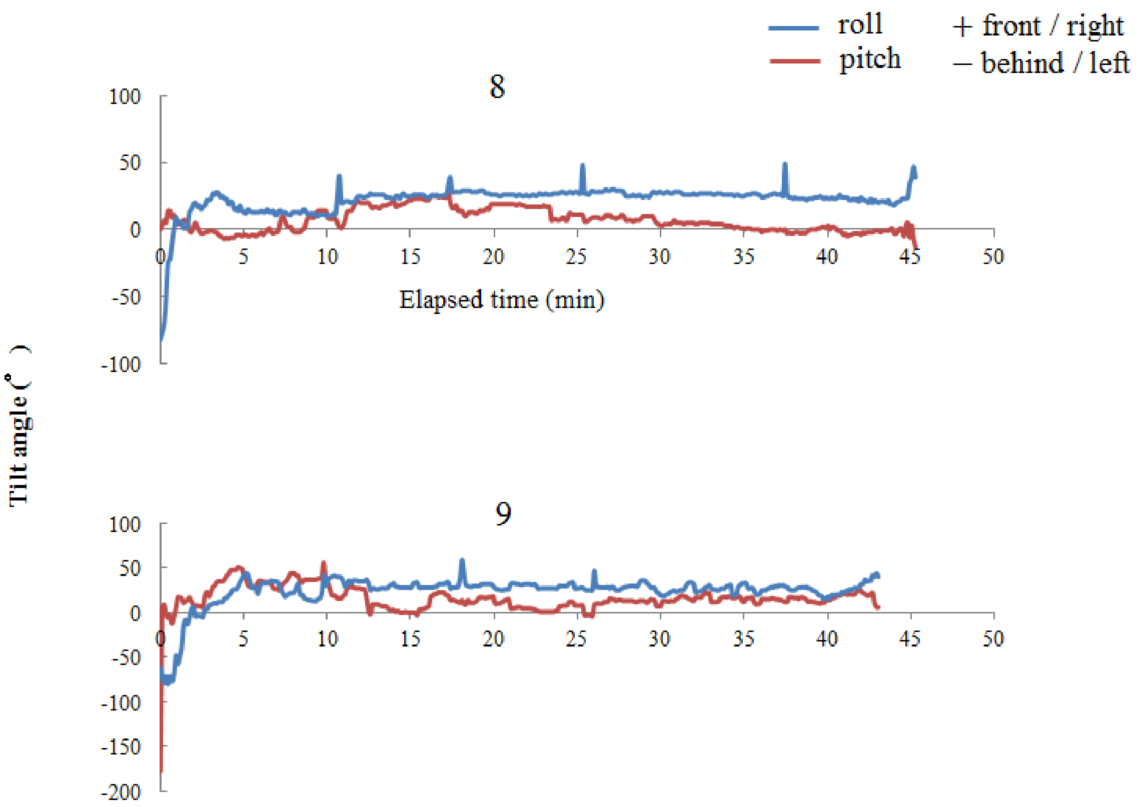

Fig. 3.6 Tilt angle of frame in horizontal tows in haul 8 and 9

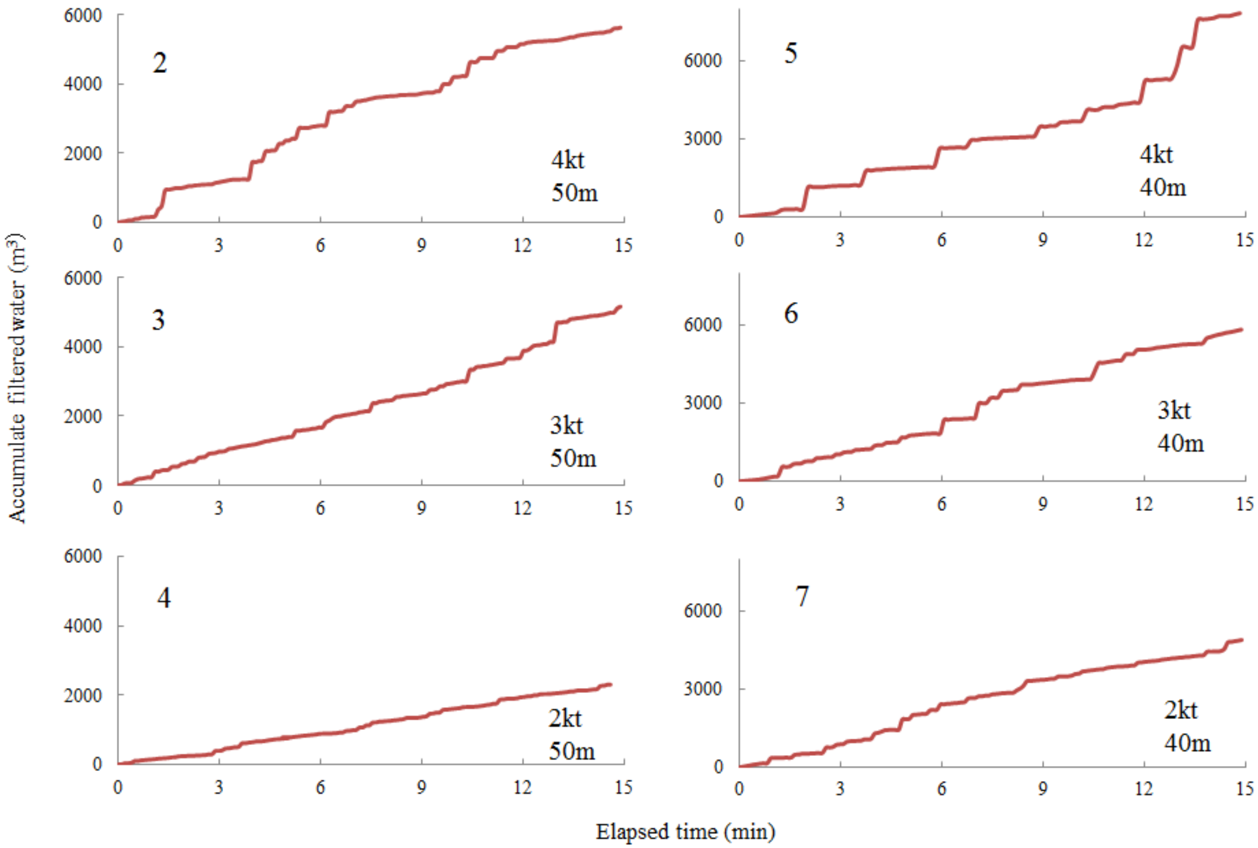

Fig. 3.7 Accumulate filtered water for each codend in horizontal tows in haul 2~7

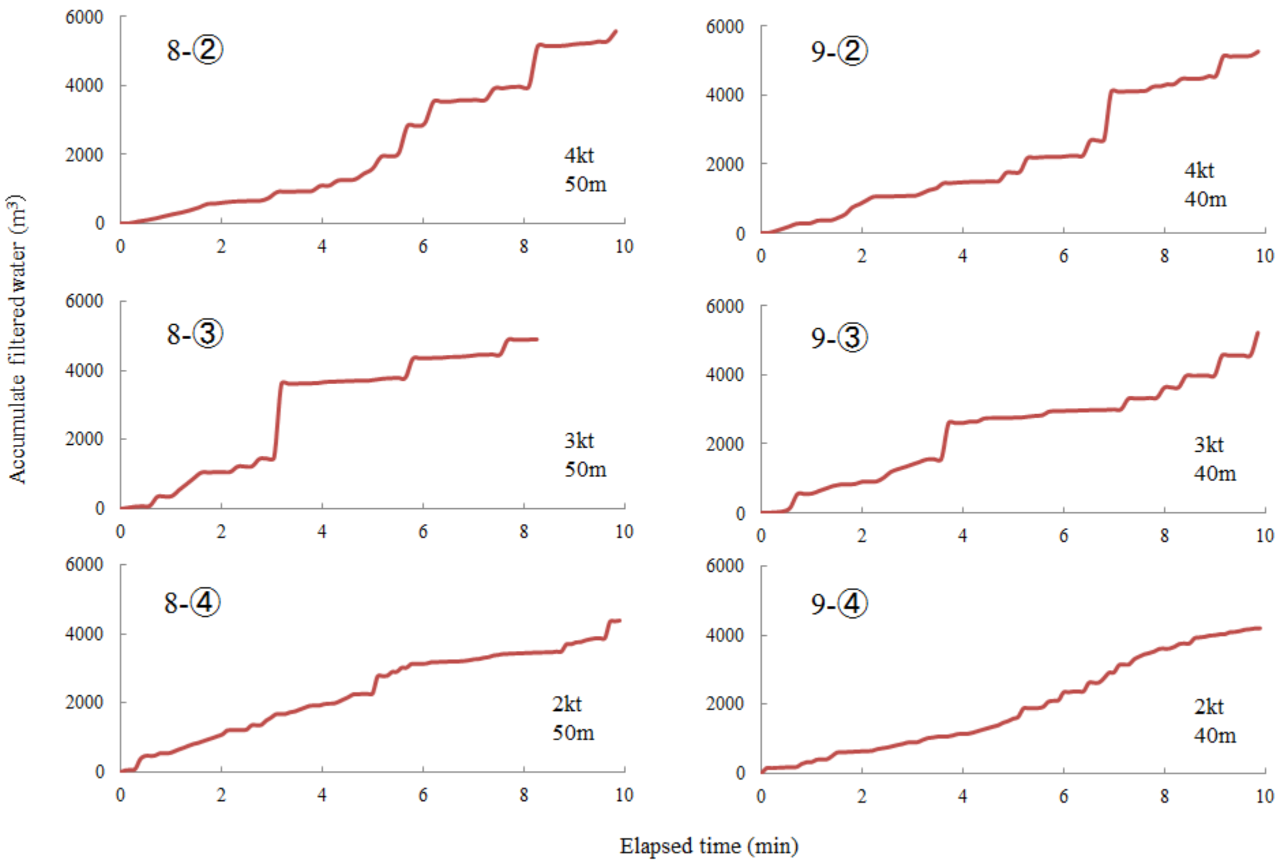

Fig. 3.8 Accumulate filtered water for each codend in horizontal tows in haul 8 and 9

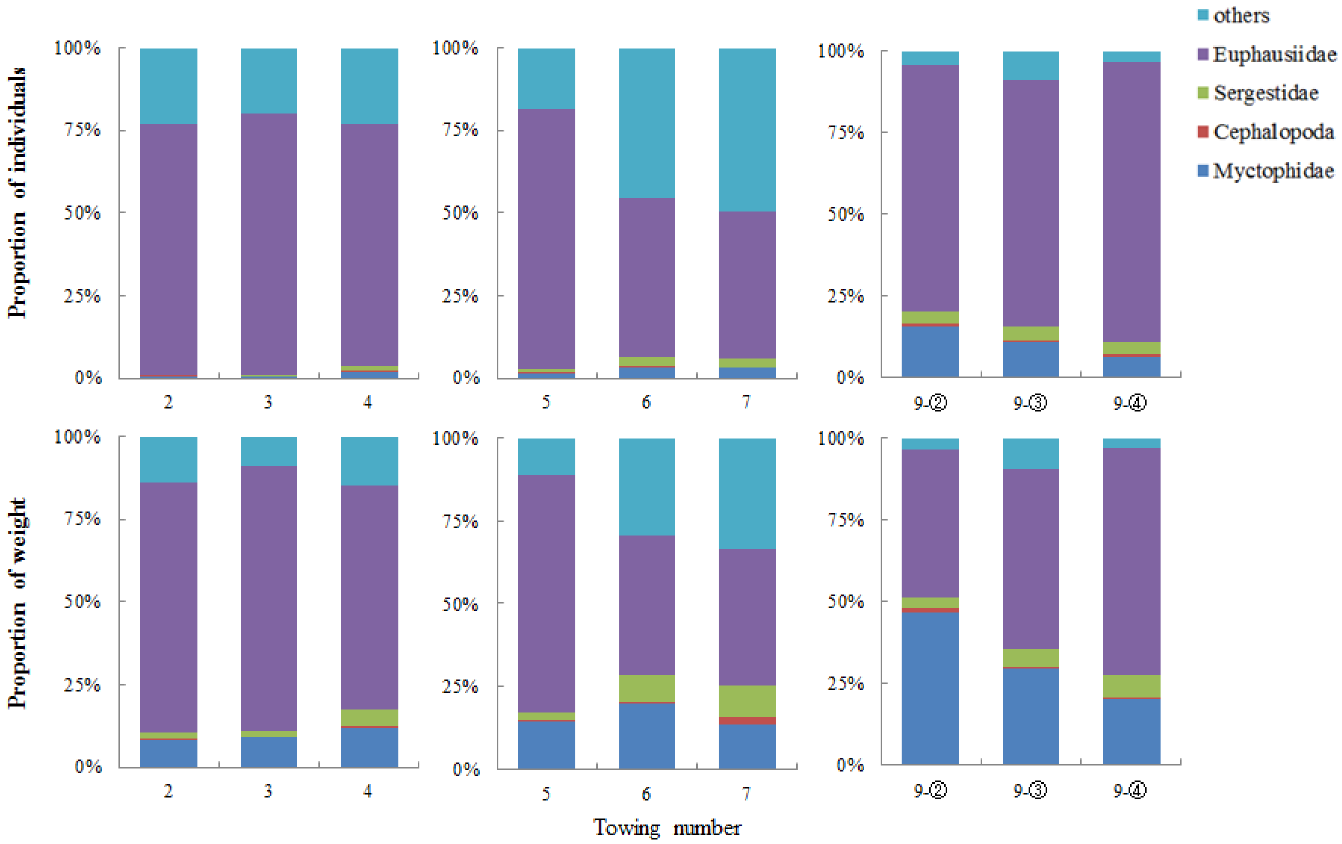

Fig. 3.9 Proportion of individuals/weight for specimen in horizontal tow

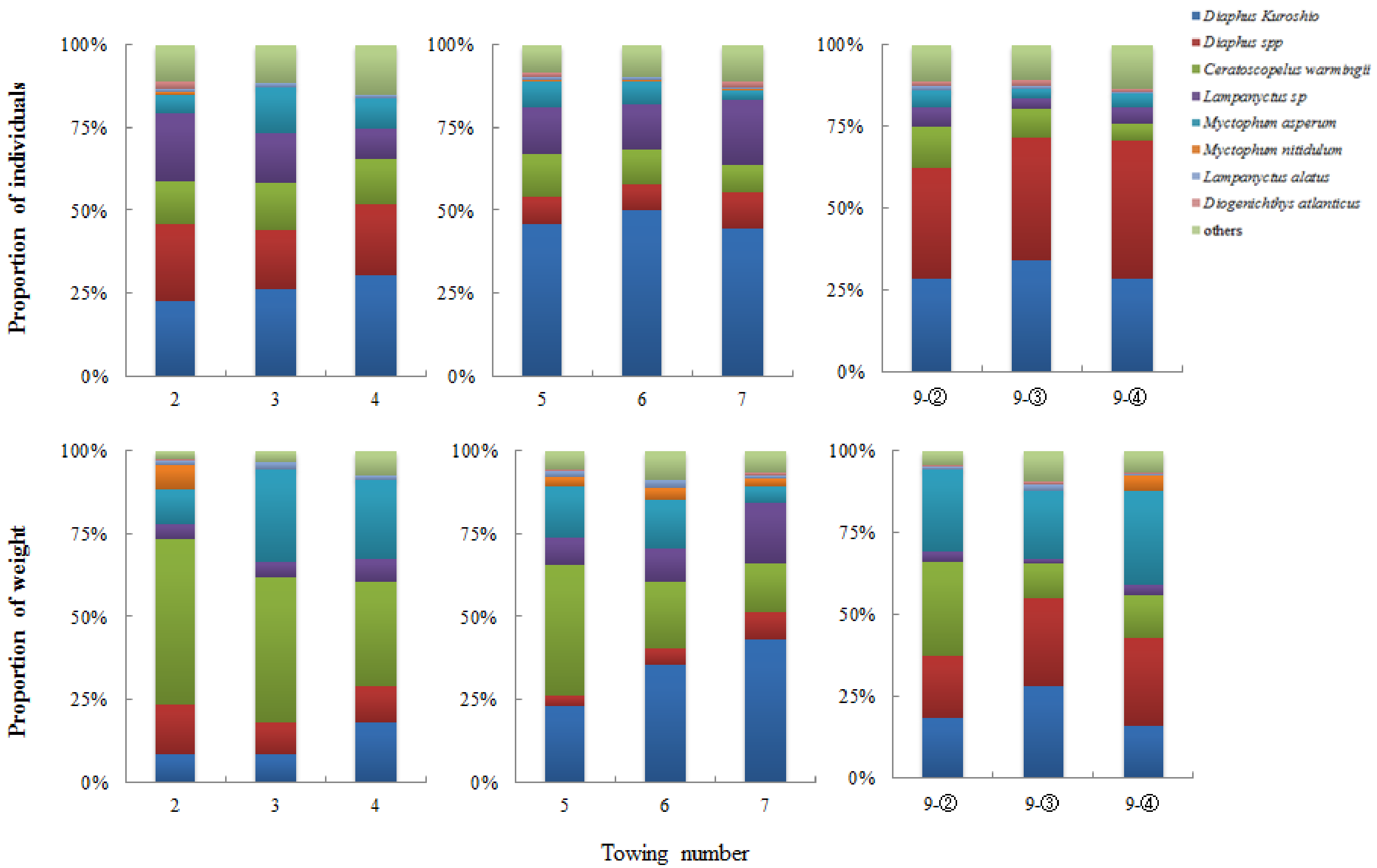

Fig. 3.10 Proportion of individuals/weight for myctophid fishes in horizontal tow

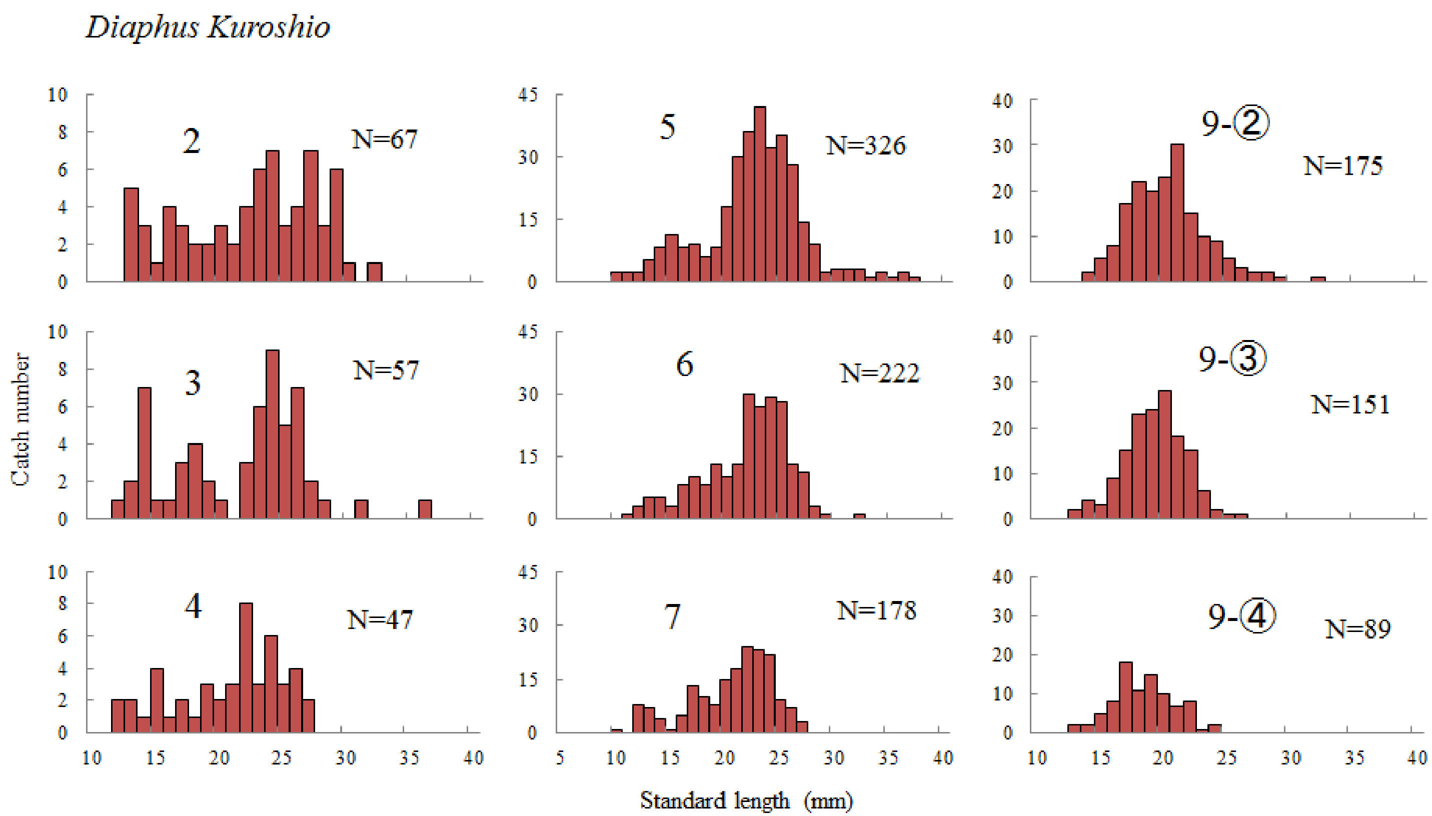

Fig. 3.11 Length distributions for *Diaphus Kuroshio* of MOC-MOHT trails

Diaphus spp

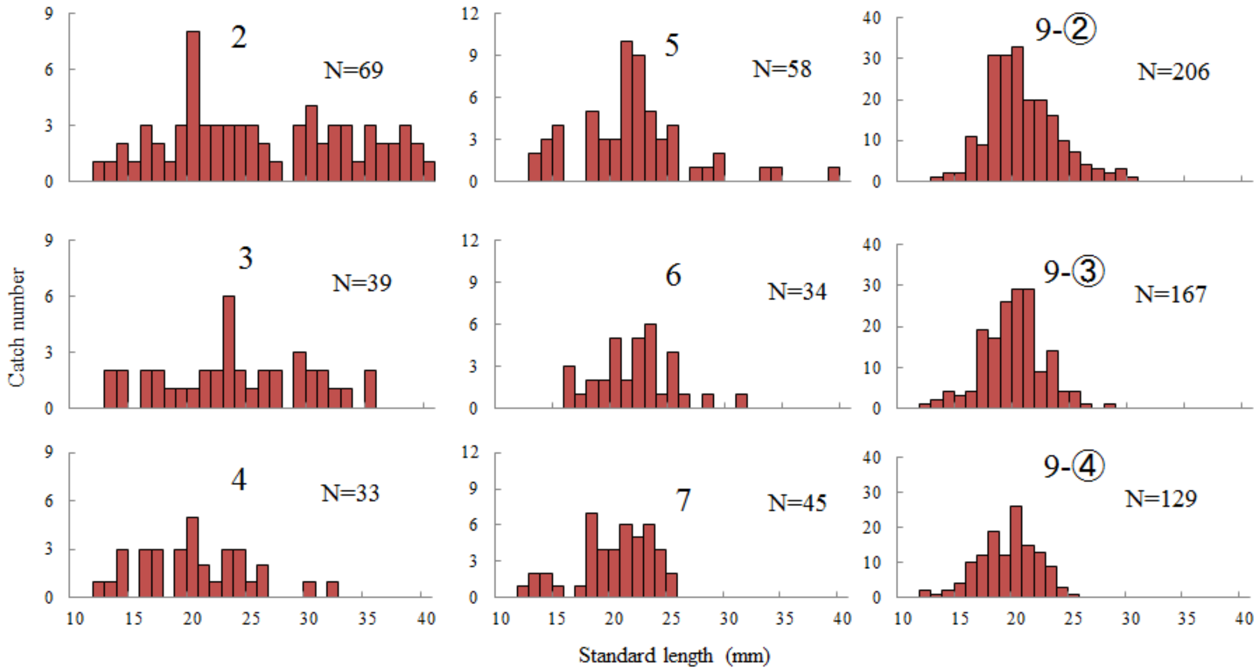

Fig. 3.12 Length distributions for *Diaphus* spp of MOC-MOHT trails

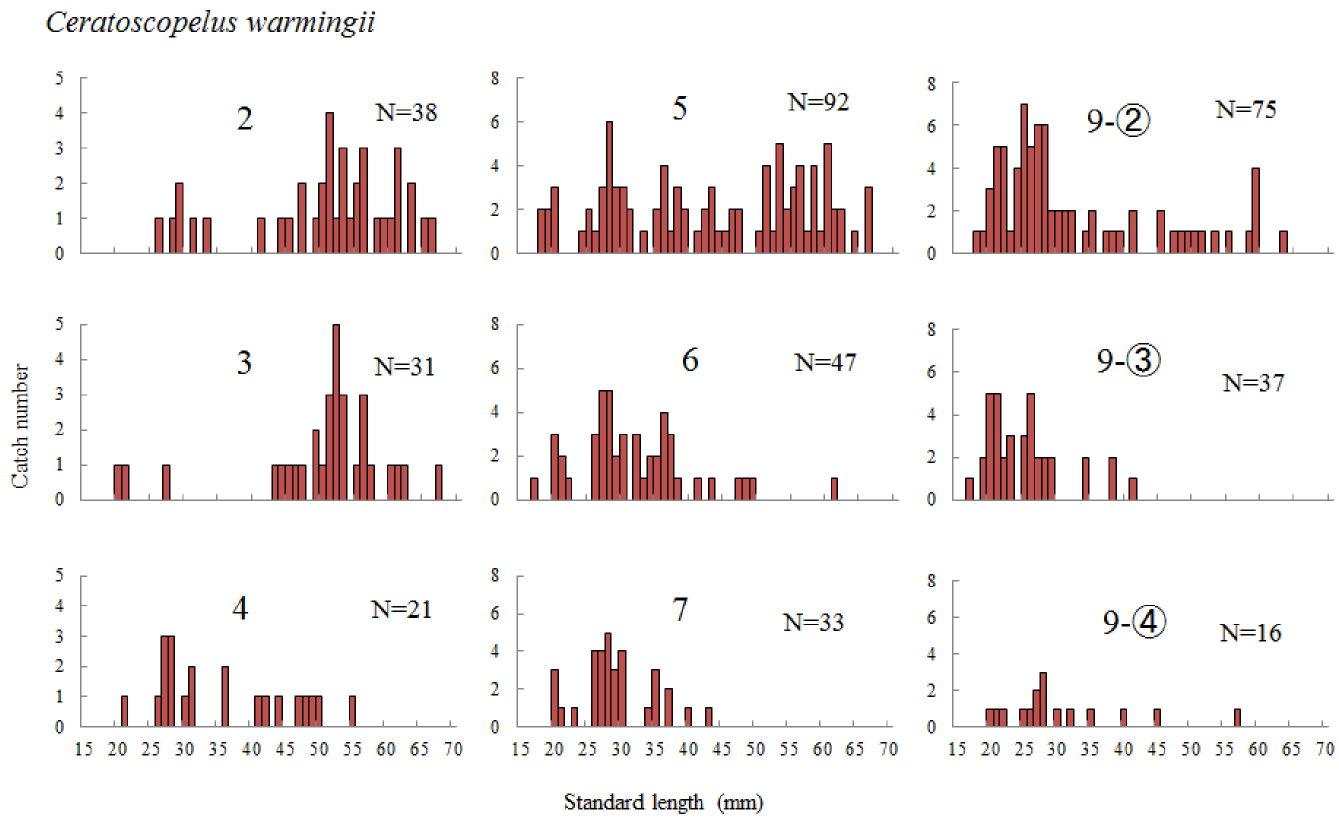

Fig. 3.13 Length distributions for *Ceratoscopelus warmingii* of MOC-MOHT trails

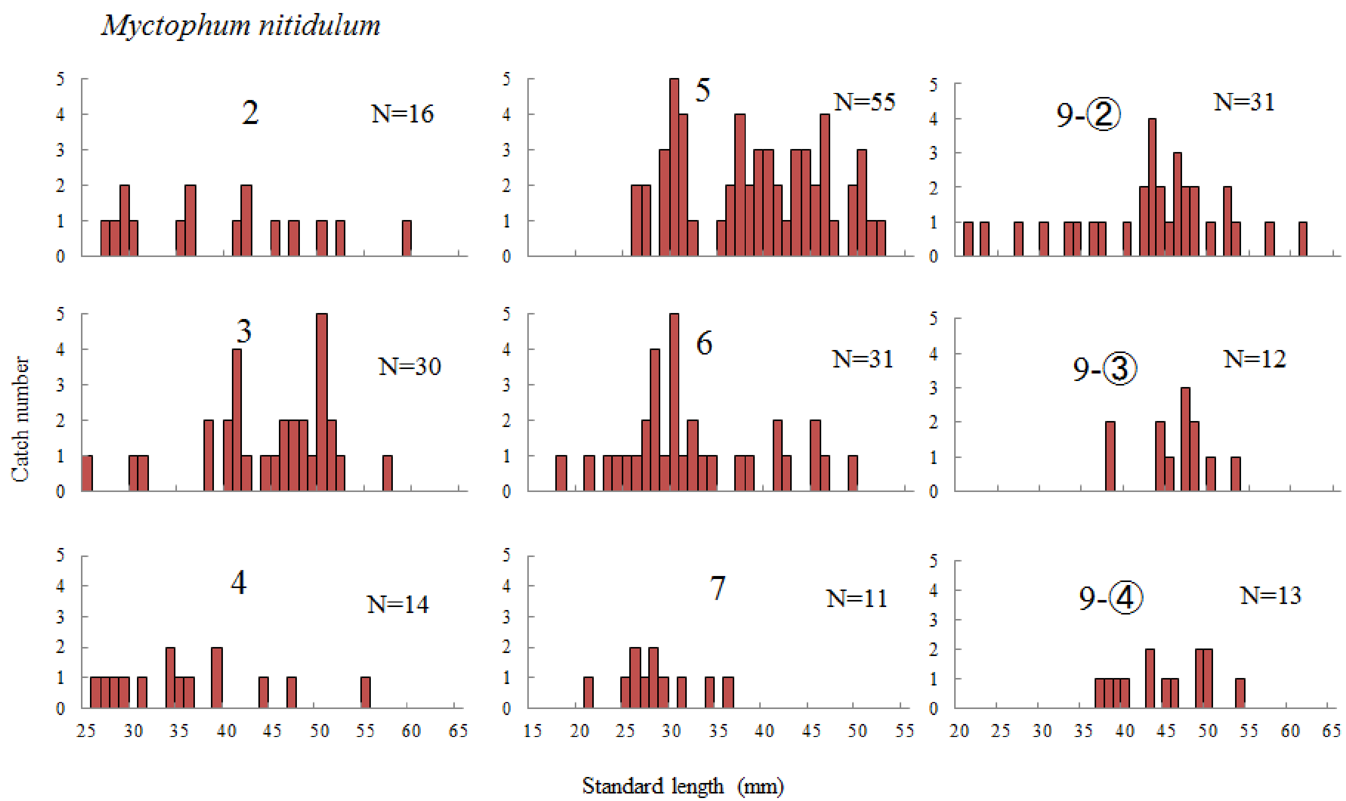

Fig. 3.14 Length distributions for *Myctophum asperum* of MOC-MOHT trails

Lampanyctus spp

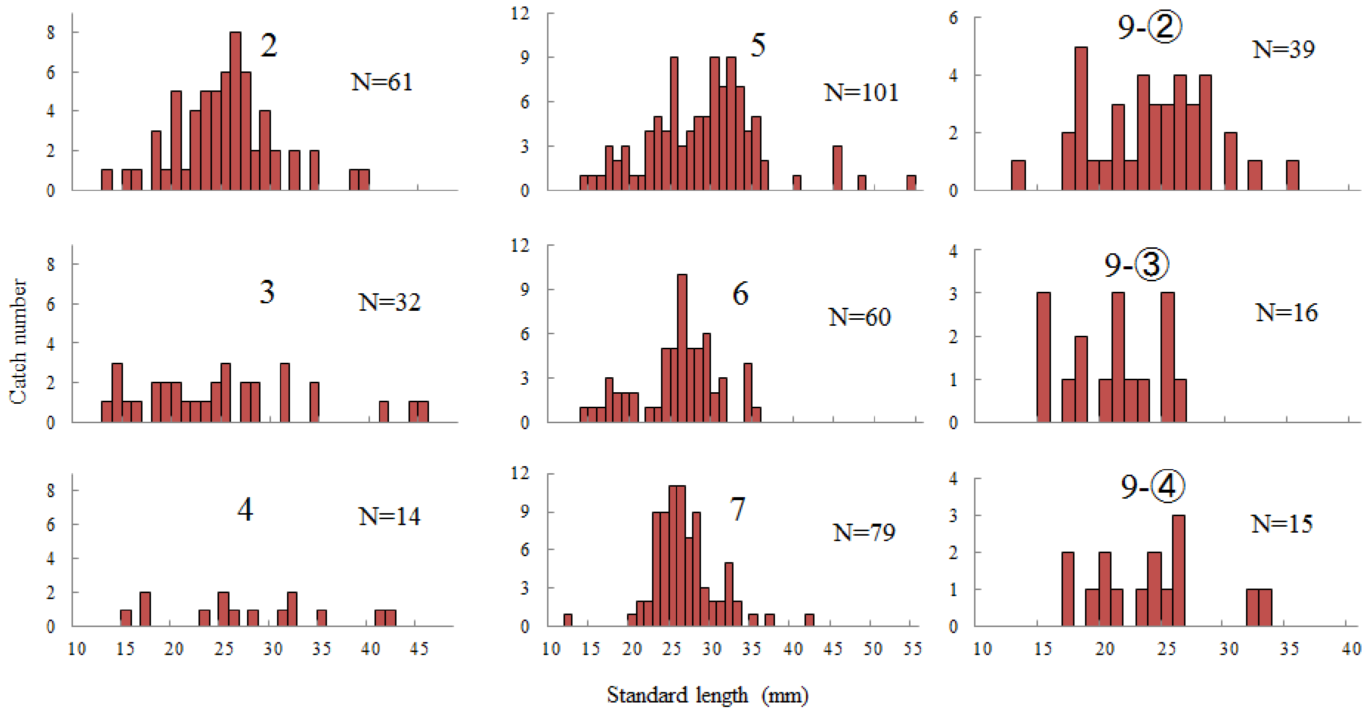

Fig. 3.15 Length distributions for *Lampanyctus* spp of MOC-MOHT trails

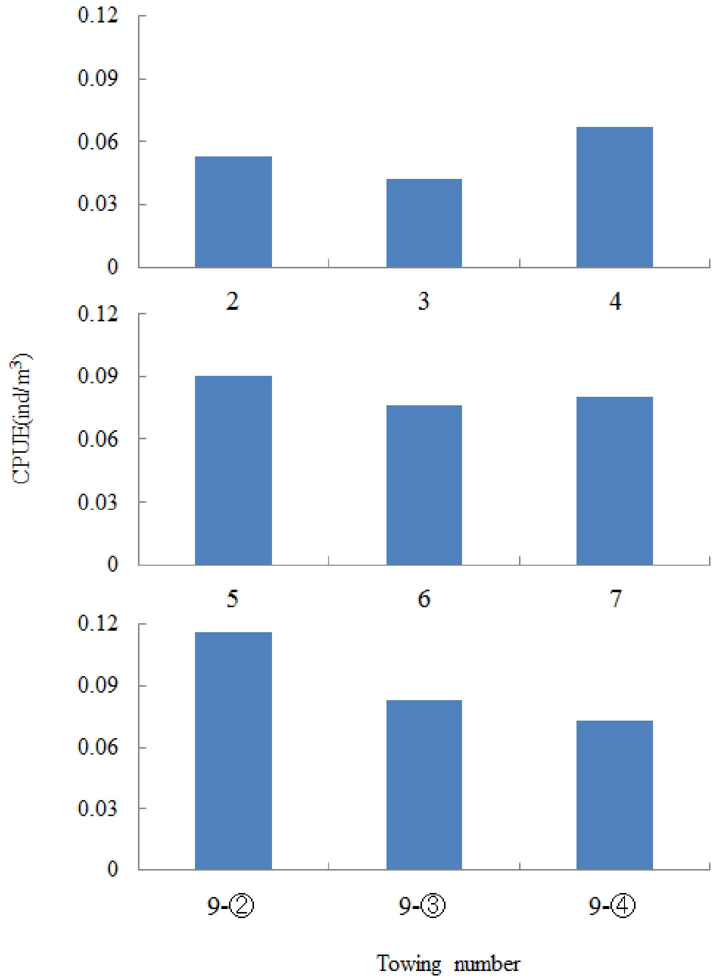

Fig. 3.16 Catch number in unit filter water in horizontal tows

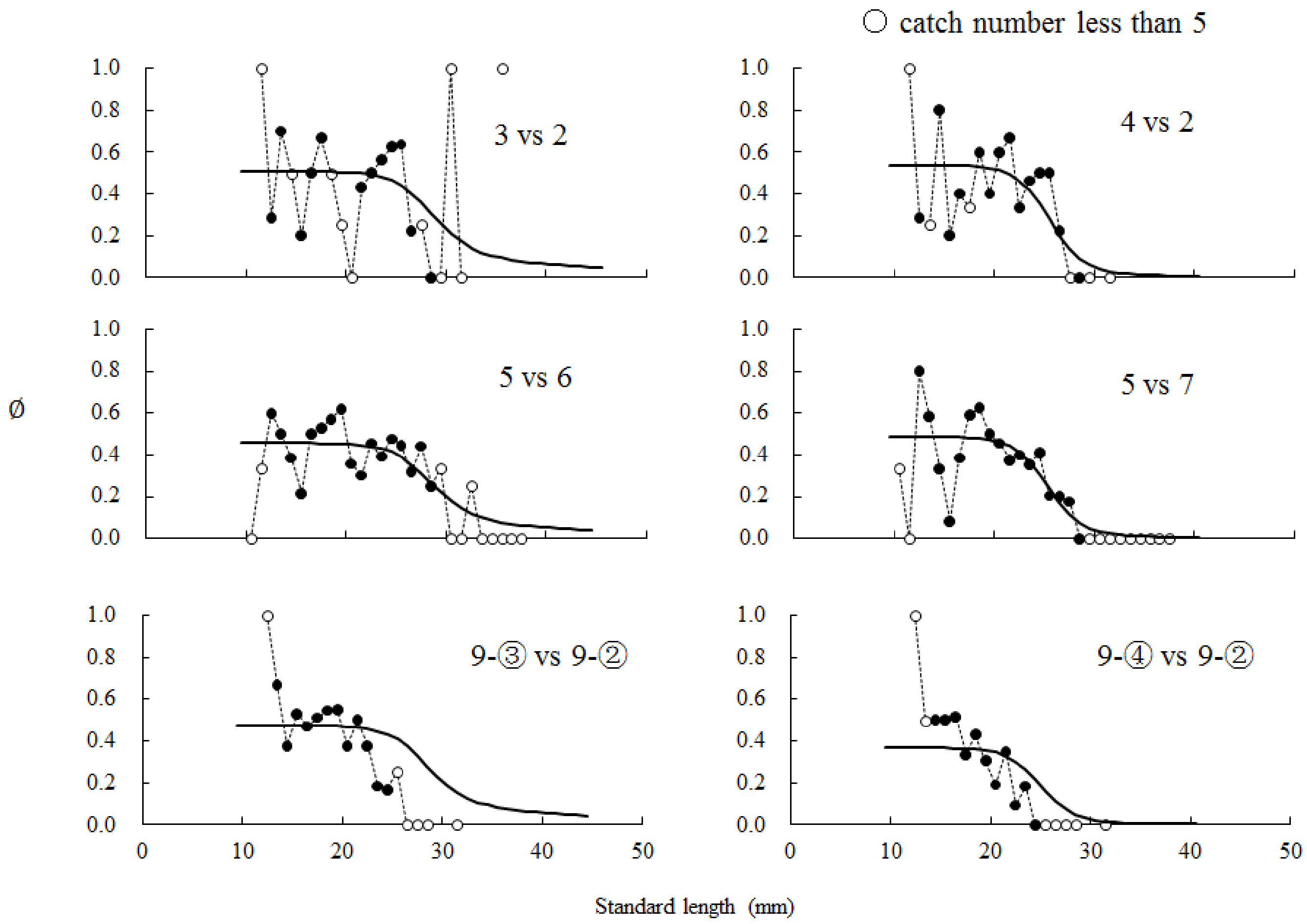

Fig. 3.17 Proportion of catch in slow speed haul for *Diaphus Kuroshio*

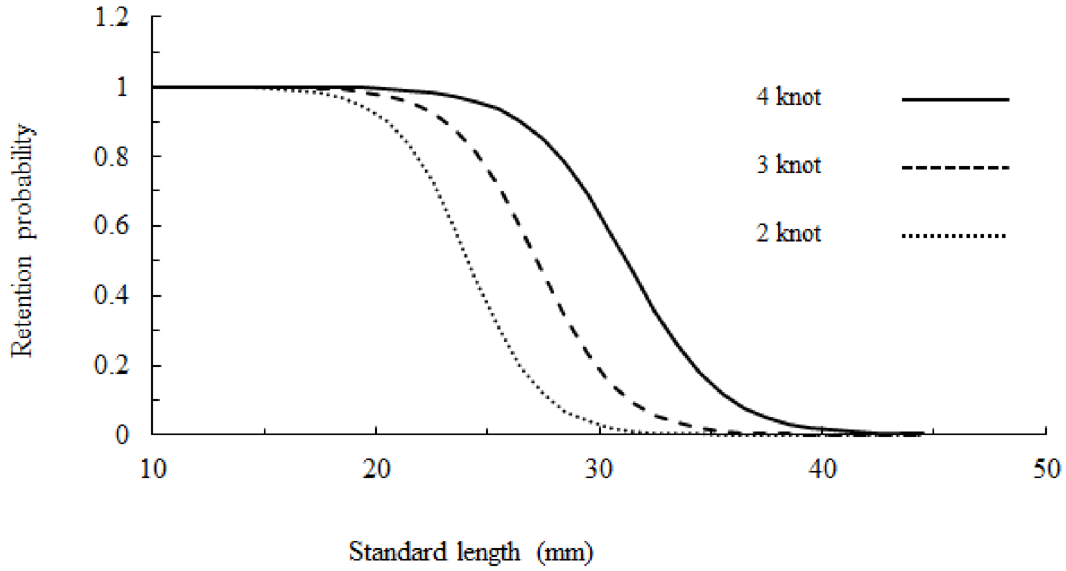

Fig. 3.18 Selection curves of net avoidance for *Diaphus Kuroshio*

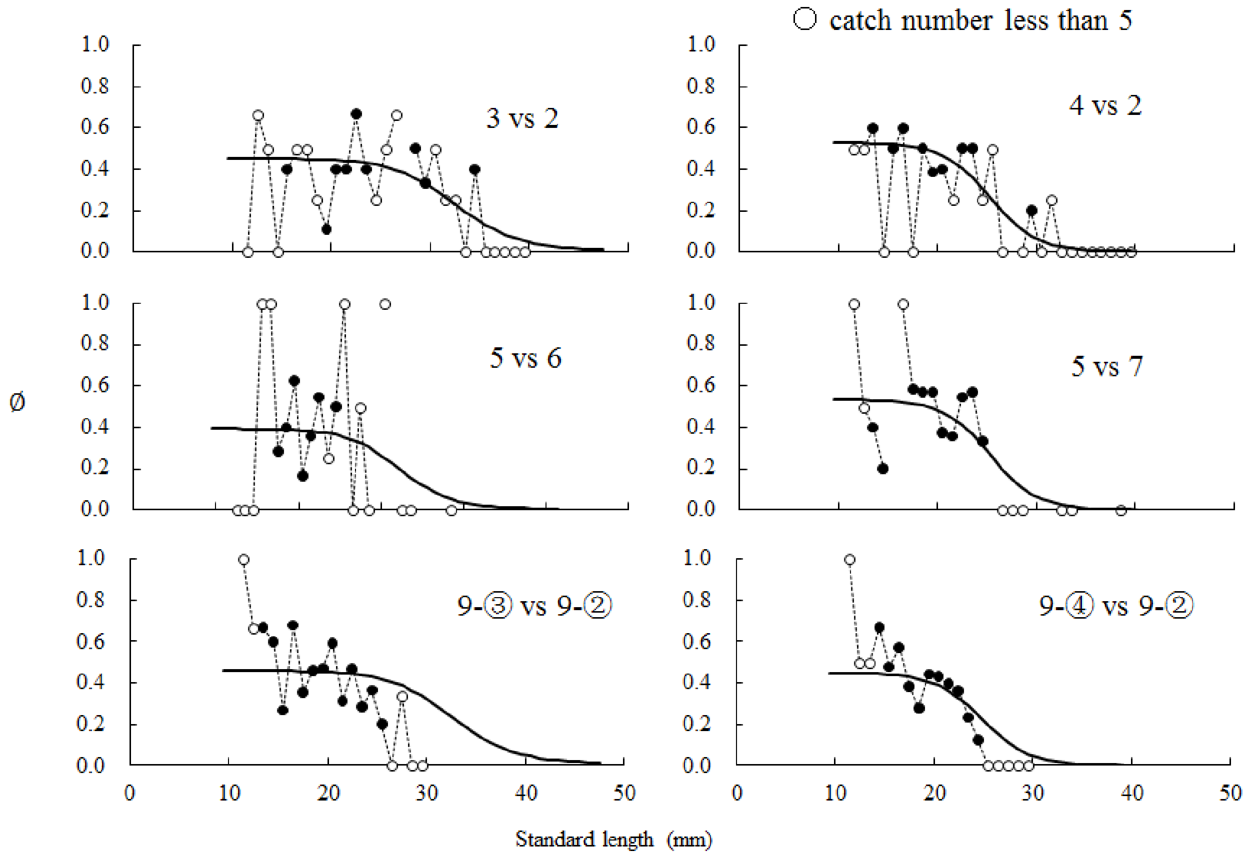

Fig. 3.19 Proportion of catch in slow speed haul for *Diaphus* spp

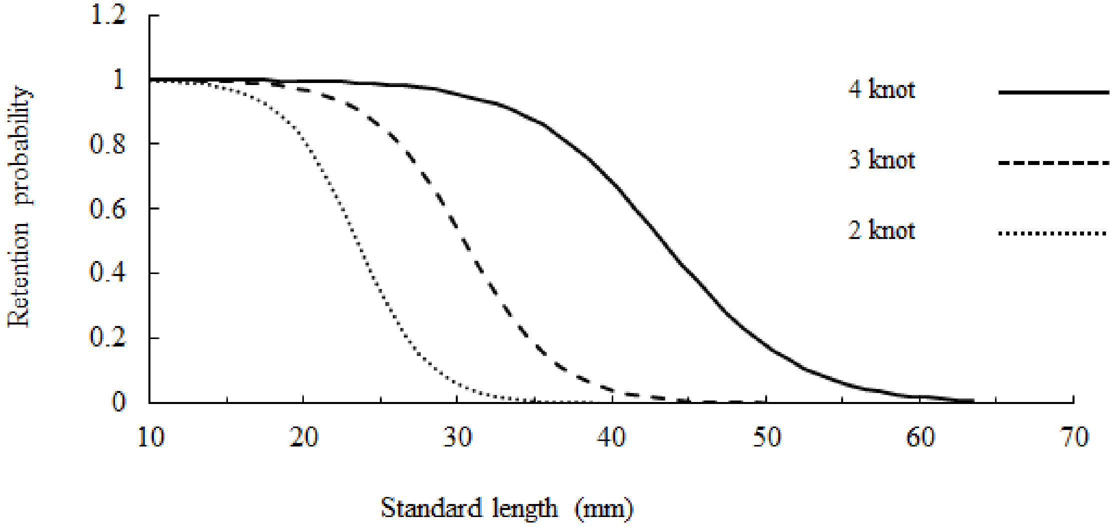

Fig. 3.20 Selection curves of net avoidance for *Diaphus* spp

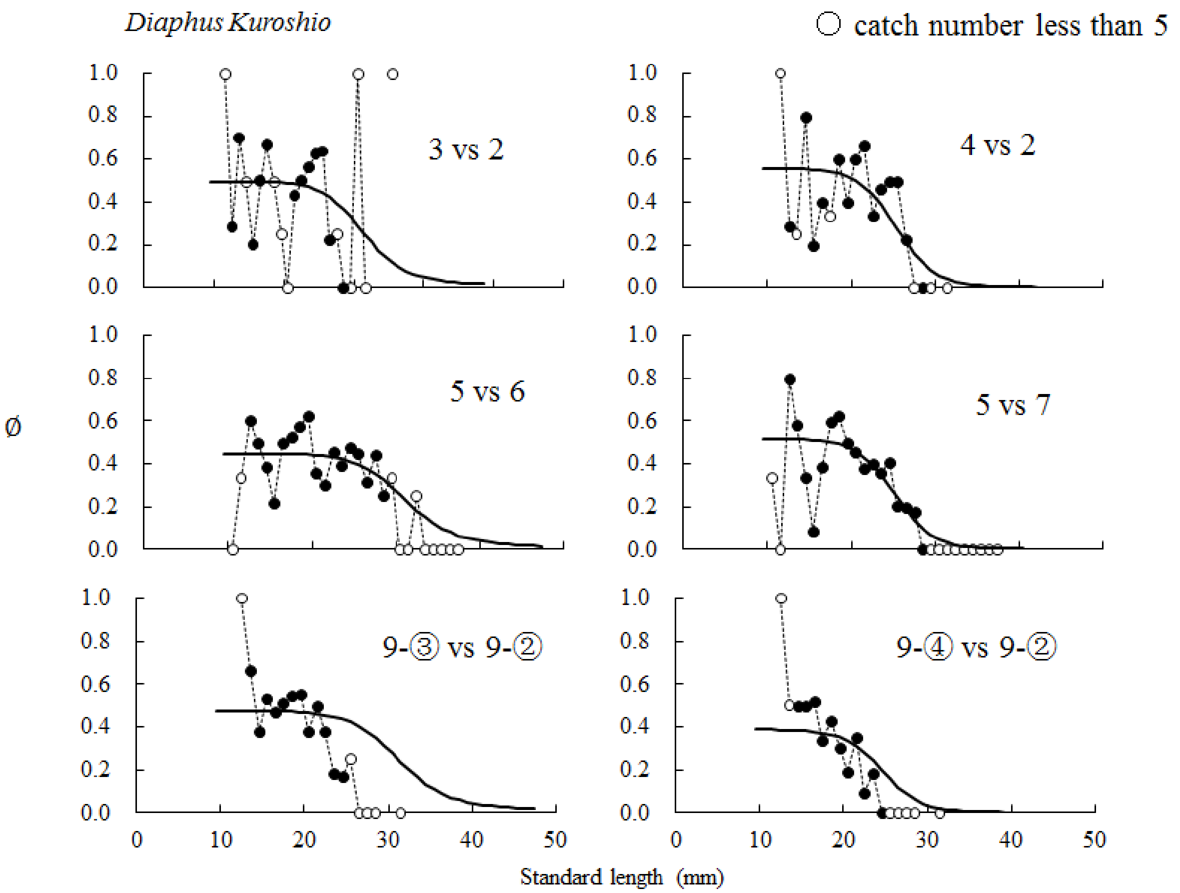

Fig. 3.21 Proportion of catch in slow speed haul for *Diaphus Kuroshio* and *Diaphus* spp

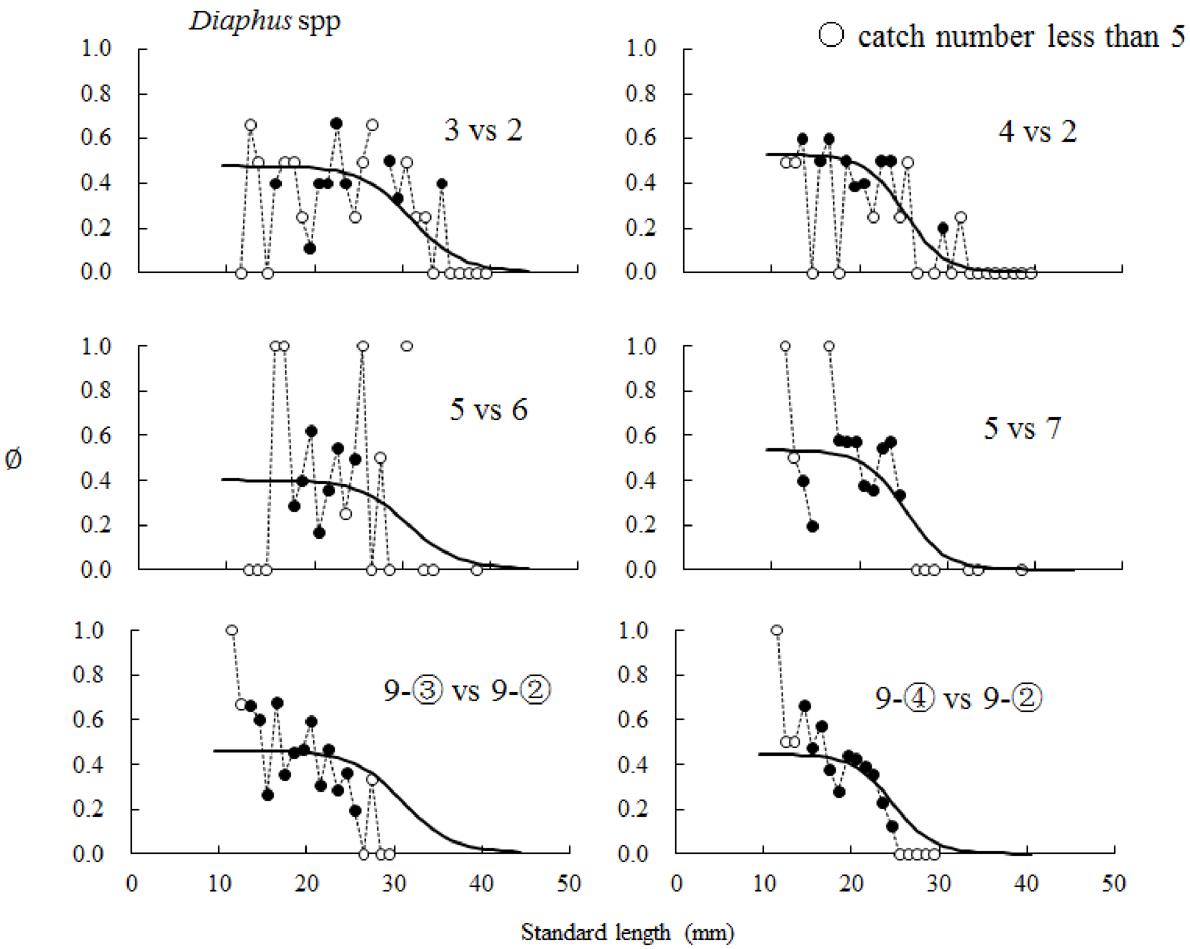

Fig. 3.22 Proportion of catch in slow speed haul for *Diaphus Kuroshio* and *Diaphus* spp (continued)

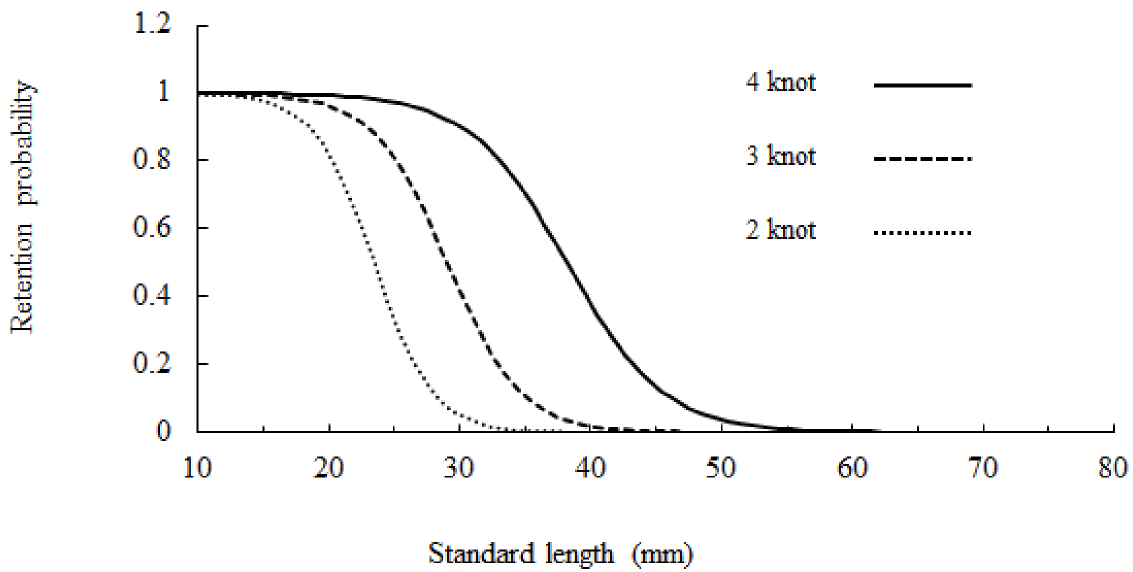

Fig. 3.23 Selection curves of net avoidance for *Diaphus* spp

Table 3.1 Towing condition of MOC-MOHT in horizontal tows

Towing no.	Date	Start time	finish time	Start location		Filtered volume	net depth (m)	Towing speed (knot)
				Latitude,N	Longitude,E			
2	2015/7/19	19:47	20:13	35°02.33	139°16.96	5628	50	4
3		20:22	20:45	35°02.55	139°18.93	5160	50	3
4		20:54	21:15	35°02.85	139°20.69	2305	50	2
5		21:23	21:48	35°03.16	139°22.13	7843	40	4
6		21:56	22:17	35°03.70	139°24.60	5831	40	3
7		22:25	22:47	35°04.28	139°26.55	4898	40	2
8-②	2015/7/20	19:10	19:20	34°58.38	139°18.24	5566	50	4
8-③		19:20	19:30	34°58.98	139°18.71	5588	50	3
8-④		19:30	19:40	34°59.54	139°19.07	4388	50	2
9-②		20:24	20:34	34°59.21	139°18.86	5255	40	4
9-③		20:34	20:44	34°59.76	139°19.20	5215	40	3
9-④		20:44	20:54	35°00.15	139°19.43	4206	40	2

Table 3.2 Taxonomic composition of catch number and weight in each codend in horizontal tows

Towing no.		Myctophidae		Cephalopoda		Sergestidae		Euphausiidae		others		Total	
2	catch number	296	(0.007)	66	(0.002)	162	(0.004)	32590	(0.757)	9923	(0.231)	43037	(1.000)
	weight[mg]	131,520	(0.085)	4900	(0.003)	29200	(0.019)	1162300	(0.753)	215700	(0.140)	1543620	(1.000)
3	catch number	217	(0.006)	48	(0.001)	148	(0.004)	29760	(0.790)	7508	(0.199)	37681	(1.000)
	weight[mg]	114770	(0.091)	1100	(0.001)	25200	(0.020)	1016000	(0.802)	110320	(0.087)	1267390	(1.000)
4	catch number	154	(0.018)	38	(0.004)	126	(0.014)	6415	(0.732)	2032	(0.232)	8765	(1.000)
	weight[mg]	37870	(0.119)	1570	(0.005)	16260	(0.051)	216110	(0.678)	46800	(0.147)	318610	(1.000)
5	catch number	709	(0.016)	92	(0.002)	392	(0.009)	35290	(0.790)	8204	(0.184)	44687	(1.000)
	weight[mg]	256210	(0.142)	7440	(0.004)	44240	(0.025)	1289120	(0.716)	202600	(0.113)	1799610	(1.000)
6	catch number	442	(0.033)	43	(0.003)	377	(0.028)	6402	(0.483)	6004	(0.453)	13268	(1.000)
	weight[mg]	99900	(0.197)	2740	(0.005)	41300	(0.081)	215690	(0.425)	148470	(0.292)	508100	(1.000)
7	catch number	401	(0.033)	19	(0.002)	293	(0.024)	5399	(0.447)	5954	(0.493)	12066	(1.000)
	weight[mg]	59140	(0.134)	10010	(0.023)	43410	(0.098)	182370	(0.412)	147770	(0.334)	442700	(1.000)
9-②	catch number	610	(0.158)	32	(0.008)	140	(0.036)	2920	(0.756)	161	(0.042)	3863	(1.000)
	weight[mg]	120850	(0.467)	3130	(0.012)	8520	(0.033)	117530	(0.454)	8940	(0.035)	258970	(1.000)
9-③	catch number	442	(0.107)	24	(0.006)	168	(0.041)	3115	(0.756)	369	(0.090)	4118	(1.000)
	weight[mg]	65510	(0.293)	1890	(0.008)	12140	(0.054)	123760	(0.553)	20600	(0.092)	223900	(1.000)
9-④	catch number	308	(0.063)	38	(0.008)	181	(0.037)	4183	(0.856)	174	(0.036)	4884	(1.000)
	weight[mg]	51170	(0.200)	2060	(0.008)	17260	(0.068)	178000	(0.696)	7100	(0.028)	255590	(1.000)

Values in parentheses are percentage

Table 3.3 Length frequency distribution for *Diaphus Kuroshio*

Standard length (mm)	Towing number								
	2	3	4	5	6	7	9-②	9-③	9-④
10				2		1			
11				2	1				
12		1	2	2	3	8			
13	5	2	2	5	5	7		2	2
14	3	7	1	8	5	4	2	4	2
15	1	1	4	11	3	1	5	3	5
16	4	1	1	8	8	5	8	9	8
17	3	3	2	9	10	13	17	15	18
18	2	4	1	6	8	10	22	23	11
19	2	2	3	8	13	8	20	24	15
20	3	1	2	18	10	15	23	28	10
21	2		3	30	13	18	30	18	7
22	4	3	8	36	30	24	15	15	8
23	6	6	3	42	27	23	10	6	1
24	7	9	6	32	29	22	9	2	2
25	3	5	3	35	28	9	5	1	
26	4	7	4	29	13	7	3	1	
27	7	2	2	15	11	3	2		
28	3	1		10	3		2		
29	6			2	1		1		
30	1			3					
31		1		3					
32	1			3	1		1		
33				1					
34				2					
35				1					
36		1		2					
37				1					
38									
39									
40									
Total	67	57	47	326	222	178	175	151	89

Table 3.4 Length frequency distribution for *Diaphus* spp

Standard length (mm)	Towing number								
	2	3	4	5	6	7	9-②	9-③	9-④
10									
11									
12	1		1			1		1	2
13	1	2	1	2		2	1	2	1
14	2	2	3	3		2	2	4	2
15	1			4		1	2	3	4
16	3	2	3		3		11	4	10
17	2	2	3		1	1	9	19	12
18	1	1		5	2	7	31	17	19
19	3	1	3	3	2	4	31	26	12
20	8	1	5	3	5	4	33	29	26
21	3	2	2	10	2	6	20	29	15
22	3	2	1	9	5	5	20	9	13
23	3	6	3	5	6	6	16	14	9
24	3	2	3	3	1	4	10	4	3
25	3	1	1	4	4	2	7	4	1
26	2	2	2		1		4	1	
27	1	2		1			3		
28				1	1		2	1	
29	3	3		2			3		
30	4	2	1				1		
31	2	2			1				
32	3	1	1						
33	3	1		1					
34	1			1					
35	3	2							
36	2								
37	2								
38	3								
39	2			1					
40	1								
Total	69	39	33	58	34	45	206	167	129

Table 3.5 Length frequency distribution for *Ceratoscopelus warmingii*

Standard length (mm)	Towing number								
	2	3	4	5	6	7	9-②	9-③	9-④
16									
17					1			1	
18				2			1		
19				2			1	2	
20		1		3	3	3	3	5	
21		1	1		2	1	5	5	
22					1		5	2	
23						1	1	3	
24				1			4		
25				2			7	3	1
26	1		1	1	3	4	5	5	1
27		1	3	3	4	4	6	2	1
28	1		3	6	4	5	6	2	
29	2			3	2	3	2	2	
30			1	3	3	4	2		1
31	1		2	2			2		1
32					3		2		2
33	1			1	1				3
34					2	1	1	2	
35				2	2	3	2		1
36			2	4	4				
37				1	3	2	1		1
38				3	1		1	2	
39				2			1		
40						1			1
41	1		1	1	1		2	1	
42			1	2					
43		1		3	1	1			
44	1	1	1	1					
45	1	1		1			2		1
46		1		2					
47	2	1	1	2	1		1		

48			1		1		1		
49	1	2	1		1		1		
50	2	1	1	1			1		1
51	4	3		4			1		
52	1	5		1					
53	3	3		5			1	1	
54	1			2					
55	2	1	1	3			1	2	
56	3	3		4				1	
57		1		1					
58	1			4			1		1
59	1			1			4		
60	1	1		5					1
61	3	1		2	1				
62		1		2					1
63	2						1		
64				1					
65	1						2		
66	1			3			1		
67		1							
Total	38	31	21	92	45	33	78	41	18

Table 3.6 Length frequency distribution for *Lampanyctus* spp

Standard length (mm)	Towing number								
	2	3	4	5	6	7	9-②	9-③	9-④
10									
11									
12						1			
13	1	1					1		
14		3		1	1				
15	1	1	1	1	1			3	
16	1	1		1	1				
17			2	3	3		2	1	2
18	3	2		2	2		5	2	
19	1	2		3	2		1		1
20	5	2		1	2	1	1	1	2
21	1	1		1		2	3	3	1
22	4	1		4	1	2	1	1	
23	5	1	1	5	1	9	4	1	1
24	5	2		4	5	8	3		2
25	6	3	2	9	5	10	3	3	1
26	8		1	3	10	11	4	1	3
27	6	2		4	5	7	3		
28	2	2	1	5	5	9	4		
29	4			5	6	3			
30	2			9	2	2	2		
31		3	1	7	3	2			
32	2		2	9		5	1		1
33				7		2			1
34	2	2		4	4				
35			1	5	1	1	1		
36				2					
37						1			
38	1								
39	1								
40				1					
41		1	1						
42			1			1			
43									
44		1							
45		1		3					
46									
47									2
48				1					
49									
50									
51									
52									
53									
54				1					
55									
Total	61	32	14	101	60	77	39	16	17

Table 3.7 Length frequency distribution for *Myctophum asperum*

Standard length (mm)	Towing number								
	2	3	4	5	6	7	9-②	9-③	9-④
18					1				
19									
20									
21					1	1	1		
22									
23					1		1		
24					1				
25		1			1	1			
26			1		1	2			
27	1		1		2	1	1		
28	1		1		4	2			
29	2		1		1	1			
30	1	1			5		1		
31		1	1		1	1			
32					2				
33					1		1		
34			2		1	1	1		
35	1		1						
36	2		1	2		1	1		
37				2	1		1		1
38		2			1			2	1
39			2	3					1
40		2		5			1		1
41	1	4		4	2				
42	2	1		1	1		2		
43							4		2
44		1	1				2	2	
45	1	1		1	2		1	1	1
46		2		2	1		3		1
47	1	2	1	4			2	3	
48		2		2			2	2	
49		1		3	1				2
50	1	5		3			1	1	2
51		2		2					
52	1	1		1			2		
53				3			1	1	
54				3					1
55			1	2					
56				4					
57		1		1			1		
58									
59	1			2					
60				3					
61				1			1		
62				1					
63									
Total	16	30	14	55	32	11	31	12	13

Table 3.8 Parameters for expressing size selectivity and the values of AIC for *Diaphus Kuroshio*

Model	*a*	*b*	*c*	*d*	*p1*	*p2*	*p3*	*p4*	*p5*	*p6*	MLL	AIC
Model A	0.32	14.07	0.06	-0.72	0.45	0.49	0.50	0.54	0.47	0.37	-203.65	427.31
Model B	0.00	14.56	0.07	-0.74	0.46	0.49	0.51	0.54	0.47	0.37	-203.66	425.31[a]
Model C	2.05	11.23	0.00	-0.63	0.45	0.48	0.50	0.53	0.47	0.36	-203.70	425.40
Model D	3.74	26.09	-0.06	-1.16	0.38	0.36	0.48	0.29	0.50	0.44	-225.91	459.83
Model E	0.00	33.89	0.06	-1.41	0.38	0.36	0.48	0.29	0.50	0.44	-226.18	458.36
Model F	1.89	29.79	0.00	-1.28	0.38	0.36	0.48	0.29	0.50	0.44	-225.98	457.96

MLL, Maximum log-likelihood. AIC, Akaike's information criterion

[a] Model with the smallest AIC value

Table 3.9 Selection parameters in the optimal Model B for *Diaphus Kuroshio*

Towing speed	α	β	l_{50}	S.R.
4kt	14.56	-0.47	31.22	-4.71
3kt	14.56	-0.53	27.24	-4.11
2kt	14.56	-0.60	24.16	-3.65

Table 3.10 Parameters for expressing size selectivity and the values of AIC for *Diaphus* spp

Model	*a*	*b*	*c*	*d*	*p1*	*p2*	*p3*	*p4*	*p5*	*p6*	MLL	AIC
Model A	-0.02	10.03	0.10	-0.62	0.45	0.53	0.39	0.53	0.46	0.45	-161.01	342.03
Model B	0.00	10.00	0.10	-0.62	0.39	0.53	0.45	0.53	0.46	0.45	-161.01	340.03[a]
Model C	3.40	3.04	0.00	-0.42	0.38	0.54	0.44	0.53	0.45	0.45	-161.09	340.17
Model D	-3.22	15.45	0.16	-0.70	0.38	0.36	0.48	0.29	0.50	0.44	-172.68	353.37
Model E	0.00	12.33	0.07	-0.62	0.38	0.36	0.48	0.29	0.50	0.44	-173.69	353.37
Model F	2.48	7.80	0.00	-0.50	0.38	0.36	0.48	0.29	0.50	0.44	-174.16	354.33

MLL, Maximum log-likelihood. AIC, Akaike's information criterion

[a] Model with the smallest AIC value

Table 3.11 Selection parameters in the optimal Model B for *Diaphus* spp

Towing speed	α	β	l_{50}	S.R.
4kt	10.00	-0.23	43.38	-9.53
3kt	10.00	-0.33	30.46	-6.69
2kt	10.00	-0.43	23.46	-5.16

Table 3.12 Parameters for expressing size selectivity and the values of AIC for *Diaphus Kuroshio* and *Diaphus* spp

Model	*a*	*b*	*c*	*d*	*p1*	*p2*	*p3*	*p4*	*p5*	*p6*	*p1*	*p2*	*p3*	*p4*	*p5*	*p6*	MLL	AIC
Model A	-5.64	23.96	0.27	-1.07	0.45	0.46	0.49	0.51	0.46	0.34	0.49	0.51	0.42	0.51	0.48	0.43	-365.27	762.54[b]
Model B	0.00	10.43	0.09	-0.62	0.45	0.52	0.50	0.56	0.47	0.39	0.48	0.53	0.40	0.53	0.46	0.44	-365.97	761.94[a]
Model C	2.53	4.78	0.00	-0.42	0.44	0.52	0.49	0.56	0.47	0.39	0.47	0.53	0.39	0.54	0.46	0.45	-366.61	763.22
Model D	-8.66	34.89	0.38	-1.44	0.38	0.36	0.48	0.29	0.50	0.44	0.48	0.29	0.38	0.36	0.50	0.44	-399.11	806.22[b]
Model E	0.00	15.90	0.09	-0.78	0.38	0.36	0.48	0.29	0.50	0.44	0.48	0.29	0.38	0.36	0.50	0.44	-403.83	813.66
Model F	2.53	10.30	0.00	-0.59	0.38	0.36	0.48	0.29	0.50	0.44	0.48	0.29	0.38	0.36	0.50	0.44	-404.41	814.81

MLL, Maximum log-likelihood. AIC, Akaike's information criterion

[a] Model with the smallest AIC value

Table 3.13 Selection parameters in the optimal Model B for *Diaphus Kuroshio* and *Diaphus* spp

Towing speed	α	β	l_{50}	S.R.
4kt	10.43	-0.27	38.19	-8.05
3kt	10.43	-0.36	29.06	-6.12
2kt	10.43	-0.44	23.46	-4.94

Chapter 4. The collection characteristics of COC-MOHT

4.1 Introduction

As a kind of multiple layer sampling gears, COC-MOHT net consists of five codends could be towed under various operating conditions. For instance, COC-MOHT could be used not only in various towing depth, but also at various towing speed in one cast trial. In this chapter, in order to verify the diel vertical migration phenomenon of lantern fish, as well as to clarify whether the fish size varies in different water depth, COC-MOHT was applied under oblique tows with different towing depths. Moreover, COC-MOHT was carried out under horizontal tows to evaluate the effect of towing speed on net avoidance.

4.2 Materials and methods

4.2.1 Sampling gear

COC-MOHT net (Fig. 4.1) has a rigid frame of 2.3 m high and 2.3 m wide, the same as the MOHT (Oozeki et al., 2004), maintaining a vertical attitude under towing speed of 1.0-2.25 ms^{-1}. A cambered V-shape depressor with an aspect ratio 6.0 and a camber ratio of 15% hang below the frame, of which wingspread is 2.44 m and wing area is 0.99 m^2. An electrical flowmeter is placed at the center of the upper frame, and four spherical floats are attached at the top of the frame. The COC-MOHT is composed of the front net and back net, between them was the automatic opening/closing system.

The multiple codend opening/closing system has the same opening/closing mechanism as COC-MOHT, 1.28 m high and 0.75 m wide. Nets are constructed of the same knotless ultra-high strength polyethylene (Toyobo, Japan; Dyneema SK60) square mesh of 1.95 mm bar length and 0.36 mm twine diameter. A net release mechanism is located at the center of the upper frame and a net-response sensor is located inside the bottom of the left side of frame. The underwater control unit equipped with depth and temperature sensor is used to retrieve flowmeter count signals and net closing signals.

Five codend nets attached to the codend frame had the same mesh as the main net with a rectangular mouth of 0.62m×0.8m. Three spherical floats were attached to the top of the codend frame. The mass of the multiple codend opening/closing system was 80 kg and the total mass of the main frame with the depressor was approximately 360kg in air.

Command settings and the control software of the COC-MOHT was also the same as the MOC-MOHT. Commands of net opening/closing were sorted in the control unit via a Data read/write unit on deck. Also, data including depth, temperature, flowmeter counts, net releasing and closing time were stored in the control unit.

4.2.2 Open sea trial

Sea trials were conducted on 15-16 October 2014, using COC-MOHT carried out by research vessel Umitaka-maru (Tokyo University of Marine Science and

Technology) in Sagami Bay, Pacific. COC-MOHT has a 5 m^2 mouth opening and five codend nets with a mesh size of 1.59 mm. Three times oblique tows and once horizontal tow were carried out, except one haul in the daytime. In twice oblique tows, the towing speed was 3 knot, and codend nets were opened or closed at water depth of 200 m, 150 m, 100 m, and 50 m. In an oblique tow in daytime, the towing speed was 3 knot, and codend nets were opened or closed at water depth of 450 m, 350 m, 250 m, and 150 m. In horizontal tow at 100 m, the towing speeds of the second, third, fourth nets were changed into 4, 3, and 2 knot, respectively. Besides, the same method used in horizontal tow as the MOC-MOHT experiment, scientific echo sounder (38kHz) was used to estimate acoustic abundance of myctophid fishes.

Specimens collected in each codend nets were preserved in 10% formalin and preserved in specimen bottle for further analysis in laboratory. In all collected samples, 13 bottles of samples were carried out to species identification experiment. The samples of oblique tows used for the identification analysis were as follows: 1-②, 1-③, 1-④, 2-②, 2-③, 2-④, 2-⑤, 3-③, 3-④, 3-⑤. The samples of horizontal tow were as follows: 4-②, 4-③, 4-④. Specimens collected were classified as follows: *Myctophidae*, *Cephalopoda*, *Euphausiidae*, *Sergestidae*, other fish. Furthermore, lantern fish species were classified as follows: *Diaphus Kuroshio, Diaphus spp, Ceratoscopelus warmingii, Myctophum asperum, Lampanyctus sp, Myctophidae spp.* The whole lantern fish were picked out for body length measurement and grouped into standard length in millimeter.

4.2.3 Data Analysis

The same experiment as MOC-MOHT, COC-MOHT was used to capture myctophid fishes at speeds of 2, 3 and 4 knots under horizontal tow. In this study, we considered 4 knot as a control towing speed when analyzing the towing speeds of 2 and 3 knot. Moreover, we also predict the net avoidance was caused at high speed of 4 knot.

SELECT method was applied for continuous hauls, and parameters of net avoidance under various towing speeds were calculated. The net avoidance of MOC-MOHT was expressed with monotonically decreased logistic function *a* (*l*) with logistic parameters α and β.

$$a(l) = \frac{\exp(\alpha + \beta l)}{1 + \exp(\alpha + \beta l)} \tag{1}$$

Also, from the logistic parameter estimates of α and β, the length of 50% retention l_{50} and the selection range S.R. can be calculated with the following two equations.

$$l_{50} = -\alpha / \beta \tag{2}$$

$$\text{S.R.} = 2\log_e(3)/\beta \tag{3}$$

Here, we used linear equations of towing speed *V* to express logistic parameters α and β. Of which, *a, b, c, d* are parameters.

$$\alpha = a\,V + b \tag{4}$$

$$\beta = c\,V + d \tag{5}$$

Accordingly, logistic function of net avoidance at 2, 3 and 4 knot can be calculated. They were expressed with logistic function $a_4\,(l)$, $a_3\,(l)$ and $a_2\,(l)$. Meanwhile, catch numbers of l-length fish at towing speeds of 4, 3 and 2 knots are C_4, C_3 and C_2, respectively. Two hauls of different towing speed, C_4 and C_3, C_4 and C_2, the proportion of catch at relatively low speed to the total catch was defined as follows:

$$\phi_{3vs4} = \frac{C_3}{C_3 + C_4} \tag{6}$$

$$\phi_{2vs4} = \frac{C_2}{C_2 + C_4} \tag{7}$$

Split parameter p_3 and p_2 were expressed by the following formula. The proportion of catch $\phi_{(l)}$ expressed by logistic function $a_4\,(l)$, $a_3\,(l)$ and $a_2\,(l)$ were converted into formulas as follows.

$$\phi_{3vs4}(l) = \frac{p_3 \cdot a_3(l)}{(1 - p_3)a_4(l) + p_3 \cdot a_3(l)} \tag{8}$$

$$\phi_{2vs4}(l) = \frac{p_2 \cdot a_2(l)}{(1 - p_2)a_4(l) + p_2 \cdot a_2(l)} \tag{9}$$

In the formula, a, b, c, d, p_2, p_3 are parameters estimated.

According to whether towing speed influences the logistic parameters α and β, as well as estimated parameter or fixed parameter determined by the filter water, we built six models to examine variation in net avoidance.

Model	*p*-estimated Model			*p*-fixed Model		
	Model A1	Model A2	Model A3	Model B1	Model B2	Model B3
a	≠0	=0	≠0	≠0	=0	≠0
c	≠0	≠0	=0	≠0	≠0	=0
parameters	*a, b, c, d, p2, p3*	*b, c, d, p2, p3*	*a, b, d, p2, p3*	*a, b, c, d,*	*b, c, d*	*a, b, d*

Solver in Excel was implemented to maximize the functions. The AIC (Akaike's Information Criterion) model selection was performed for optimal model among 6 models. π means number of parameters, and MLL means maximum log-likelihood.

$$AIC= -2\times MLL+2\pi \quad (10)$$

Within a reasonable range, the smallest AIC model was chosen as the optimal model.

4.3 Results

4.3.1Towing conditions (Start time, maximum net depth, towing speed)

On 15-16 October 2014, the towing condition in Sagami Bay is shown in Table 4.1. The latitude and longitude of all trawling were obtained by GPS tracking, track of vessel was shown in Fig. 4.2. On 15, one towing experiments under oblique tow was conducted at night. Towing durations was 71 minutes, and filtered volume was 37742 m^3. On 16, one towing experiments under oblique tow was conducted in daytime. Towing durations was 84 minutes, and filtered volume was 41881 m3. Two towing experiments were conducted at night, one time oblique tow and one time horizontal tow. Towing durations were 43, 58 minutes, and filtered volumes were 18081, 28996 m3. In the process of horizontal tow, the length of warp was adjusted in order to maintain the fishing gear in a certain depth.

4.3.2 Towing performance

4.3.2.1 Towing depth in experiment

In haul 1 under oblique tow, the first bar was released at a depth of 200 m and the following two bars were released at depths of 150, 100 m, the fourth bar was failed to release at the depth of 50m. Therefore, the towing duration of 1-②, 1-③ and 1-④ were 10, 10, 20 minutes. In haul 2 under oblique tow, the first bar was released at a depth of 450 m and the following two bars were released at depths of 350, 250 and 150m. The towing duration of 2-②, 2-③, 2-④, 2-⑤ were 13, 10, 10 and 14 minutes, respectively. In haul 3 under oblique tow, the first bar was failed to release at the depth of 200m, the following three were released at depths of 150, 100, 50m. The towing duration of 3-③, 3-④, 3-⑤ were 4, 4 and 7 minutes, respectively. In haul 4 under horizontal tow, the target depth is 40 m and towing speed were 4, 3 and 2knot in the order. The towing duration of 4-②, 4-③, 4-④ were all 10 minutes.

4.3.2.2 Filtered water in each net

Filtered water in each net is shown in Table 4.2 and Fig. 4.3- Fig. 4.4. In haul 1-②, 1-③ and 1-④, the filter water were 5373, 5707 and 10596 m^3, respectively. Filter water in haul 1-④ were approximately twice the volume in haul 1-② and 1-③. In haul 2-② ~2-⑤, the filter water were 7919, 5788, 6300 and 6434 m^3, respectively. In haul 3-③, 3-④ and 3-⑤, the filter water were 2630, 2219 and 3292 m^3, respectively. In haul 4-②, 4-③ and 4-④ under horizontal tow, the filter water were 5957, 4846 and 3461 m^3, respectively. Filter water was reduced as towing speed decreased. Growth rates of filtered water in 1^{st}~4^{th} hauls were relatively consistent without variation expect small fluctuation in haul 1-④ and 3-⑤.

4.3.3 Fish species composition

4.3.3.1 Species composition of specimen in each haul

A total of 35431 individuals of micronekton were identified into five species: Myctophidae, Cephalopoda, Euphausiidae, Sergestidae and other Ichthyoplankton. Composition of catch number and weight in each codend is shown in Table 4.3 and Fig. 4.5- Fig. 4.6.

In all oblique and horizontal tows, proportion of Euphausiidae was the largest and

Cephalopoda was the lowest. Specimens were rarely caught in haul 1-②, 1-③ and 1-④, of which there was no lantern fish captured in 1-②, 1-③. The number of lantern fish were 263 and 289 in haul 2-② and 2-⑤, but only few numbers in haul 2-③ and 2-④. The number of lantern fish was 184 in haul 3-⑤, but only few numbers in haul 3-③ and 3-④. Species composition of specimen in each haul were very similar in haul 4-②, 4-③ and 4-④ under horizontal tow, and the numbers of lantern fish were 385, 249 and 208.

4.2.3.2 Catch numbers and length distributions of lantern fish in each haul

Length distributions of *Diaphus* spp and *Diaphus Kuroshio* are shown in Fig. 4.7 and Table 4.5. Lantern fish were not captured in 1-②, 1-③, and were rarely captured in haul 1-④, 2-③, 2-④, 3-③, 3-④. In haul 2-② and 2-⑤ under oblique tow, the numbers of *Diaphus spp* were 207 and 116, and the numbers of *Diaphus Kuroshio* were all 16. Length distributions of *Diaphus spp* were ranged from 11~38 mm in haul 2-② and 11~20 mm in haul 2-⑤. Length distributions of *Diaphus Kuroshio* were ranged from 12~35 mm in haul 2-② and 11~20 mm in haul 2-⑤. In haul 3-⑤, the number of *Diaphus spp* was 125, and the length distribution was ranged from 12~31 mm. In haul 4-②, 4-③ and 4-④ under horizontal tow, the numbers of *Diaphus spp* were 220, 140 and 118, and the length distributions were ranged from 10~44 mm, 12~38 mm and 11~34 mm, respectively. Meanwhile, the numbers of *Diaphus Kuroshio* were 111, 87 and 61, and the length distributions were ranged from 14~42 mm, 14~39 mm and 13~37 mm, respectively.

4.3.3.3 Catch number in unit filtered water of Myctophidae

The CPUE (catch number in unit filter water) of lantern fish is shown in Fig. 4.8. The value of CPUE was 0.001 ind/m^3 in 1-④ haul and there were no lantern fish caught in 1-② and 1-③. In 2-②~ 2-⑤ hauls, the values of CPUE in 2-② and 2-⑤ hauls were 0.033 and 0.045 ind/m^3, significantly higher than CPUE in 2-③ and 2-④ hauls. In 3-③, 3-④ and 3-⑤ hauls, the values of CPUE in 3-⑤ hauls was 0.056, higher than CPUE in 3-③ and 3-④ hauls. In 4-②, 4-③ and 4-④ hauls, the values of CPUE were 0.07, 0.05, 0.06 ind/m^3, respectively. There was no obvious difference among each hauls.

4.3.4 Parameter estimation and model selection

Linear model was successfully obtained for *Diaphus Kuroshio* and *Diaphus* spp in 4-②, 4-③ and 4-④ hauls. According to AIC model selection, the optimal model for *Diaphus Kuroshio* was model C with a smallest AIC value of 147.81. Similarly, the optimal model for *Diaphus spp* was model E with a smallest AIC value of 187.36. Further, the optimal model for both *Diaphus Kuroshio* and *Diaphus spp* was model C with a smallest AIC value of 332.35.

In optimal model C for *Diaphus Kuroshio*, the proportion of catch in slow speed haul is shown in Table 4.5 and Fig. 4.9. In 4-② and 4-④ combinations, the standard length was mainly gathered in 15.5~31.5 mm. As the standard length of *Diaphus Kuroshio* increased, the percentage of catch in 2 knots haul was decreased. There was obvious fluctuation between standard length of 21.5~26.5 mm. In 4-② and 4-③

combinations, the standard length was mainly gathered in 15.5~34.5 mm. As the standard length of *Diaphus Kuroshio* increased, the percentage of catch in 3 knots haul was decreased.

In optimal model E for *Diaphus spp*, the proportion of catch in slow speed haul is shown in Table 4.7 and Fig. 4.11. In 4-② and 4-④ combinations, the standard length was mainly gathered in 10.5~29.5 mm. As the standard length of *Diaphus spp* increased, the percentage of catch in 2 knots haul was decreased. There was obvious fluctuation between standard length of 12.5~22.5 mm. In 4-② and 4-③ combinations, the standard length was mainly gathered in 11.5~32.5 mm. As the standard length of *Diaphus Kuroshio* increased, the percentage of catch in 3 knots haul was decreased.

In optimal model C for *Diaphus Kuroshio* and *Diaphus spp*, the proportion of catch in slow speed haul is shown in Table 4.9 and Fig. 4.13. The same variation trend can be seen as mentioned in proportion of catch in slow speed haul for *Diaphus Kuroshio* (Fig. 4.9) and *Diaphus spp* (Fig. 4.11), respectively.

4.3.5 Selection curve for net avoidance

Selection parameters and selection curve for *Diaphus Kuroshio* and *Diaphus spp* are shown in Table 4.6, 4.8 and 4.10, Fig. 4.10, 4.12 and 4.14.

For *Diaphus Kuroshio*, in six hypothetical models, according to the AIC model selection, the net avoidance model with estimated parameter p and linear parameter c equaled to zero was selected as the optimal model. The selection curve of net avoidance was monotonous decreased. When compared to towing speed of 4 knot, it is obviously that lantern fish were smaller in towing speed of 3 and 2 knot. In three selection curves, standard lengths of lantern fish were increased in sequence of 2, 3 and 4 knot. 50% retention length and selection range were 27.90 and -5.30 mm in 2knot, 35.69 and -5.30 mm in 3 knot, 43.49 and -5.30 mm in 4 knot, respectively. There were little lantern fish larger than 27 mm collected in 2 knot and little fish larger than 35 mm in 3 knot, which indicated net avoidance phenomenon of slower net was more obvious than faster net.

For *Diaphus spp*, in six hypothetical models, according to the AIC model selection, the net avoidance model with fixed parameter p and linear parameter a equaled to zero was selected as the optimal model. The selection curve of net avoidance was monotonous decreased. In three selection curves, standard lengths of lantern fish were increased in sequence of 2, 3 and 4 knot. 50% retention length and selection range were 30.72 and -3.56 mm in 2knot, 35.74 and -4.14 mm in 3 knot, 42.73 and -4.95 mm in 4 knot, respectively. There were no lantern fish larger than 33 mm collected in 2 knot and no fish larger than 37 mm in 3 knot, which indicated net avoidance phenomenon of slower net was more obvious than faster net.

For *Diaphus Kuroshio* and *Diaphus spp*, they belong to the same genera and have similar range of body length. So we use the same selection curve with logistic parameters α and β, but different split parameter p to express net avoidance. In these six models, according to the AIC model selection, the net avoidance model with estimated parameter p and linear parameter c equaled to zero was selected as the optimal model. In model A and model D, extreme bias was observed in estimates of selection parameters. As we can see from three selection curves, standard lengths of lantern fish were increased in sequence of 2, 3 and 4 knot. 50% retention lengths were 42.35, 35.87 and 29.40 mm, respectively. While the selection ranges of 4, 3 and 2 knots were all -4.32 mm.

4.4 Discussion

According to the results of three oblique tows, we can infer that lantern fish distributed in different water depth. Also, when we compare 3-③ with 3-⑤ hauls, there was a tendency that lantern fish individuals were bigger in deep water than shallow water at night. In horizontal tows, towing depths were set at 40 m and species composition of sampling were similar in 4-②, 4-③ and4-④ hauls. So it is appropriate to compare the effect of towing speed on escape phenomenon in front of sampling net.

In linear model using SELECT method, selectivity curve of *Diaphus Kuroshio* and *Diaphus spp* were successfully obtained. 50% retention length of 4, 3 and 2 knots were 43.49, 35.69 and 27.90 mm for *Diaphus Kuroshio*, and 42.73, 35.74 and 30.72 mm for *Diaphus spp*, respectively. From which we can see that 50% retention lengths were similar in two lantern fish. From the perspective of classification, the two species belong to the same genus, so they are similar in morphology. So we tried to use the same selectivity curve to express net avoidance of both lantern fish and succeeded. The results show that 50% retention length of 4, 3 and 2 knots were 42.35, 35.87 and 29.40 mm, respectively. Among them, 50% retention length of 4 knot was smaller than that in separate selectivity curve of *Diaphus Kuroshio* or *Diaphus spp*. This is because number of large individuals was less than smaller sized individuals when combined two lantern fish together. Meanwhile, selection range of 4, 3 and 2 knots in mean selectivity curve were all -4.32 mm. It showed that logistic parameter α was affected by towing speed, while parameter β was not affected by towing speed.

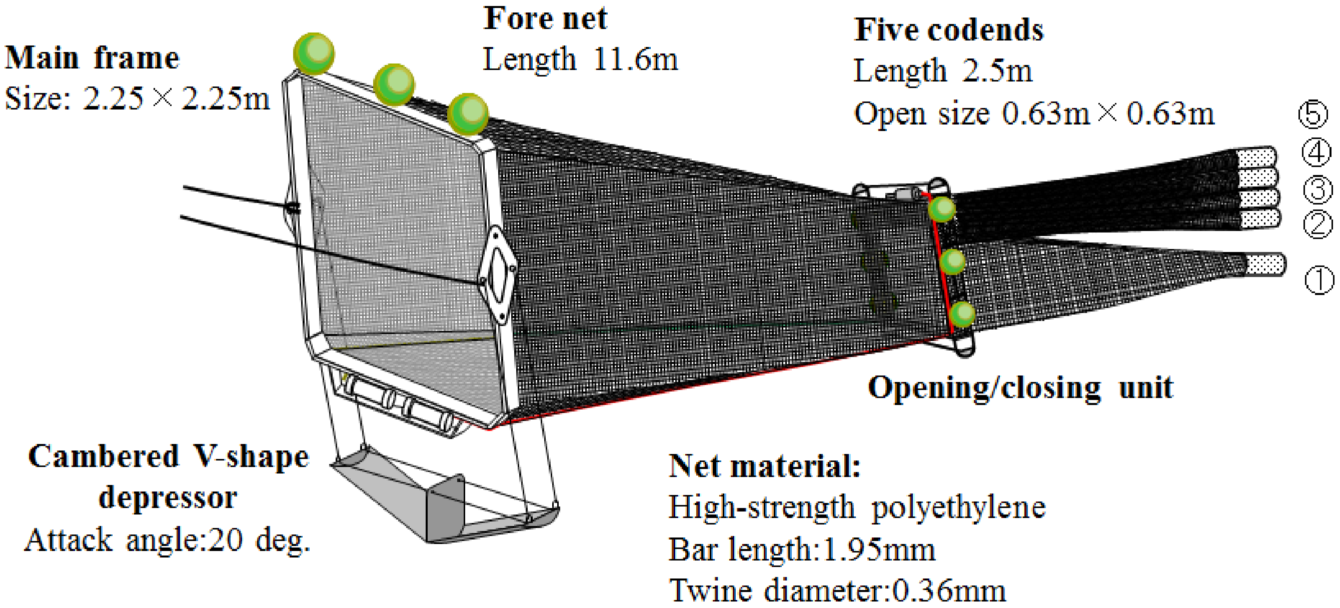

Fig. 4.1 Details of COC-MOHT sampling gear

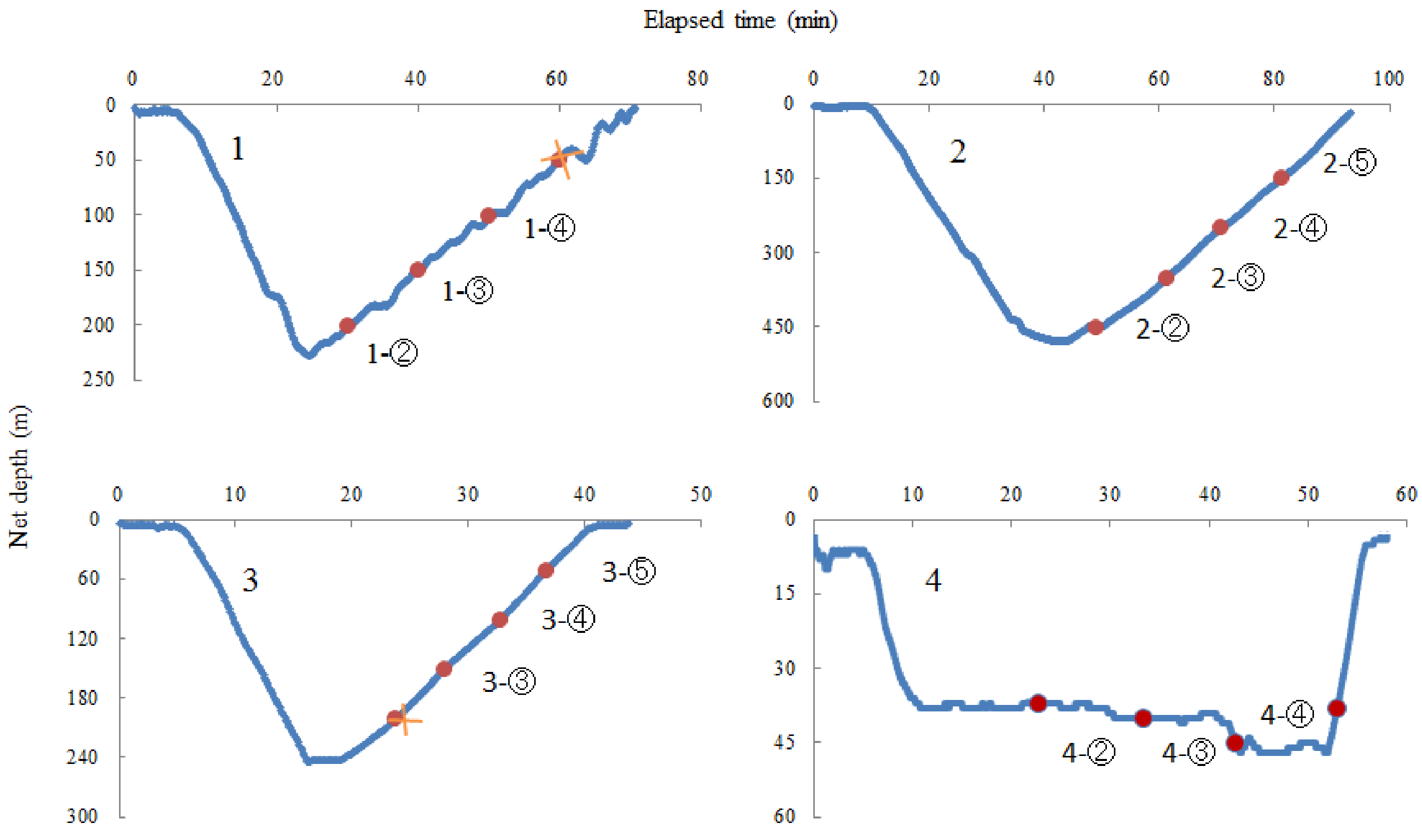

Fig. 4.2 Towing depth of COC-MOHT in oblique and horizontal tows

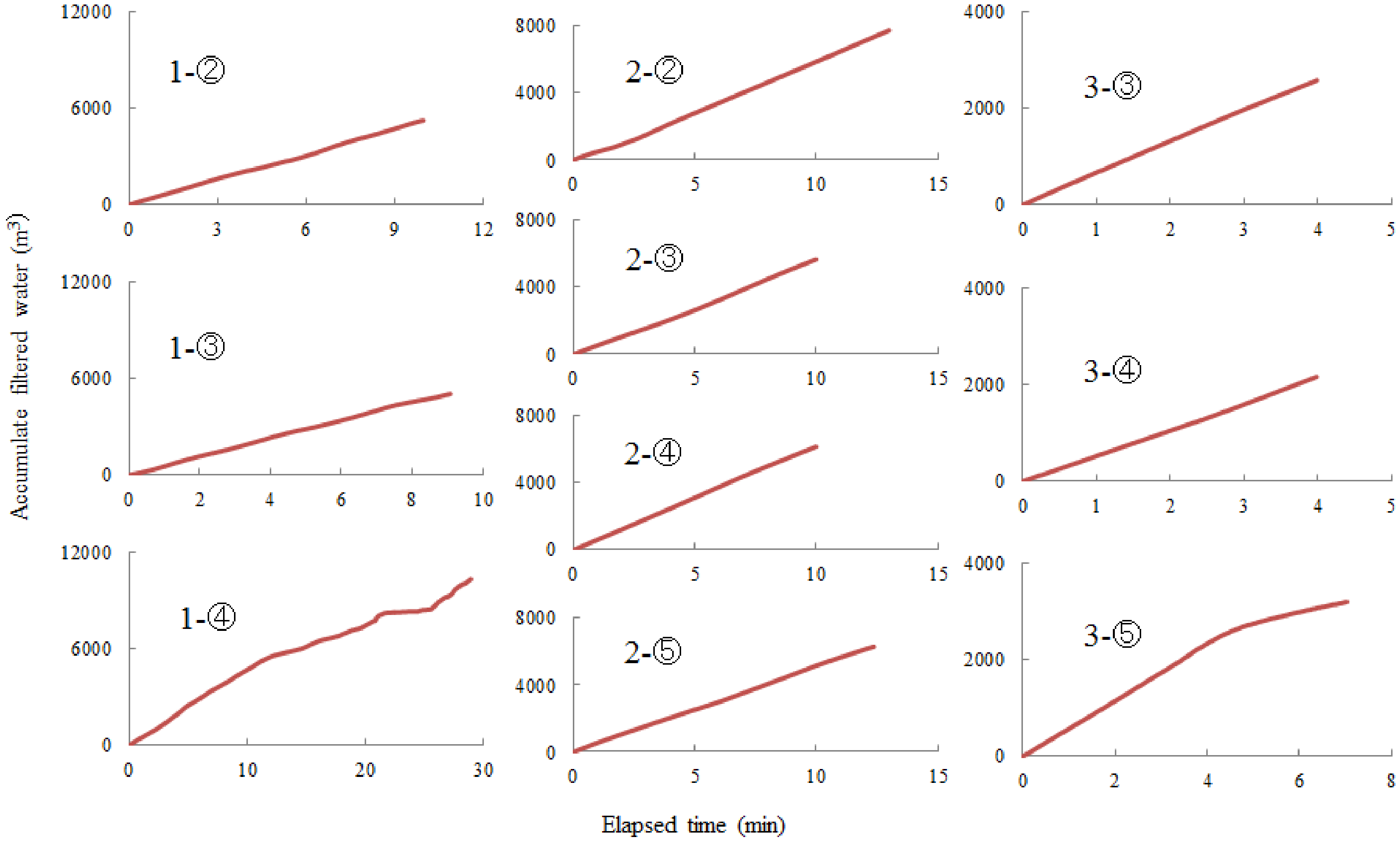

Fig. 4.3 Accumulate filtered water for each codend in oblique tow

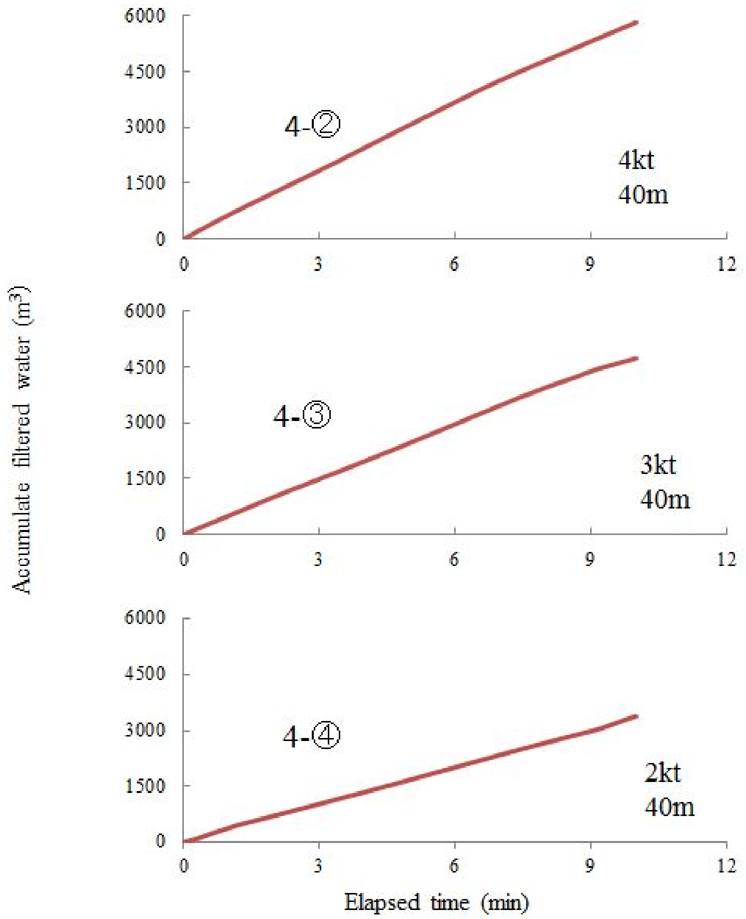

Fig. 4.4 Accumulate filtered water for each codend in horizontal tow

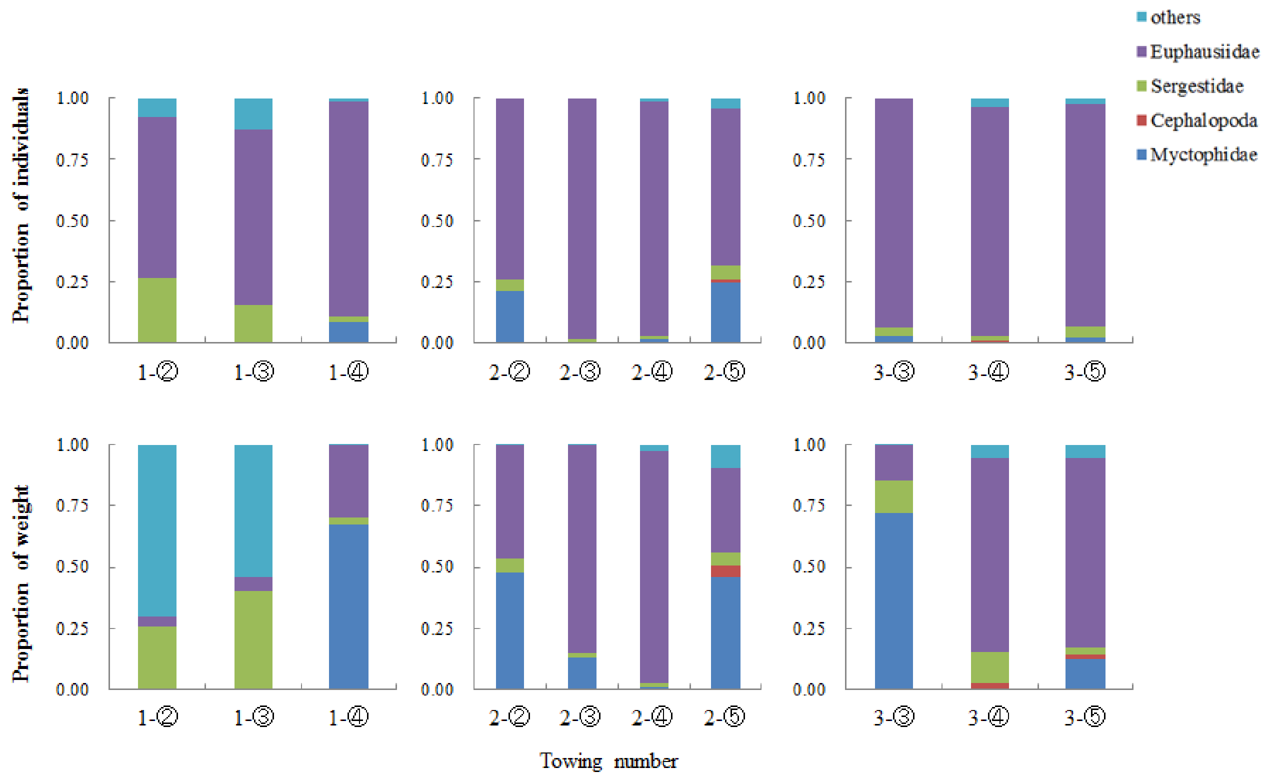

Fig. 4.5 Proportion of individuals/weight for specimen in oblique tow

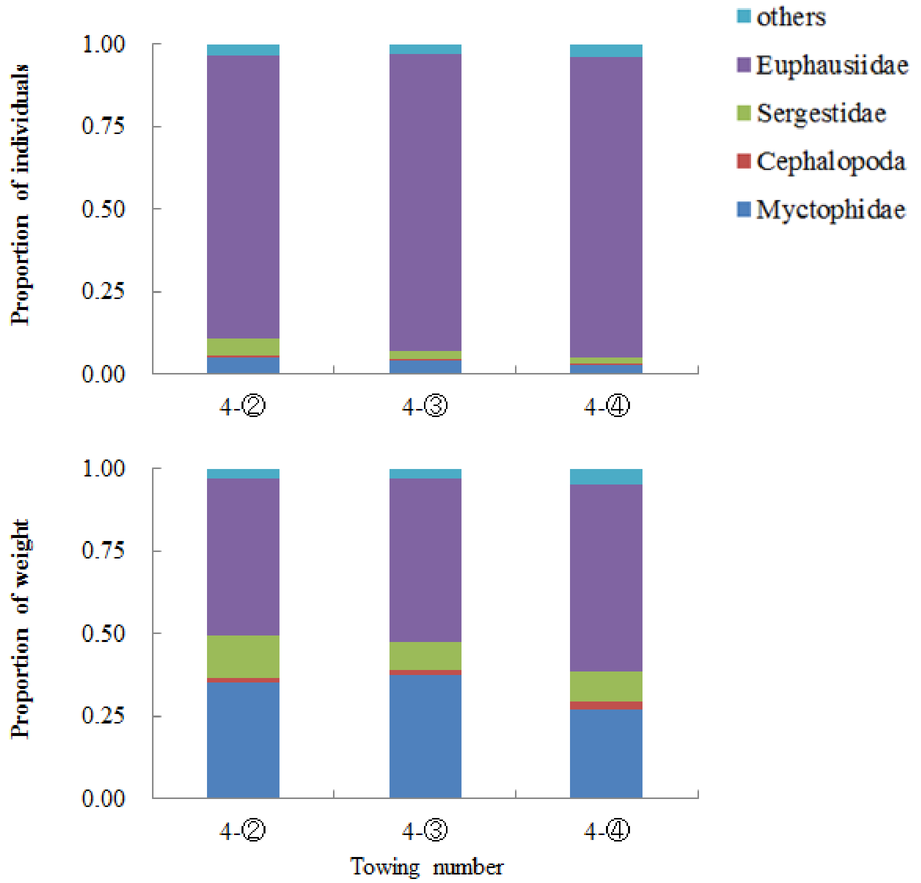

Fig. 4.6 Proportion of individuals/weight for specimen in horizontal tow

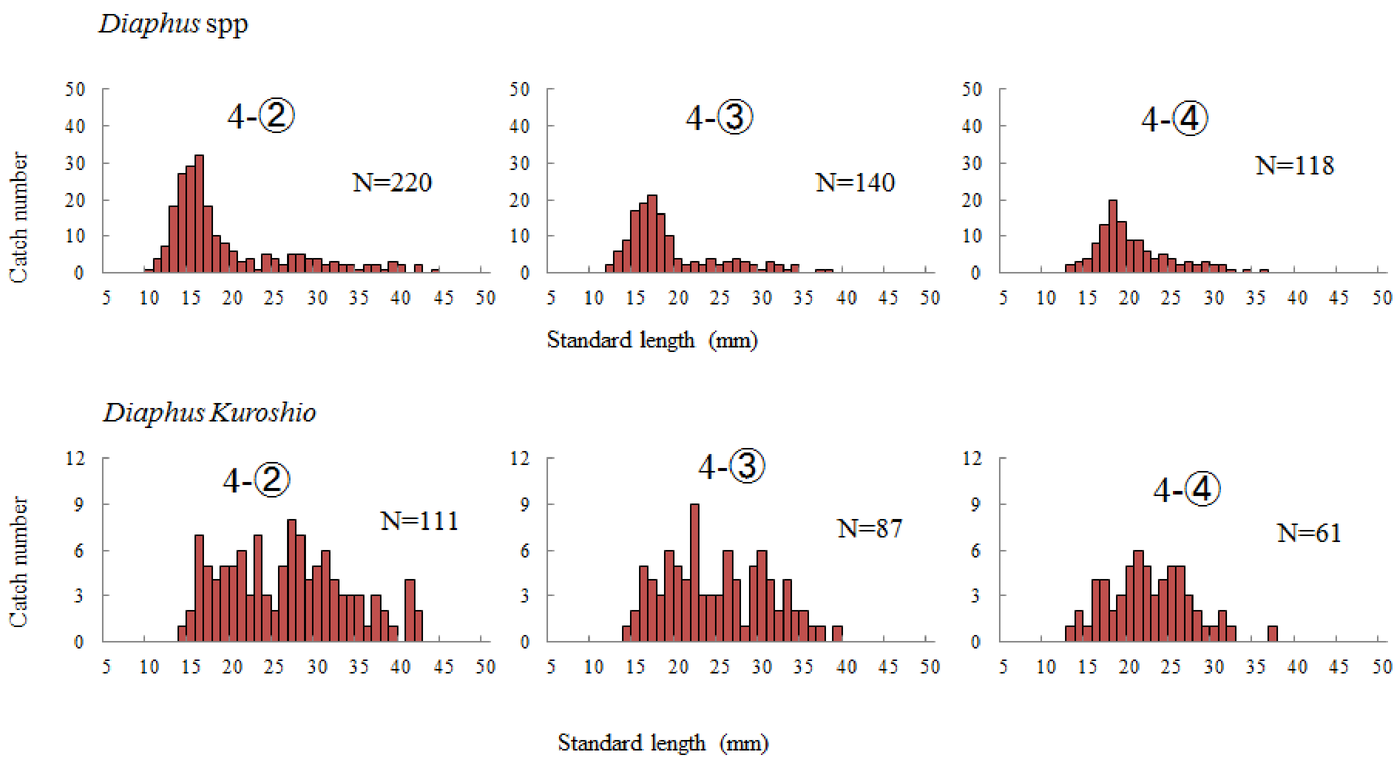

Fig. 4.7 Length distributions of *Diaphus* spp and *Diaphus Kuroshio*

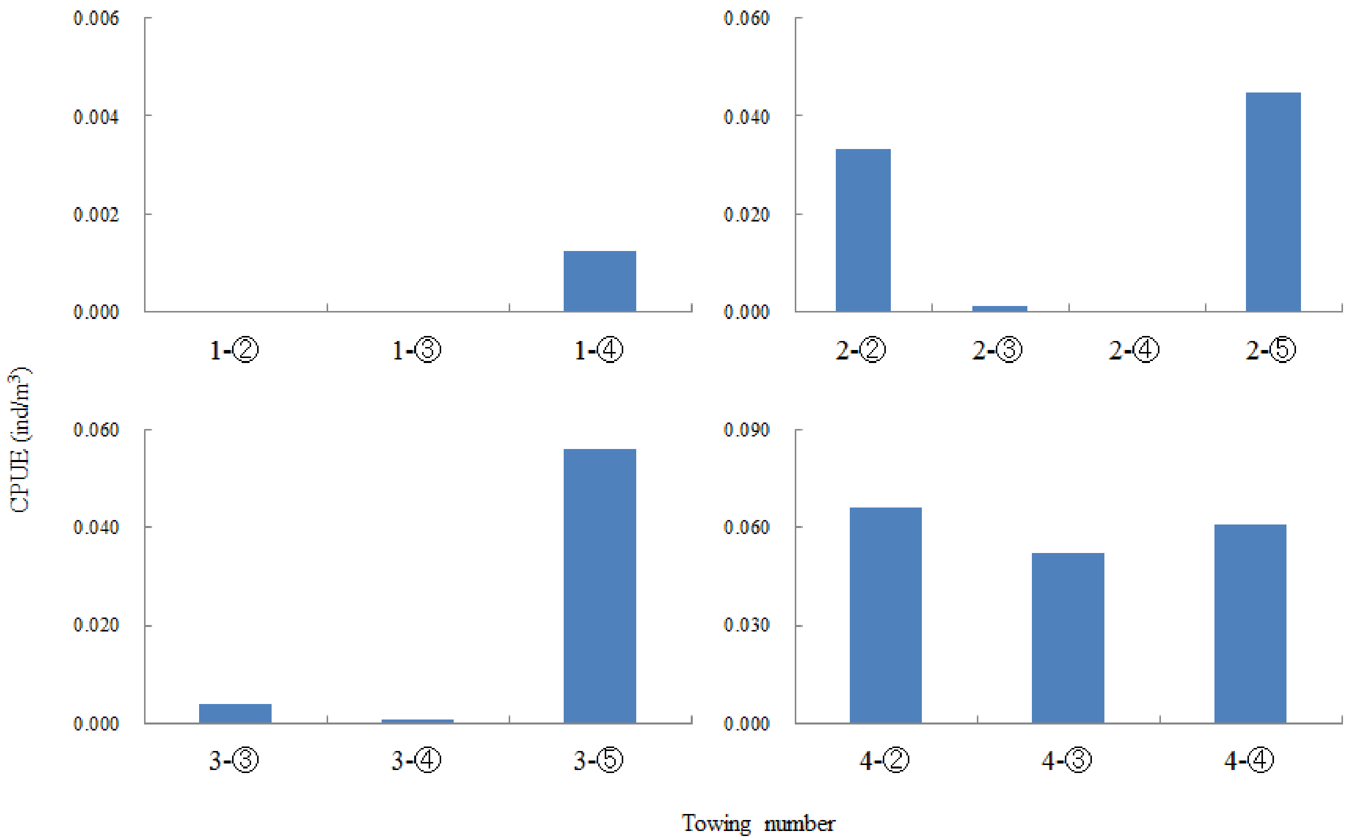

Fig. 4.8 Catch number in unit filter water in oblique and horizontal tows

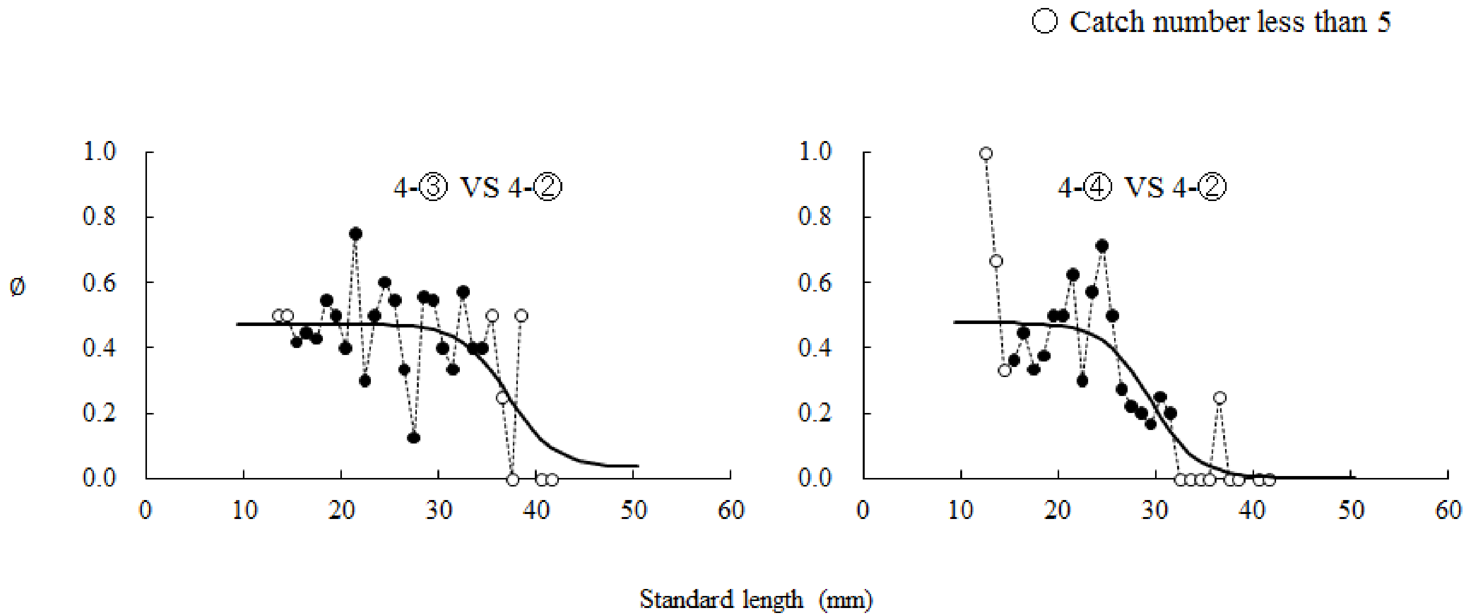

Fig. 4.9 Proportion of catch in slow speed haul for *Diaphus Kuroshio*

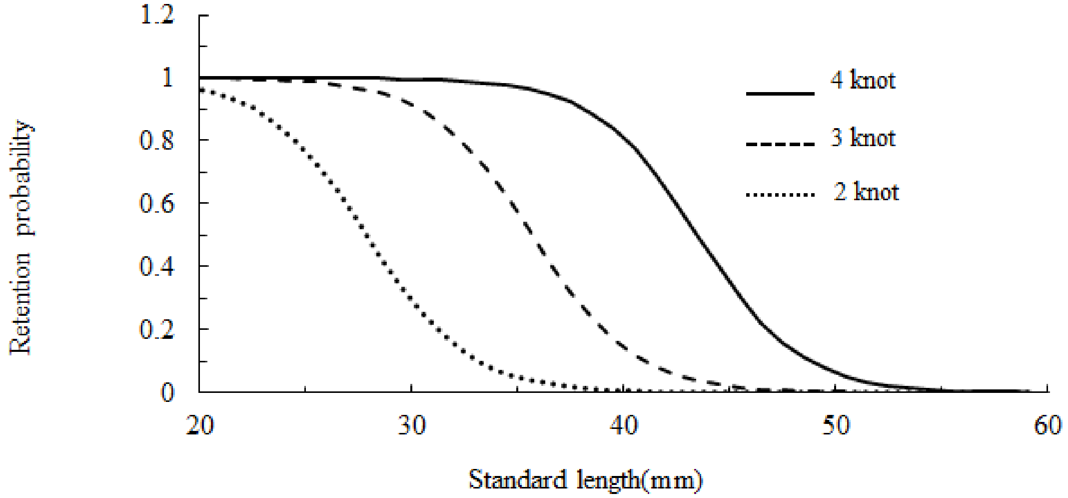

Fig. 4.10 Selection curves of mesh size and net avoidance for *Diaphus Kuroshio*

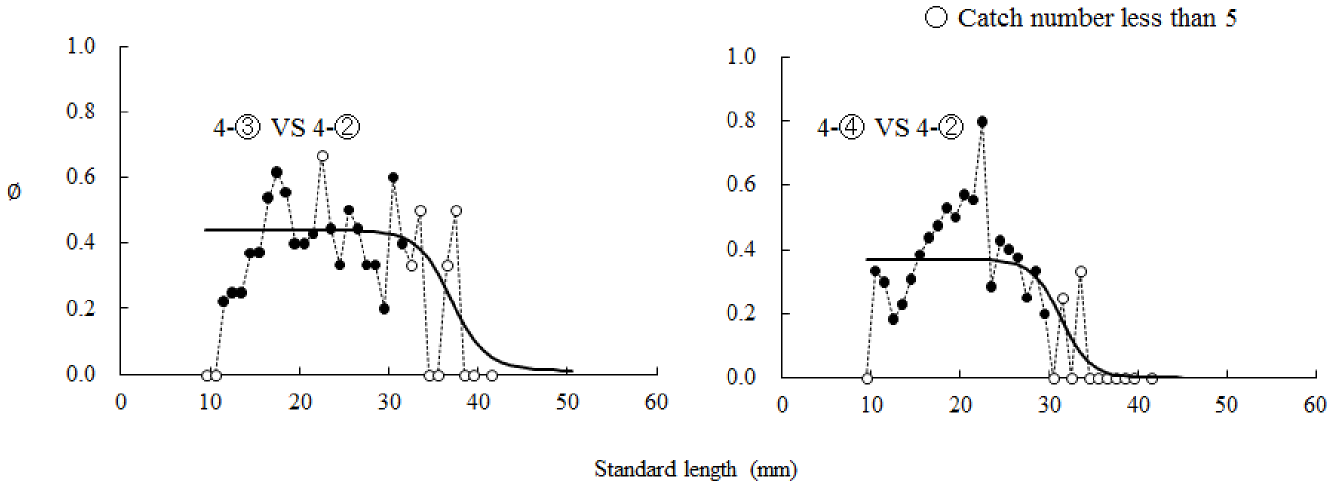

Fig. 4.11 Proportion of catch in slow speed haul for *Diaphus* spp

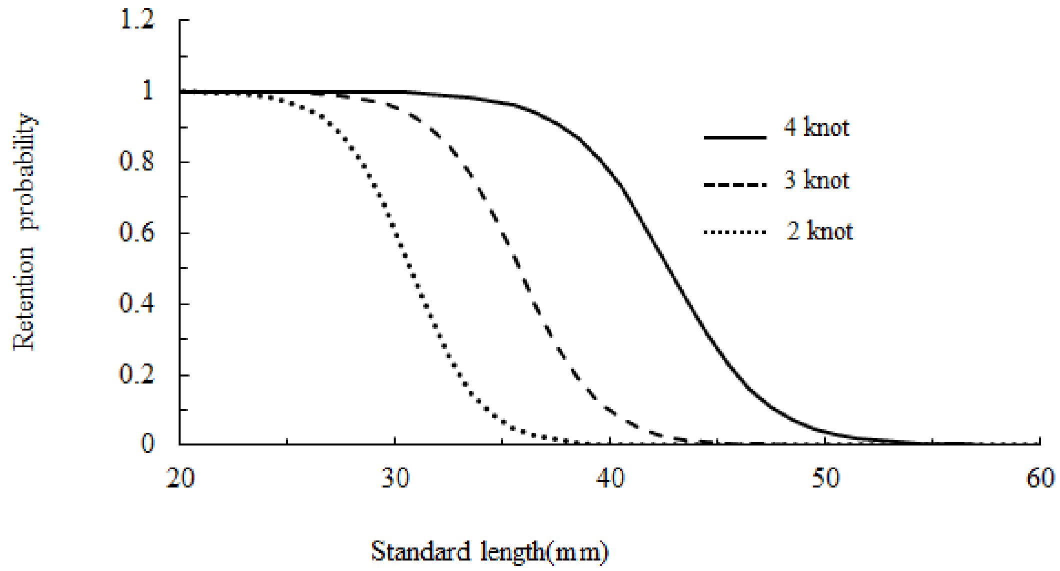

Fig. 4.12 Selection curves of net avoidance for *Diaphus* spp

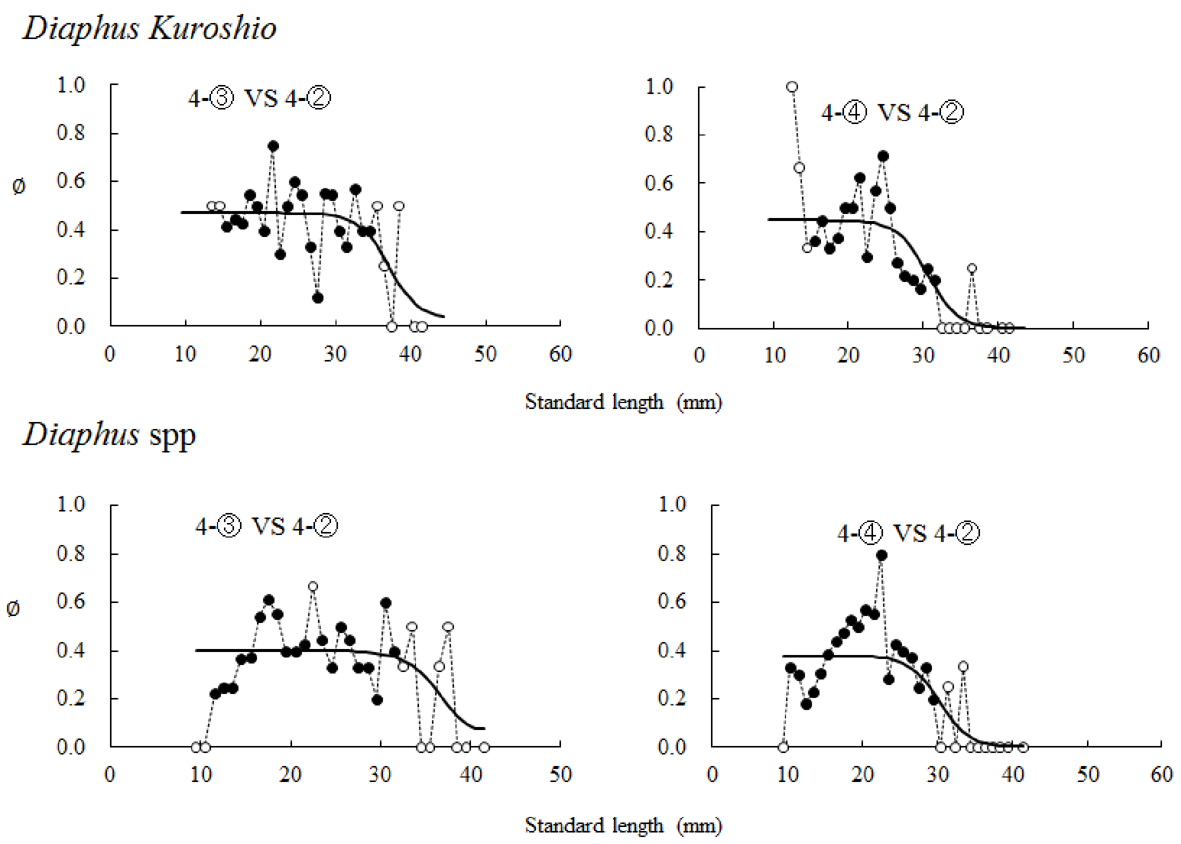

Fig. 4.13 Proportion of catch in slow speed haul for *Diaphus Kuroshio* and *Diaphus* spp

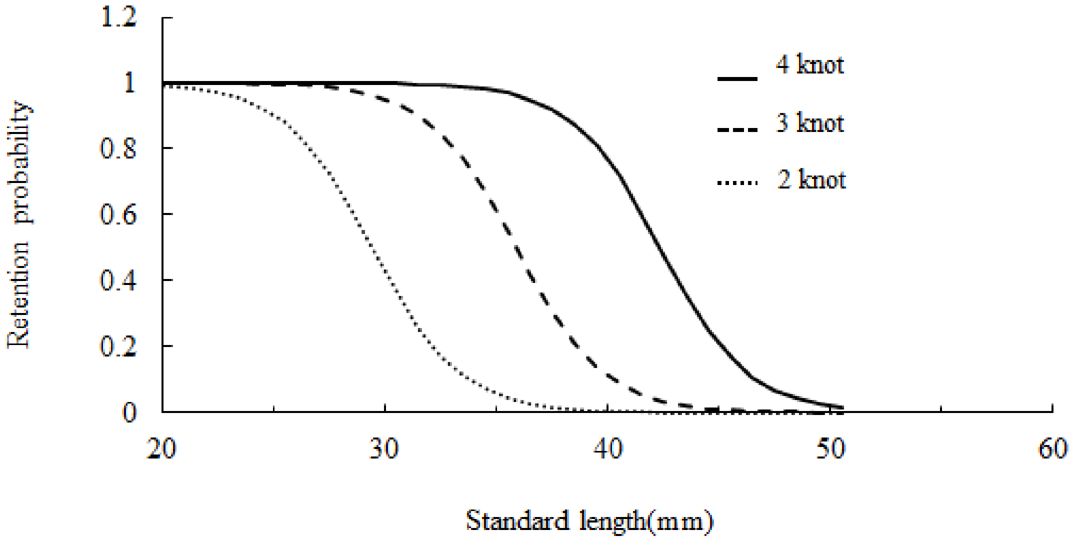

Fig. 4.14 Selection curves of net avoidance for *Diaphus Kuroshio* and *Diaphus garmani*

Table 4.2 Towing condition of standard MOHT in oblique and horizontal tows

Date	Towing no.	Towing method	start location		Start time	finish time	Towing duration	Filtered volume
			Latitude, N	Longitude, E				
2014/10/15	1	oblique tows	34°08.83	138°29.58	18:42	19:53	71	37742
2014/10/16	2	oblique tows	34°55.55	139°21.23	9:07	10:31	84	41881
2014/10/16	3	oblique tows	35°00.17	139°26.15	17:45	18:28	43	18081
2014/10/16	4	horizontal tows	35°02.04	139°24.95	19:10	20:08	58	28996

Table 4.1 Towing condition of each codend in oblique and horizontal tows

Towing no.	Codend no.	Start time	Towing duration	Maximum net depth	Towing speed (knot)	Filtered volume
1	②	19:11	10	201	3	5373
	③	19:21	10	151	3	5708
	④	19:31	21	101	3	10596
2	②	9:48	13	451	3	7919
	③	10:01	10	351	3	5788
	④	10:11	10	251	3	6300
	⑤	10:21	14	151	3	6435
3	③	18:13	4	151	3	2631
	④	18:17	4	101	3	2219
	⑤	18:21	7	51	3	3292
4	②	19:33	10	37	4	5958
	③	19:43	10	40	3	4846
	④	19:53	10	45	2	3462

Table 4.3 Taxonomic composition of catch number and weight in each codend in oblique tows

Towing no.		Myctophidae		Cephalopoda		Sergestidae		Euphausiidae		others		Total	
1-②	catch number	0	(0.000)	0	(0.000)	10	(0.263)	25	(0.658)	3	(0.079)	38	(1.000)
	weight[mg]	0	(0.000)	0	(0.000)	2400	(0.259)	380	(0.041)	6490	(0.700)	9270	(1.000)
1-③	catch number	0	(0.000)	0	(0.000)	6	(0.154)	28	(0.718)	5	(0.128)	39	(1.000)
	weight[mg]	0	(0.000)	0	(0.000)	1440	(0.404)	200	(0.056)	1920	(0.539)	3560	(1.000)
1-④	catch number	13	(0.087)	0	(0.000)	3	(0.020)	131	(0.879)	2	(0.013)	149	(1.000)
	weight[mg]	3720	(0.673)	0	(0.000)	170	(0.031)	1630	(0.295)	10	(0.002)	5530	(1.000)
2-②	catch number	263	(0.211)	0	(0.000)	57	(0.046)	924	(0.742)	2	(0.002)	1246	(1.000)
	weight[mg]	17660	(0.478)	0	(0.000)	2050	(0.055)	17230	(0.466)	10	(0.000)	36950	(1.000)
2-③	catch number	6	(0.007)	0	(0.000)	6	(0.007)	825	(0.983)	2	(0.002)	839	(1.000)
	weight[mg]	1530	(0.134)	0	(0.000)	160	(0.014)	9710	(0.850)	30	(0.003)	11430	(1.000)
2-④	catch number	1	(0.014)	0	(0.000)	1	(0.014)	67	(0.957)	1	(0.014)	70	(1.000)
	weight[mg]	10	(0.013)	0	(0.000)	10	(0.013)	760	(0.950)	20	(0.025)	800	(1.000)
2-⑤	catch number	289	(0.245)	18	(0.015)	67	(0.057)	755	(0.639)	53	(0.045)	1182	(1.000)
	weight[mg]	8650	(0.462)	890	(0.047)	920	(0.049)	6520	(0.348)	1760	(0.094)	18740	(1.000)
3-②	catch number	11	(0.030)	0	(0.000)	11	(0.030)	343	(0.937)	1	(0.003)	366	(1.000)
	weight[mg]	22790	(0.721)	0	(0.000)	4140	(0.131)	4660	(0.147)	10	(0.000)	31600	(1.000)
3-③	catch number	2	(0.005)	1	(0.003)	7	(0.019)	346	(0.938)	13	(0.035)	369	(1.000)
	weight[mg]	20	(0.003)	160	(0.024)	840	(0.128)	5190	(0.792)	340	(0.052)	6550	(1.000)
3-④	catch number	184	(0.020)	27	(0.003)	395	(0.044)	8178	(0.908)	223	(0.025)	9007	(1.000)
	weight[mg]	14370	(0.128)	1600	(0.014)	3020	(0.027)	87210	(0.779)	5780	(0.052)	111980	(1.000)

Values in parentheses are percentage

Table 4.4 Taxonomic composition of catch number and weight in each codend in horizontal tows

Towing no.		Myctophidae		Cephalopoda		Sergestidae		Euphausiidae		others		Total	
4-②	catch number	385	(0.050)	31	(0.004)	410	(0.053)	6571	(0.855)	288	(0.037)	7685	(1.000)
	weight[mg]	67080	(0.352)	2040	(0.011)	24800	(0.130)	90420	(0.475)	6090	(0.032)	190430	(1.000)
4-③	catch number	249	(0.039)	33	(0.005)	171	(0.027)	5710	(0.899)	190	(0.030)	6353	(1.000)
	weight[mg]	52680	(0.373)	2140	(0.015)	11760	(0.083)	69880	(0.495)	4620	(0.033)	141080	(1.000)
4-④	catch number	208	(0.026)	52	(0.006)	157	(0.019)	7352	(0.909)	319	(0.039)	8088	(1.000)
	weight[mg]	30080	(0.269)	2760	(0.025)	10010	(0.090)	63200	(0.565)	5770	(0.052)	111820	(1.000)

Values in parentheses are percentage

Table 4.5 Length frequency distribution for *Diaphus Kuroshio* and *Diaphus* spp

Standard length(mm)	Towing number					
	4-②		4-③		4-④	
	Diaphus Kuroshio	*Diaphus* spp	*Diaphus Kuroshio*	*Diaphus* spp	*Diaphus Kuroshio*	*Diaphus* spp
10		1				
11		4				2
12		7		2		3
13		18		6	1	4
14	1	27	1	9	2	8
15	2	29	2	17	1	13
16	7	32	5	19	4	20
17	5	18	4	21	4	14
18	4	10	3	16	2	9
19	5	8	6	10	3	9
20	5	6	5	4	5	6
21	6	3	4	2	6	4
22	3	4	9	3	5	5
23	7	1	3	2	3	4
24	3	5	3	4	4	2
25	2	4	3	2	5	3
26	5	3	6	3	5	2
27	8	5	4	4	3	3
28	7	6	1	3	2	2
29	4	4	5	2	1	2
30	5	4	6	1	1	1
31	6	2	4	3	2	
32	4	3	2	2	1	1
33	3	2	4	1		
34	3	2	2	2		1
35	3	1	2			
36	1	1	1			
37	3	2	1	1	1	
38	2	1		1		
39	1	2	1			
40		2				
41	4					
42	2	2				
43						
44		1				
45						
Total	111	220	87	140	61	118

Table 4.6 Parameters for expressing size selectivity and the values of AIC for *Diaphus Kuroshio*

Model	*a*	*b*	*c*	*d*	p_1	p_2	MLL	AIC
Model A	8.43	-5.47	-0.13	-0.14	0.48	0.47	-68.84	149.68
Model B	0.00	11.69	0.08	-0.58	0.47	0.48	-69.04	148.07
Model C	3.23	5.11	0.00	-0.41	0.48	0.47	-68.91	147.81[a]
Model D	8.53	-2.03	-0.14	-0.22	0.37	0.44	-71.14	150.28
Model E	0.00	15.66	0.08	-0.68	0.37	0.44	-71.33	148.66
Model F	3.22	8.92	0.00	-0.51	0.37	0.44	-71.20	148.41

MLL, Maximum log-likelihood. AIC, Akaike's information criterion

[a] Model with the smallest AIC value

Table 4.7 Selection parameters in the optimal Model C for *Diaphus Kuroshio*

Towing speed	α	β	l_{50}	S.R.
4kt	18.03	-0.41	43.49	-5.30
3kt	14.80	-0.41	35.69	-5.30
2kt	11.57	-0.41	27.90	-5.30

Table 4.8 Parameters for expressing size selectivity and the values of AIC for *Diaphus* spp

Model	*a*	*b*	*c*	*d*	*p1*	*p2*	MLL	AIC
Model A	11.45	-2.95	-0.20	-0.26	0.37	0.40	-89.42	190.83
Model B	0.00	20.16	0.10	-0.85	0.37	0.40	-89.50	189.01
Model C	3.77	12.25	0.00	-0.64	0.37	0.40	-89.45	188.90
Model D	0.16	18.66	0.08	-0.78	0.37	0.44	-90.68	189.36
Model E	0.00	18.97	0.09	-0.79	0.37	0.44	-90.68	187.36[a]
Model F	3.45	12.38	0.00	-0.63	0.37	0.44	-90.69	187.38

MLL, Maximum log-likelihood. AIC, Akaike's information criterion

[a] Model with the smallest AIC value

Table 4.9 Selection parameters in the optimal Model C for *Diaphus* spp

Towing speed	α	β	l_{50}	S.R.
4kt	18.97	-0.44	42.73	-4.95
3kt	18.97	-0.53	35.74	-4.14
2kt	18.97	-0.62	30.72	-3.56

Table 4.10 Parameters for expressing size selectivity and the values of AIC for *Diaphus Kuroshio* and *Diaphus* spp

Model	*a*	*b*	*c*	*d*	*p1*	*p2*	*p1*	*p2*	MLL	AIC
Model A	13.20	-12.21	-0.26	0.03	0.45	0.46	0.40	0.38	-158.87	333.73[b]
Model B	0.00	15.36	0.09	-0.69	0.44	0.47	0.40	0.38	-159.49	332.99
Model C	3.28	8.32	0.00	-0.51	0.45	0.47	0.40	0.38	-159.18	332.35[a]
Model D	11.04	-5.82	-0.21	-0.12	0.37	0.44	0.37	0.44	-161.90	331.80[b]
Model E	0.00	16.55	0.09	-0.73	0.37	0.44	0.37	0.44	-164.67	335.34
Model F	3.47	8.92	0.00	-0.53	0.37	0.44	0.37	0.44	-164.27	334.54

MLL, Maximum log-likelihood. AIC, Akaike's information criterion

[a] Model with the smallest AIC value

[b] In these models, extreme bias was observed in estimates of selection parameters

Table 4.11 Selection parameters in the optimal Model C for *Diaphus Kuroshio and Diaphus* spp

Towing speed	α	β	l_{50}	S.R.
4kt	21.42	-0.51	42.35	-4.34
3kt	18.15	-0.51	35.87	-4.34
2kt	14.87	-0.51	29.40	-4.34

Chapter 5. The collection characteristics of standard MOHT

5.1 Introduction

In the previous second chapter, net avoidance of small MOHT, IKPT and IKMT were estimated on the assumption of standard MOHT as a control fishing gear with no net avoidance. However, the net avoidance may also occur in standard MOHT in which larger fish can also escape in front of the net. According to the result we obtained in the third and fourth chapters, net avoidance occurred not only at lower towing speed of 2 and 3 knots, but also occurred at higher towing speed of 4 knots. Therefore, for standard MOHT, the escape of large sized fish was inevitable. Therefore, in order to evaluate net avoidance of standard MOHT, we carried out a series of comparative experiments under various towing speeds. Capturing the same fish was importantly desirable to contrast experiments at different towing speed. Because the standard MOHT has only one codend, operations of cast and draw net were inevitable for each haul. To maintain the consistency of the fish school as much as possible, we applied acoustic method to focus the same target fish.

5.2 Material and methods

5.2.1 Sampling gear

Standard MOHT has a total length of 12.5 m, with a 2.24x2.24 m square stainless steel frame, operates in a routine towing speed of 2.0-2.5 m/s. The net is constructed of knotless ultra-high-strength polyethylene square mesh of 1.59mm bar length and 0.36mm twine diameter.

The depressor is a cambered V-shape, which is connected by two bridles from quadrilateral frames attached at the net mouth. The attack angle of the depressor is maintained at 20° by four equal length depressor bridles. The weight of the depressor is 62 kg in air and the total weight of net frame is 230 kg in air.

The net is attached to the frame by black canvas supported by the nylon webbing. The ratio of pore area to mouth area is 8.8 in total. The codend bucket is constructed from 21.6 cm outer diameter polyvinyl chloride (PVC) pipe.

The depth and tilt sensor was fixed inside the upper part of the net frame, which can record the depth of net, roll tilt and pitch tilt of the frame. Meanwhile, the filter water meter was fixed inside the net frame by rope, used to record propeller revolutions during the trawl towing.

5.2.2 Open sea trial

Sea trials were tested on the Nagasaki coastal area on 27 August 2016 using the Shinyo-maru (Tokyo University of Marine Science and Technology). MOHT was towed horizontally six times at a target depth of lantern fish biomass. These six trails were conducted into two sets of experiments. In three periods of tows, when the net arrived at target water depth, the towing speeds were changed into the three stages of 3, 2, and 4 knot in order.

As a result of the diel vertical migration phenomenon of lantern fish, all hauls were conducted after sunset. Simrad EK500 scientific echo sounder (70 kHz) was used to estimate acoustic abundance of fish. Prior to trawling, the fish distribution can be identified in fish finder where fish school was most concentrated. Then, we set the target depth shown by fish finder in horizontal tow to sample lantern fish.

Specimens collected in each codend net were preserved in specimen bottles filled with 10% formalin for further analysis in laboratory.

5.2.3 Data analysis

During the experiments, standard MOHT was used to capture lantern fishes at speeds of 2, 3 and 4 knots. We considered 4 knots as a control towing speed to analyze the net avoidance of 2 and 3 knots, and used linear model to predict the avoidance of 4 knot at the same time. The same method of data analysis, multiple layers MOC-MOHT/COC-MOHT, as in second and third chapters was applied. The detail analysis method can be referred to the previous chapters.

5.3 The results

5.3.1Towing conditions (Start time, maximum net depth, towing speed)

On 27 August 2016, the towing condition in Sagami Bay was shown in table 5.1.

All trawling were carried out at night. Six towing experiments were conducted in areas with latitude 31°59.00N, longitude 128°44.23E and latitude 31°55.12N, longitude 128°51.60E. Towing durations were 24~35 minutes, and filtered volumes were 9203 - 18026 m^3. In each tow, the horizontal experiment duration was 15 minutes. The 2nd and 5th haul were set at towing speed of 3 knots, the 3rd and 6th haul were set at towing speed of 2 knots, and the 4th and 7th hauls were set at towing speed of 4 knots. In the process of horizontal towing, the length of warp was adjusted in order to maintain the fishing gear in fish aggregated depth.

5.3.2 Towing performance

5.3.2.1 Towing depth in experiment

The towing depths for each haul are shown in Fig. 5.1. The depth was obtained from depth sensor installed in the upper inside the mouth frame of fishing gear. In haul 2, 3 and 4, the horizontal experiment time were between 12-28 minutes, 9-24 minutes and 12-28 minutes at the towing speed of 3 knots after achieving 100, 70, 40 meters commencing depth, respectively. Net depths of haul 2, 3 and 4 were between 92-107 m, 52-82 m, 36-46 m, respectively. The water depth of the three hauls gradually became shallow, which showed the water depth of lantern fish changed from deep to shallow depth in echo sounder. In haul 5, 6 and 7, the horizontal experiment time were between 8-23 minutes, 5-19 minutes and 7-22 minutes at the towing speed of 3, 2 and 4 knots after achieving 45 meters depth. Net depths of haul 5, 6, 7 were 39-52 m, 41-51 m, 38-52 m, separately. The water depth of three hauls almost had no difference around 45

m. According to echogram Fig. 5.2, obvious reflect areas were seen in water depth shallower than 60m in 2nd - 7th hauls, and the reflection became strong over time.

5.3.2.2 Tilt angle of net frame

Tilt angles of mouth frame are shown in Fig. 5.3. At roll axis angle, positive direction expresses direction of rotation to the right, and negative direction expresses direction of rotation to the left. At pitch axis angle, positive direction expresses lean forward, and negative direction expresses backward tilt.

For haul 2, 3 and 4 at towing speed of 3, 2 and 4knot, the pitch angles were between -10.9°- -0.4°, -3.6°- 9.4°and -3.8°- 1.7°, respectively. It seems that as the increased of towing speed, the change of pitch angle became smaller. Besides, the frame was obviously inclined under the condition of wire-in and wire-out. Meanwhile, the roll angles of haul 2, 3 and 4 were between -8.9°~-4.8, -16.3°~-7.3°and -21.6°~2.5°, respectively. The roll angle reached the largest when the towing speed was 4 knot. For haul 5, 6 and 7, the pitch angles were between -6.2°~1.3°, -24.9°~0.4°and -5.2°~3.1°, respectively. The pitch angle attained the largest when the towing speed was 2 knot. Also, the frame was obviously inclined under the condition of wire-in and wire-out. Meanwhile, the roll angles of haul 5, 6 and 7 were between -11.1°~ 2.9, -6.4°~ -3.9° and 15.4°~ 35.9°, respectively. The roll angle became bigger as the increased towing speed.

5.3.3 Fish species composition

5.3.3.1 Species composition of specimen in each haul

Micronektons were identified into five species: Myctophidae, Cephalopoda, Euphausiidae, Sergestidae and other Ichthyoplankton. Proportion of individuals and weight for each specimen are shown in Table 5.2 and Fig. 5.4.

In all horizontal tows, proportion of individuals for Euphausiidae was the largest, exceeding 50% in each hauls. The specimen was least and no lantern fish was caught in the 2nd haul. Species composition was significantly different in haul 2, 3 and 4 at different towing depth, whereas almost the same composition in haul 5, 6 and 7 at the same towing depth. For the 3rd and 4th hauls, the numbers of lantern fish were 543 and 807, and the weight was 52990 and 57970 mg, respectively. It indicated that more large lantern fish were collected in the 3rd haul at deeper towing depth. For 5th ~7th hauls, the numbers of lantern fish were 839, 229 and 931, and the weights were 35950, 6650 and 86190 mg, respectively. The results showed that at faster towing speed, larger numbers of lantern fish were collected.

5.3.3.2 Catch numbers and length distributions of lantern fish in each haul

Lantern fish were collected in 3rd ~7th hauls and catch number exceed 200 in each haul (Table 5.3-5.4). The length distribution of *Diaphus* spp and *Myctophum asperum* were separately obtained in Fig. 5.5. In 3rd and 4th hauls, the number of *Diaphus* spp were 430 and 467, and the standard length were all concentrated from 10 to 30 mm. While for *Myctophum asperum*, obviously more large sized fish were captured in 4th haul than 3rd haul. In 5th ~ 7th hauls, the numbers of *Diaphus* spp were 327, 171 and 385, respectively. No *Myctophum asperum* were caught in the 6th haul and only two were caught in 5th haul. In 6th haul at towing speed of 2 knots, the length distributions of *Diaphus* spp ranged from 10 to 21 mm. In 5th haul at towing speed of 3 knots, the length distributions of *Diaphus* spp ranged from 10 to 27 mm. While in 7th haul at towing speed of 4 knots, the length distributions of *Diaphus* spp ranged from 10 to 32 mm, and *Myctophum asperum* ranged from 21 to 55 mm, respectively. It is clearly observed that large individuals were less collected at slower towing speed.

5.3.4 Parameter estimation and model selection

Linear model was successfully obtained for *Diaphus* spp in 5, 6 and 7 hauls in Table 5.5. According to AIC model selection, model B was chosen as the optimal model with a smallest AIC value of 143.48. In model A and model D, extreme bias was observed in estimates of selection parameters.

In optimal model B, the proportion of catch in slow speed haul is shown in Fig. 5.6. In the combination of the 5th and 7th hauls, the standard length was mainly gathered between 10.5~27.5mm. As the standard length of *Diaphus* spp increased, the percentage of catch in the 5th haul was decreased. There was no obvious fluctuation in standard length. In the combination of 5 and 7 hauls, the standard length was also mainly gathered between 10.5~27.5mm. As the standard length of *Diaphus* spp increased, the percentage of catch in 6 haul was decreased.

5.3.5 Selection curve for net avoidance

For *Diaphus* spp, in six hypothetical models, according to the AIC model selection, the net avoidance model with estimated parameter *p* and linear parameter *a* equaled to zero was selected as the optimal model. The selection curve of net avoidance showed monotonous decrease. When compared to towing speed of 4 knot, it is obviously that lantern fish were less number in towing speed of 3 and 2 knot. In three selection curves, standard lengths of lantern fish were increased in sequence of 2, 3 and 4 knot. 50% retention length and selection range were 18.56 and -2.91 mm in 2knot, 22.12 and -3.47 mm in 3 knot, 27.38 and -4.29 mm in 4 knot, respectively. There were few number lantern fish larger than 20 mm collected in 2 knot and few fish larger than 25 mm in 3 knot, which indicated net avoidance phenomenon of slower net was more apparent than faster net.

5.4 Discussion

Because of the diel vertical migration of lantern fish at night, as it was confirmed by echogram, the reflection became strong over time. However, it was difficult for us to determine the accurate water depth of lantern fish.

From the result of 3rd and 4th hauls, we can see that the length distribution of lantern fish were similar between each other. The towing speeds were two times larger in the 4th haul than the 3rd haul, while the towing depths also had difference of 20 meters. According to previous research, large sized fish were captured at higher towing speed and deeper water depth. But because of the different towing speed and towing depth, it was difficult to compare the size of lantern fish between these two hauls.

In 5th and 7th hauls, the length distributions of lantern fish were bimodal with peak value of 11~13 mm and 22~24 mm. While in 6th haul, lantern fish showed unimodal distribution with peak value of 12, 13 mm. The difference in length distribution was caused because no fish larger than 21 mm were captured. The water depths of 5th ~ 7th hauls were same at 40m, only the towing speed varies each other. This indicated the influence of towing speed on length distribution.

The model with estimated parameter p and linear parameter a equaled to zero was selected as the optimal model. It showed that logistic parameter α was not affected by towing speed, while parameter β was affected by towing speed.

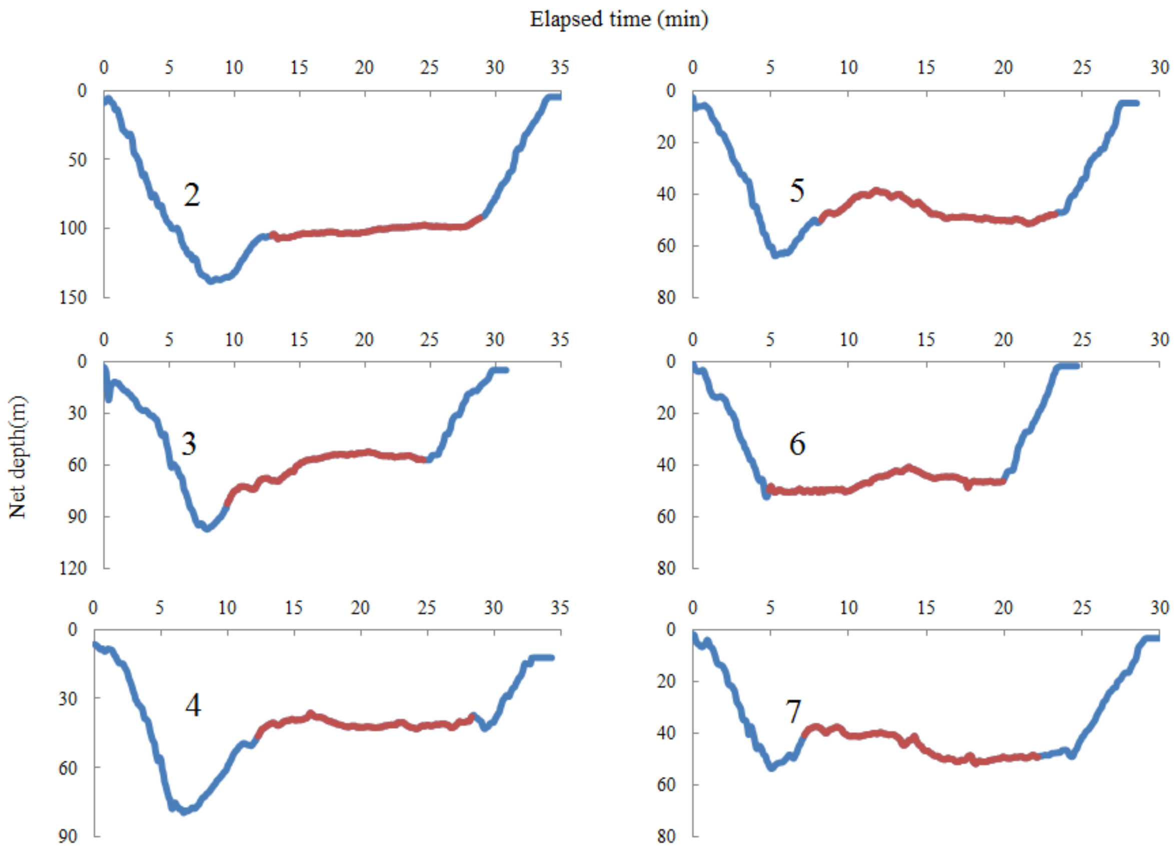

Fig. 5.1 Towing depth of standard MOHT in horizontal tows

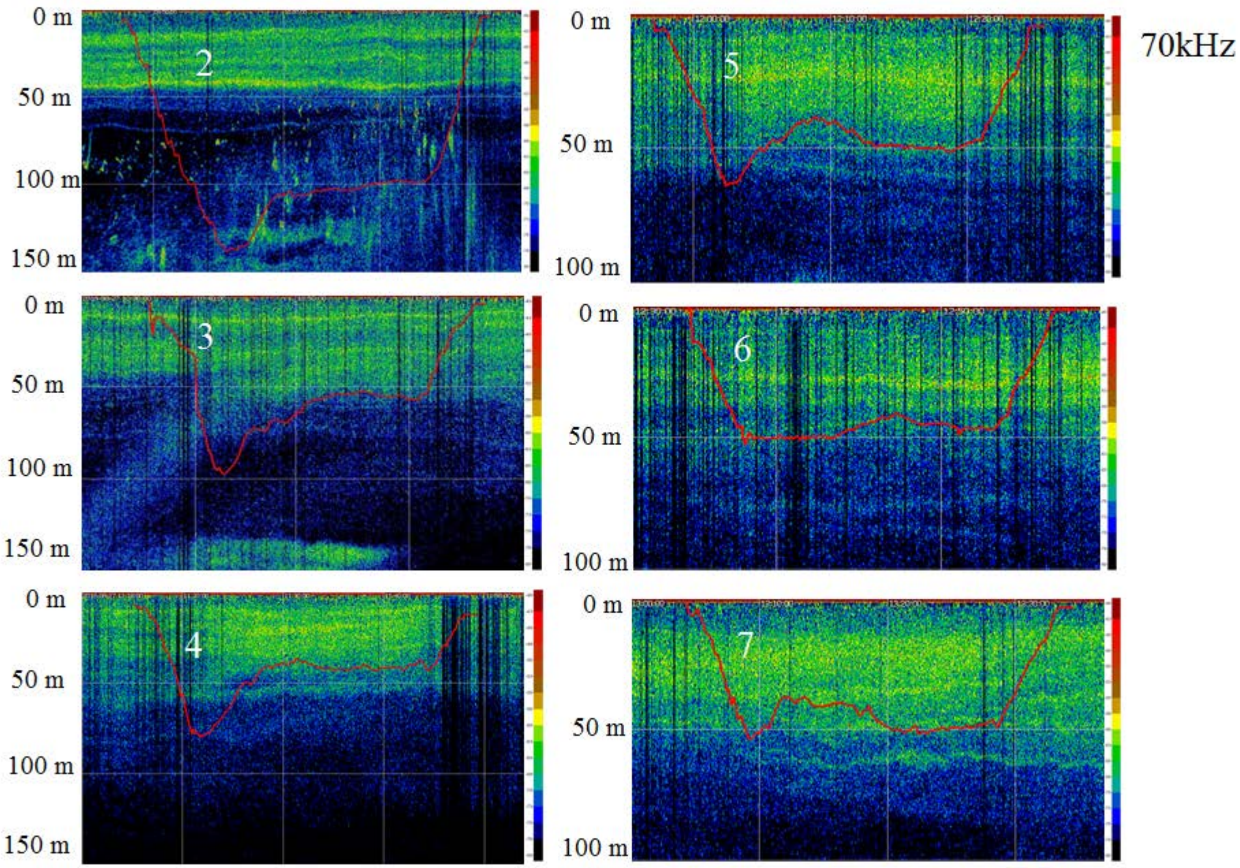

Fig. 5.2 Towing depth profile in nighttime 70kHz echogram

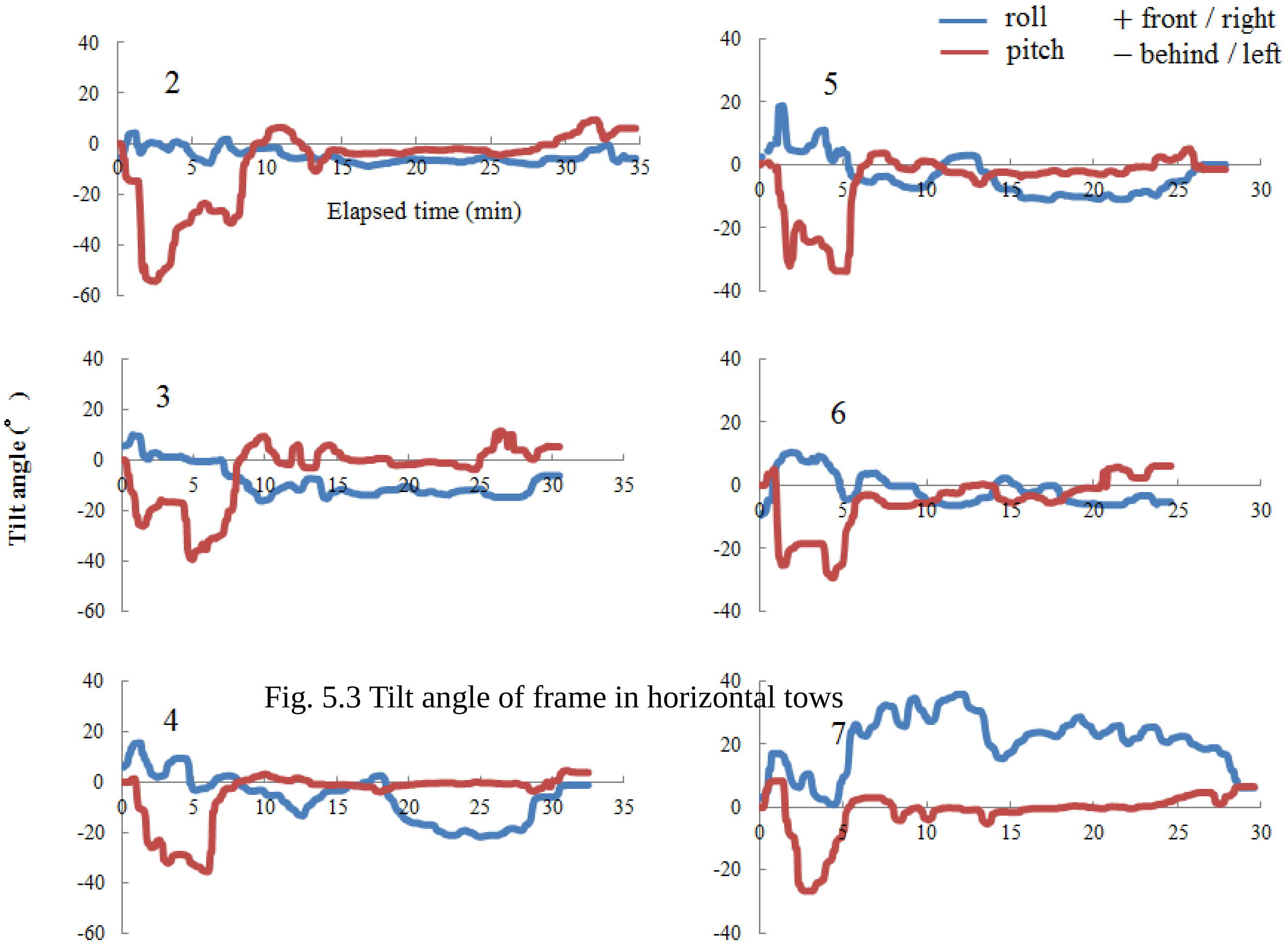

Fig. 5.3 Tilt angle of frame in horizontal tows

Fig. 5.3 Tilt angle of frame in horizontal tows

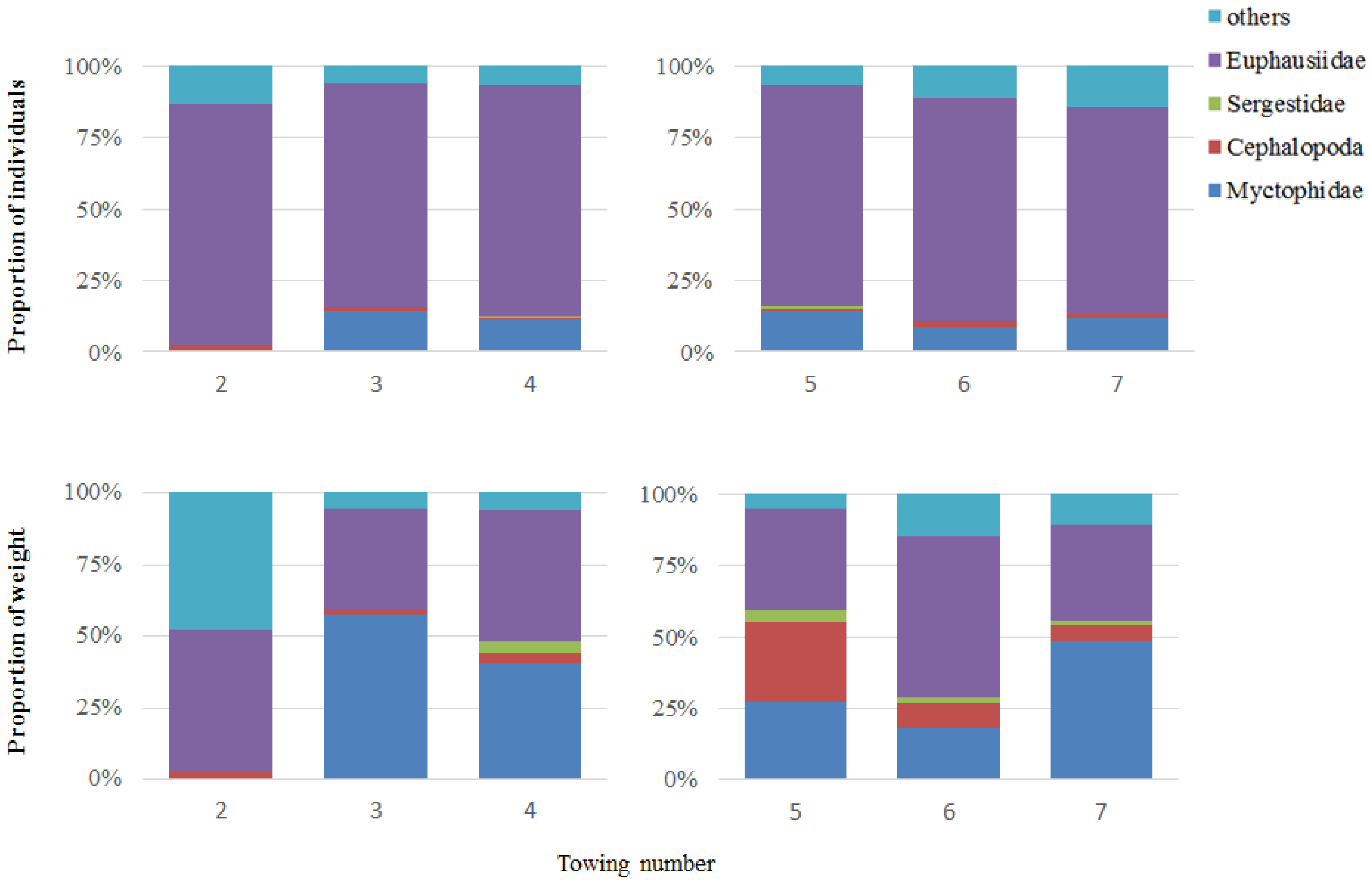

Fig. 5.4 Proportion of individuals/weight for specimen

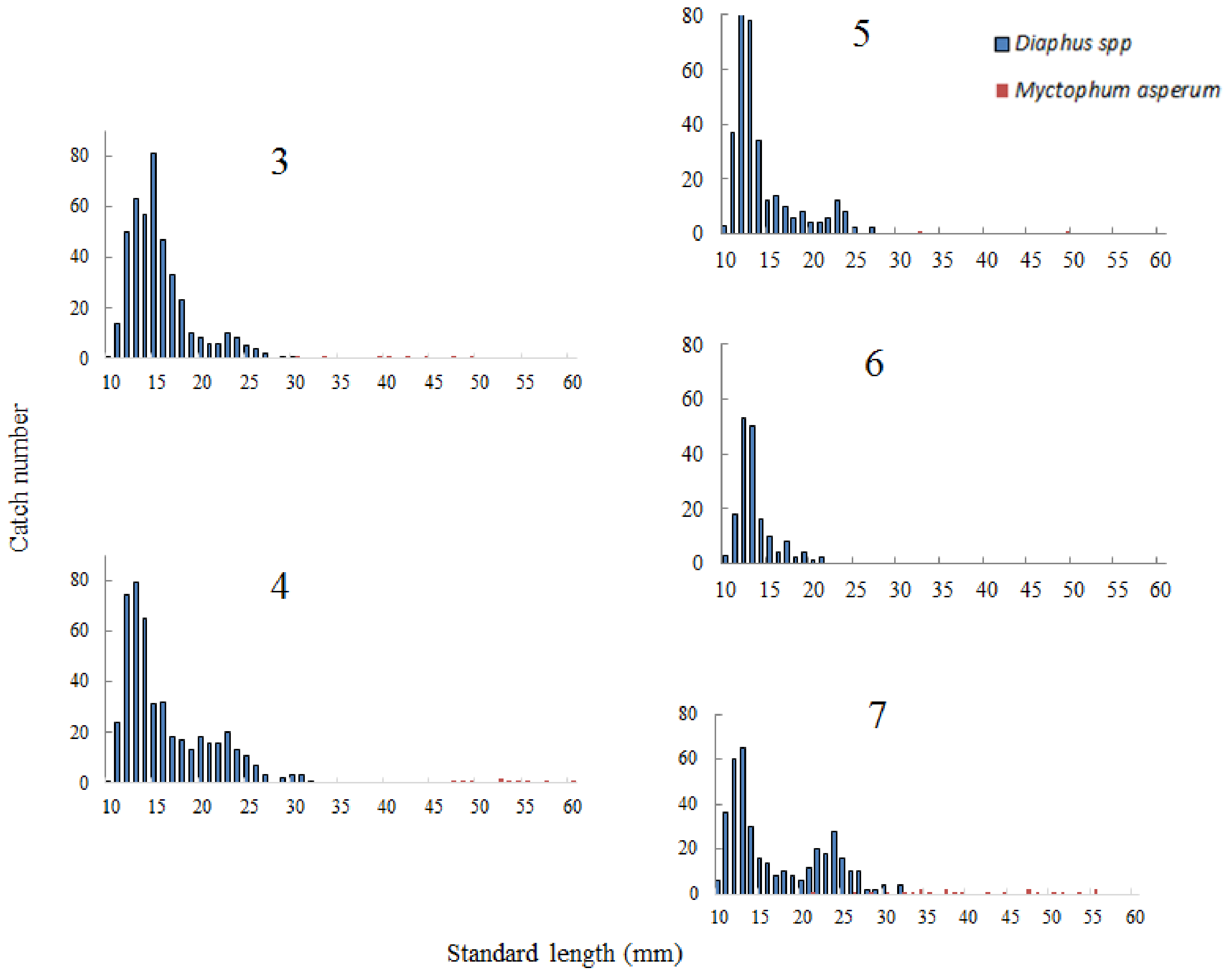

Fig. 5.5 Length distributions of lantern fishes

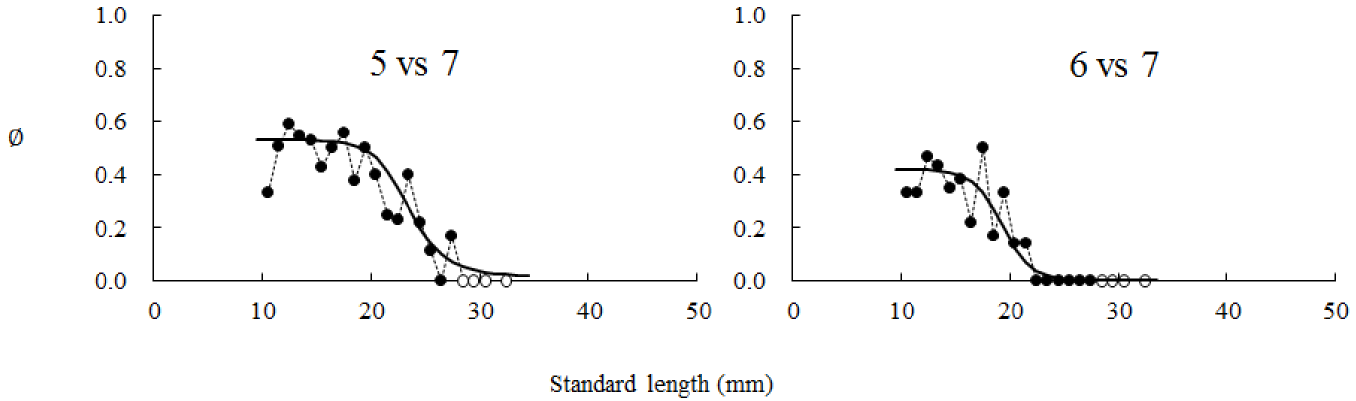

Fig. 5.6 Proportion of catch in slow speed haul for *Diaphus* spp

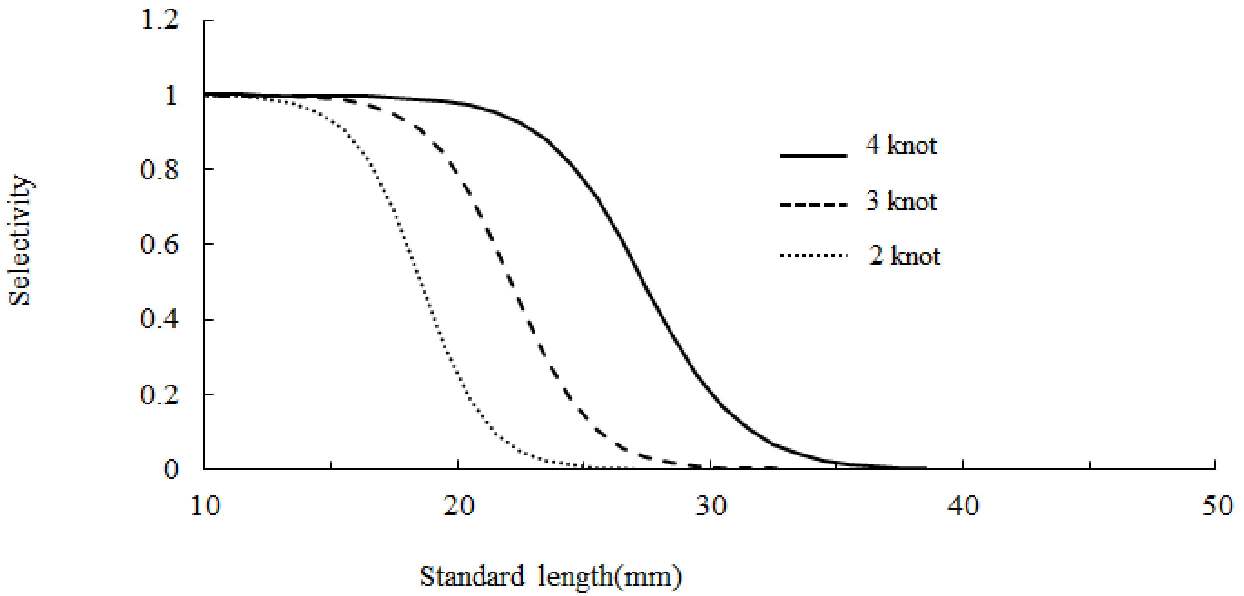

Fig. 5.7 Selection curves of net avoidance for *Diaphus* spp

Table 5.1 Towing condition of standard MOHT in horizontal tows

No.	start location		Start time	finish time	Vessel speed (knot)	Towing duration (min.)	count	Filtered volume(m^3)
	Latitude, N	Longitude, E						
2	31°59.00	128°44.23	18:47	19:22	3	35	4130	15526.32
3	31°58.88	128°46.43	19:35	20:06	2	31	3162	11887.22
4	31°58.52	128°47.99	20:14	20:49	4	35	4795	18026.32
5	31°57.52	128°50.16	20:56	21:25	3	29	3422	12864.66
6	31°56.28	128°51.34	21:33	21:57	2	24	2448	9203.01
7	31°55.12	128°51.60	22:03	22:34	4	31	4247	15966.17

Table 5.2 Taxonomic composition of catch number and weight for each codend

Towing no.		Myctophidae		Cephalopoda		Sergestidae		Euphausiidae		others		Total	
2	catch number	0	(0.000)	29	(0.026)	0	(0.000)	931	(0.843)	144	(0.130)	1104	(1.000)
	weight[mg]	0	(0.000)	520	(0.025)	0	(0.000)	10460	(0.501)	9910	(0.474)	20890	(1.000)
3	catch number	543	(0.147)	21	(0.006)	2	(0.001)	2910	(0.787)	223	(0.060)	3699	(1.000)
	weight[mg]	52990	(0.575)	1380	(0.015)	40	(0.000)	32640	(0.354)	5060	(0.055)	92110	(1.000)
4	catch number	807	(0.111)	55	(0.008)	51	(0.007)	5875	(0.810)	462	(0.064)	7250	(1.000)
	weight[mg]	57970	(0.405)	5340	(0.037)	5780	(0.040)	65570	(0.458)	8560	(0.060)	143220	(1.000)
5	catch number	839	(0.143)	41	(0.007)	58	(0.010)	4560	(0.776)	379	(0.064)	5877	(1.000)
	weight[mg]	35950	(0.272)	37100	(0.280)	5540	(0.042)	47090	(0.356)	6700	(0.051)	132380	(1.000)
6	catch number	229	(0.090)	41	(0.016)	11	(0.004)	1975	(0.778)	283	(0.111)	2539	(1.000)
	weight[mg]	6650	(0.183)	3160	(0.087)	750	(0.021)	20430	(0.563)	5300	(0.146)	36290	(1.000)
7	catch number	931	(0.116)	125	(0.016)	37	(0.005)	5780	(0.723)	1124	(0.141)	7997	(1.000)
	weight[mg]	86190	(0.486)	10060	(0.057)	3110	(0.018)	59600	(0.336)	18550	(0.105)	177510	(1.000)

Values in parentheses are percentage

Table 5.3 Length frequency distribution for *Diaphus* spp

Standard length (mm)	Towing number				
	3	4	5	6	7
10	1	1	3	3	6
11	14	24	37	18	36
12	50	74	87	53	60
13	63	79	78	50	65
14	57	65	34	16	30
15	81	31	12	10	16
16	47	32	14	4	14
17	33	18	10	8	8
18	23	17	6	2	10
19	10	13	8	4	8
20	8	18	4	1	6
21	6	16	4	2	12
22	6	16	6		20
23	10	20	12		18
24	8	13	8		28
25	5	11	2		16
26	4	7			10
27	2	3	2		10
28					2
29	1	2			2
30	1	3			4
31		3			
32		1			4
33					
34					
35					
Total	430	467	327	171	385

Table 5.4 Length frequency distribution for *Myctophum nitidulum*

Standard length (mm)	Towing number				
	3	4	5	6	7
20					
21					1
22					
23					
24					
25					
26					1
27					
28					1
29					
30	1				1
31					
32			1		1
33	1				1
34					2
35					1
36					
37					2
38					1
39	1				1
40	1				
41					
42	1				1
43					
44	1				1
45					
46					
47	1	1			2
48		1			1
49	1	1	1		
50					1
51					1
52		2			
53		1			1
54		1			
55		1			2
56					
57		1			
58					
59					
60		1			
Total	8	10	2	0	23

Table 5.5 Parameters for expressing size selectivity and the values of AIC

Model	*a*	*b*	*c*	*d*	*p1*	*p2*	MLL	AIC
Model A	-11.22	44.25	0.63	-2.35	0.49	0.35	-65.08	142.15[b]
Model B	0.00	14.03	0.12	-1.00	0.53	0.42	-66.74	143.48[a]
Model C	3.01	8.38	0.00	-0.77	0.53	0.42	-67.54	145.08
Model D	-12.97	50.18	0.72	-2.64	0.45	0.37	-66.49	140.98[b]
Model E	0.00	18.21	0.16	-1.25	0.45	0.37	-75.06	156.11
Model F	3.64	10.31	0.00	-0.90	0.45	0.37	-75.45	156.90

MLL, Maximum log-likelihood. AIC, Akaike's information criterion

[a] Model with the smallest AIC value

[b] In these models, extreme bias was observed in estimates of selection parameters

Table 5.6 Selection parameters in the optimal Model B

Towing speed	α	β	l_{50}	S.R.
4kt	14.03	-0.51	27.38	-4.29
3kt	14.03	-0.63	22.12	-3.47
2kt	14.03	-0.76	18.56	-2.91

Chapter 6. Acoustical biomass estimation

6.1 Introduction

Lantern fish (myctophid) are the most abundant group of mesopelagic fishes distributed all over the world's oceans. They feed on plankton, and play a big role as bait fish of large senior fish. They have an important role in the ecosystem. Therefore, the accurate biomass estimation of lantern fish is very important in such as aquaculture and oceanography fields. However, the current global biomass estimate of mesopelagic fishes, primarily based on catches by micronekton sampling gears, is likely an underestimate (Gjøsæter and Kawaguchi, 1980) because it is not ideal to capture them quantitatively by sampling gears. Regardless of trawl type, acoustic abundance estimates always appear to be consistently higher than the net-based estimates (Koslow et al., 1997; Kloser et al., 2009; Pakhomov and Yamamura, 2010). Acoustic abundance estimates were close to 2 orders of magnitude higher than estimates from the trawl and were roughly similar to previous acoustic estimates of *Benthosema glaciale* (one type of lantern fish) from Masfjorden (Bagøien et al., 2001).

In acoustic survey, target strength (TS) of the individual target is an essential value when estimating fish biomass. TS is a descriptor of the scattering amplitude widely used in sonar, which is defined as the logarithm of the ratio of the reflected and incident sound intensities weighted by the target to receive range. Swim bladder of a fish contributes 90~95% or more to its acoustic scatter (Foote, 1980), and so its presence and morphological features are most important considerations with regard to TS. However, knowledge about TS of the lantern fish is very scarce, and this is one of the important reasons why acoustics detection is so difficult to estimate myctophid biomass. For lantern fish, the growth of the swim bladder often does not grow in proportion to the rest of the body (McClatchie et al., 2003; Yasuma et al., 2003). Moreover, myctophid swimbladder condition varies among and within species, so there is huge variation in TS (Capen, 1967; Neighbors and Nafpaktitis, 1982; Yasuma et al., 2003). It is important to know how this condition changes with growth in each species.

Yasuma (2004) observed the swim bladder conditions of seven kinds of common lantern fish around Japan. According to his result, swim bladder conditions of main myctophid species in our study were as follows. For *Diaphus garmani*, all individuals under 30 mm length had no swim bladder. When the body length was over 30 mm, individuals with swim bladder began to appear, while individuals with no swim bladder were also existed at the same time. For *Ceratoscopelus warmingii*, individuals with no swim bladder were relatively smaller size about 23~43 mm in body length. However, when the length exceeded 33 mm, individuals with swim bladder began to appear as the development of their swim bladder. And when their length exceeded 43 mm, all individuals possessed swim bladders. For *Myctophum asperu*m, individuals with no swim bladder had two length range of 18~33 mm and 78~85 mm. In two length range, individuals with swim bladder existed at a range of 31~66 mm. Morphological studies of swim bladders in relation to acoustic backscatter have been conducted mainly on commercially important fish, such as gadoids and tuna (Foote, 1985; Bertrand and Josse, 2000), however there was little research on morphology and TS of lantern fishes. Furusawa (1988) was the first to describe fish swim bladders and bodies as prolate spheroids. Yasuma (2004) used the vacant prolate-spheroid model (PSM) to calculate the TS of dominant lantern fishes in the North Pacific. In this study, we used standard formula derived by Yasuma to estimate mean TS for all lantern fish collected in sea trials.

In this chapter, we try to evaluate fishing efficiency of MOC-MOHT by the comparison of lantern fish density estimated by acoustics and MOC-MOHT. For target strength of lantern fish calculated in acoustical method, we used estimated value under no net avoidance status based on selection model result in the previous chapter.

6.2 Materials and methods

6.2.1 Open sea trial

Samples were obtained from surveys conducted on board of Research vessel Kaiyou-maru (Fisheries Agency of Japan) in Sagami Bay, Pacific Ocean (34°58’-35°04’N, 139°17’-139°26’) on 19-20 July 2015. The R/V Kaiyou-maru is equipped with a Sonic KFS-3000 (Kaijo) echosounder system, operating at 38 and 120 kHz frequencies. Eight tows were carried out using MOC-MOHT with five nets with a mesh size of 1.59 mm. Each tow was conducted at night, and the target layer was identified with an echo-sounder around 40~50 m. Specimens collected in each codend net were preserved in 10% formalin and preserved in specimen bottles for further length distribution analysis in laboratory.

6.2.2 Data analysis

The area backscattering strength (SV) for the part of the water column swept by MOC-MOHT was recorded during all trawl operations. For visual scrutiny and for integration, Myriax Echoview® software 7.1 was used. The integration of SV resulted in mean nautical area scattering coefficients (NASC), in units of m^2 nmi^{-2} (nmi = nautical miles), which were then exported from Echoview® for further processing. For each hauls, the integrate regions were selected according to the sweeping area in experiments. In this experiment, MOC-MOHT had a 2×2 square frame mouth and depth sensor was set at the bottom of net mouth. So when we choose the integrate region, the height was set as 2 m, the same height of MOHT, and the width was set as the distance MOC-MOHT swept. Then the mean SV of integrate region was automatically outputted.

In this study, more than ten dominant species myctophid in Sagami Bay were collected, but there were no accurate TS information for each species. Besides, the swim bladder conditions for each species were even unknown. In order to calculate the mean TS all the lanterns fish, we made two assumptions in the analysis of mean target strength. One is that all the lanterns fish have a swim bladder. The other one is that all the lanterns fish have the same relational expression between target strength and standard length, and we use the standard formula of *Diaphus garmani* at 38 khz estimated by Yasuma (2004). TS (dB) = 34.5×log (Ls)-89.2, where TS is in dB and Ls is in cm.

Under the influence of net avoidance, catch number of lantern fish in MOC-MOHT was less than actual fish assemblage in front of net because large fish could not be caught effectively. In order to obtain all number of lantern fish under no influence of net avoidance, we used improved method with selection curve estimated in previous chapter. Net avoidance which occurred at low towing speed was expressed by a monotonic decreasing logistic function $a(l)$ with logistic parameters α and β.

$$a(l) = \frac{\exp(\alpha + \beta l)}{1 + \exp(\alpha + \beta l)} \qquad (1)$$

Catch number of lantern fish in MOC-MOHT was denoted by observed value $C_T(l)$, and all number of lantern fish under no influence was denoted by estimated value $C_A(l)$, respectively. Here, estimated value was obtained as follows:

$$C_A(l) = \frac{C_T(l)}{a(l)} \qquad (2)$$

Mean target strength of lantern fish was denoted as follows, where $< TS >$ is Mean target strength, $p_{df}(l)$ is proportion of catch number in same length group to total catch number.

$$<TS> = \frac{\int TS(l) p_{df}(l) dl}{\int p_{df}(l) dl} = \frac{\sum TS(l) p_{df}(l)}{\sum p_{df}(l)} \qquad (3)$$

Density of lanterns fish was defined as: $d = \frac{<SV>}{<TS>}$, where $< SV >$ is Mean volume backscattering strength.

6.3 Results

6.3.1 Nighttime Echograms in each haul

Echograms obtained at 38 and 120 khz at night were shown in Fig. 6.1, Fig. 6.2 and Fig. 6.3. Water depths were set at a range of 0~100 m from 2^{nd} ~7^{th} hauls, and the 0~70 m in 8^{th} and 9^{th} hauls. The color bar expressed strength of the reflection was set at a range of -25~-70 dB. Reflection area was more disperse at 120 khz than 38 khz. In 2^{nd} ~ 7^{th} hauls, obvious reflect areas were seen in water depth shallower than 60 m. Especially in 2^{nd} haul, there was obvious reflect belt at water depth of 50 m. In the 8^{th} and 9^{th} hauls, several reflect patches were distributed within 70 m water depth. It is clearly seen that lantern fish had a rise trend over the period of time, and the most strongest reflect area were gathered in 40~50 m depth.

6.3.2 Volume backscattering strength

At 38 khz channels, the values of SV(Volume backscattering strength) were -66.25, -65.85 and -65.93 dB in 2, 3 and 4 hauls, -64.83, -65.54 and -65.31 dB in 5, 6 and 7 hauls, -64.18, -63.32 and -65.74 dB in 9-②, 9-③ and 9-④ hauls, respectively. From which we can see, the SV values were approximate in each set of 4, 3 and 2 knot hauls. At 120 khz channels, the values of SV were -66.91, -66.72 and -66.28 dB in 2, 3 and 4 hauls, -66.46, -66.54 and -67.12 dB in 5, 6 and 7 hauls, -66.34, -66.52 and -68.41 dB in 9-②, 9-③ and 9-④ hauls, respectively. When compared SV values in same hauls at 38 and 120 khz, there was no significant difference between these two channels.

6.3.3 Target strength

Length distribution of all species lantern fish were shown in Table 6.1 and Fig. 6.4. The standard length were at a range of 13~72 mm, 11~66 mm and 12~58 mm in 2, 3 and 4 hauls, 11~66 mm, 11~66 mm and 10~56 mm in 5, 6 and 7 hauls, 13~66 mm, 12~62 mm and 12~58 mm in 5, 6 and 7 hauls, respectively. Relationship formula of *Diaphus garmani* TS=34.5log (Ls)-89.2 was used, where TS is in dB and Ls is in cm. When using catch number of lantern fish in MOC-MOHT, we obtained the TS values of -70.23, -69.51 and -72.71 dB in 2, 3 and 4 hauls, -71.46, -74.20 and -75.70 dB in 5, 6 and 7 hauls, -73.68, -74.65 and -75.01 dB in 9-②, 9-③ and 9-④ hauls, respectively. In comparison, when using all number of lantern fish under no influence, we obtained the TS values of -62.14, -63.48 and -64.37 dB in 2, 3 and 4 hauls, -63.96, -63.05 and -65.78 dB in 5, 6 and 7 hauls, -64.15, -64.26 and -64.40 dB in 9-②, 9-③ and 9-④ hauls, respectively.

6.3.4 Comparative biomass between acoustic and sampling gears

Estimated densities of lantern fish by the acoustics and MOC-MOHT net are presented in Table 6.2 and Table 6.3. The density of lantern fish estimated by acoustical method were 2.50, 2.32 and 4.77 ind.m^{-3} in 2, 3 and 4 hauls, 4.61, 7.34 and 10.93 ind.m^{-3} in 5, 6 and 7 hauls, 8.90, 13.60 and 8.45 ind.m^{-3} in 9-②, 9-③ and 9-④ hauls, respectively. Correspondingly, the density of lantern fish estimated by MOC-MOHT net were 0.05, 0.04 and 0.07 ind.m^{-3} in 2, 3 and 4 hauls, 0.09, 0.08 and 0.08 ind.m^{-3} in 5, 6 and 7 hauls, 0.12, 0.08 and 0.07 ind.m^{-3} in 9-②, 9-③ and 9-④ hauls, respectively. It showed density of lantern fish at 4 knot haul was higher than other hauls except in the 4th haul. When compared with acoustics, estimated density of lantern fish by MOC-MOHT was showed less value, about 50 to 170 times in difference.

When the length distribution was compensated using selection curve (Fig. 6.5), estimated densities of lantern fish by the acoustics and MOC-MOHT net are presented in Table 6.4 and Table 6.5. The density of lantern fish estimated by acoustical method were 0.39, 0.58 and 0.70 ind.m^{-3} in 2, 3 and 4 hauls, 0.82, 0.56 and 1.11 ind.m^{-3} in 5, 6 and 7 hauls, 0.99, 1.25 and 0.73 ind.m^{-3} in 9-②, 9-③ and 9-④ hauls, respectively. Then compared fish density between MOC-MOHT and acoustic, the difference was narrowed, about 7 to 15 times in difference.

6.4 Discussion

Based on our previous chapters, net avoidance was existed not only at relatively slower towing of 2 and 3 knot, but also existed at high speed of 4 knot. Under the influence of net avoidance, density estimates by MOC-MOHT was underestimated, to be about 2 orders of magnitude smaller than that estimates by acoustic. Considering the net avoidance, large fish with higher swimming ability could not be caught effectively. When we calculate TS, it would be an underestimation because larger fish with higher TS were less collected. At the same time, we obtained mean SV from echogram automatically. Fish density d was estimated by SV and TS. Therefore, TS with an underestimated value would lead to overestimation of fish density. In order to estimate number of lantern fish catch under no influence of net avoidance, we compensated length distribution of lantern fish using selection curve. As a result, density estimates by MOC-MOHT was 1 order of magnitude less than that of acoustic survey.

Considering many other fish juveniles were also collected at the same time by MOC-MOHT, differences in density become smaller between MOC-MOHT and acoustic. Except for lantern fish, other specimens including *Cephalopoda, Euphausiidae, Sergestidae*, other micronekton fish were also collected in towing experiments. Since *Cephalopoda, Euphausiidae* and *Sergestidae* have no swim bladders, the TS are more than ten times weaker than the same size of lantern fish (Yasuma, 2004). Therefore, reflection of these species was very small and can be ignored. However, other micronekton fish with swim bladder may have an influence on calculating SV. Meanwhile, in the process of towing, large sized fish whose reflection were stronger than lantern fish which are not collected by sampling gear may also causing overestimation on SV.

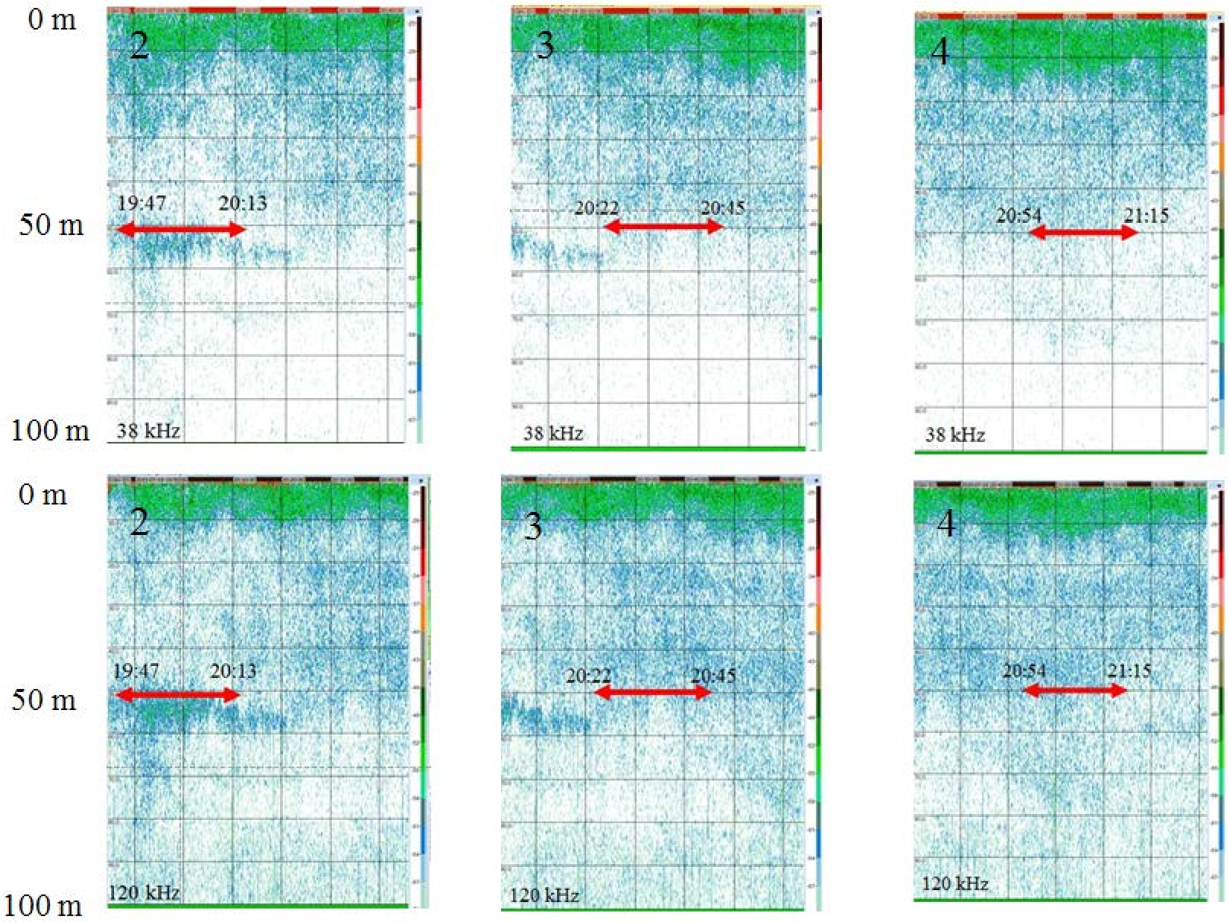

Fig. 6.1 Nighttime echogram recorded passing area in 2 , 3 and 4 hauls

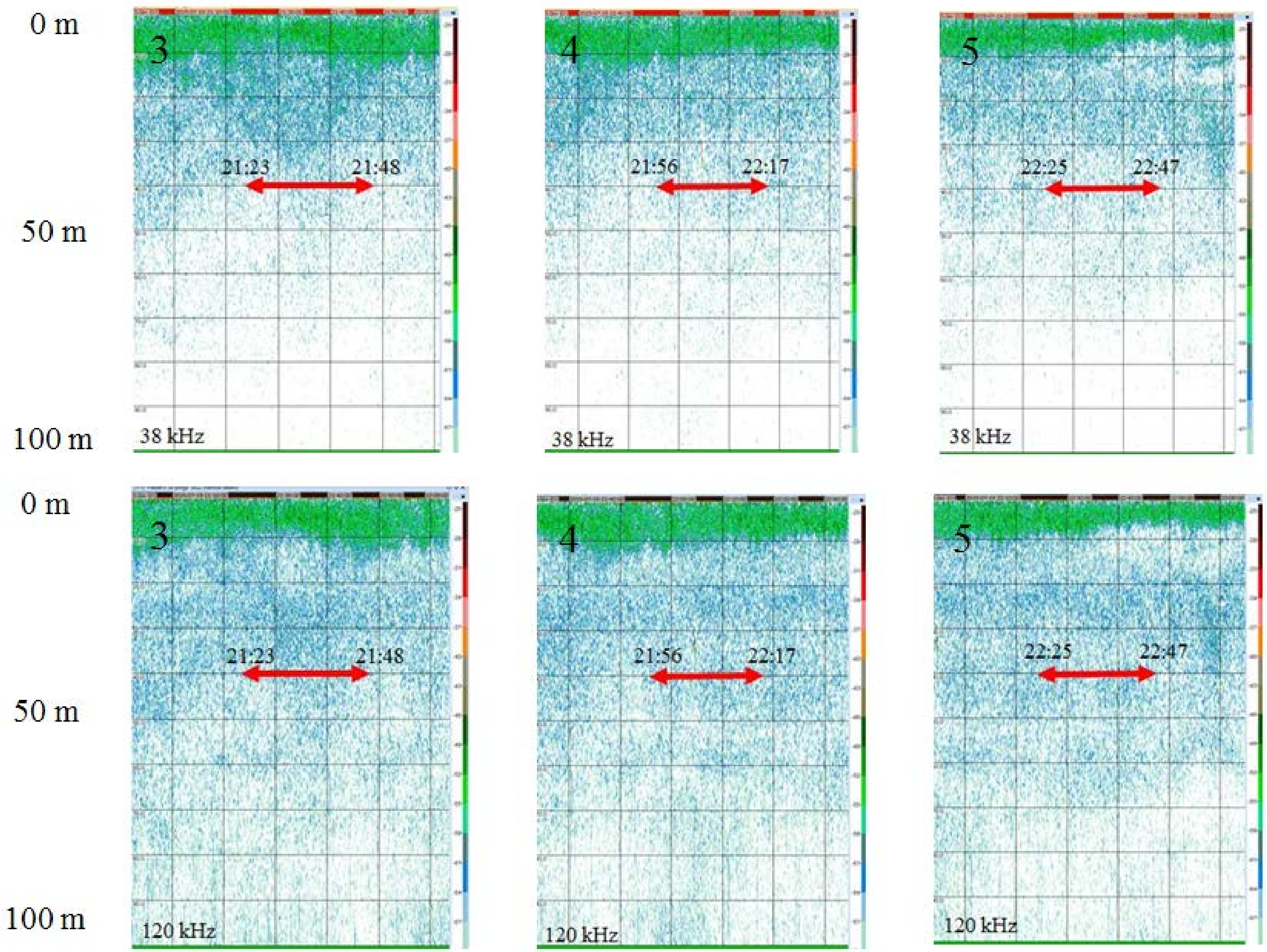

Fig. 6.2 Nighttime echogram recorded passing area in 5 , 6 and 7 hauls

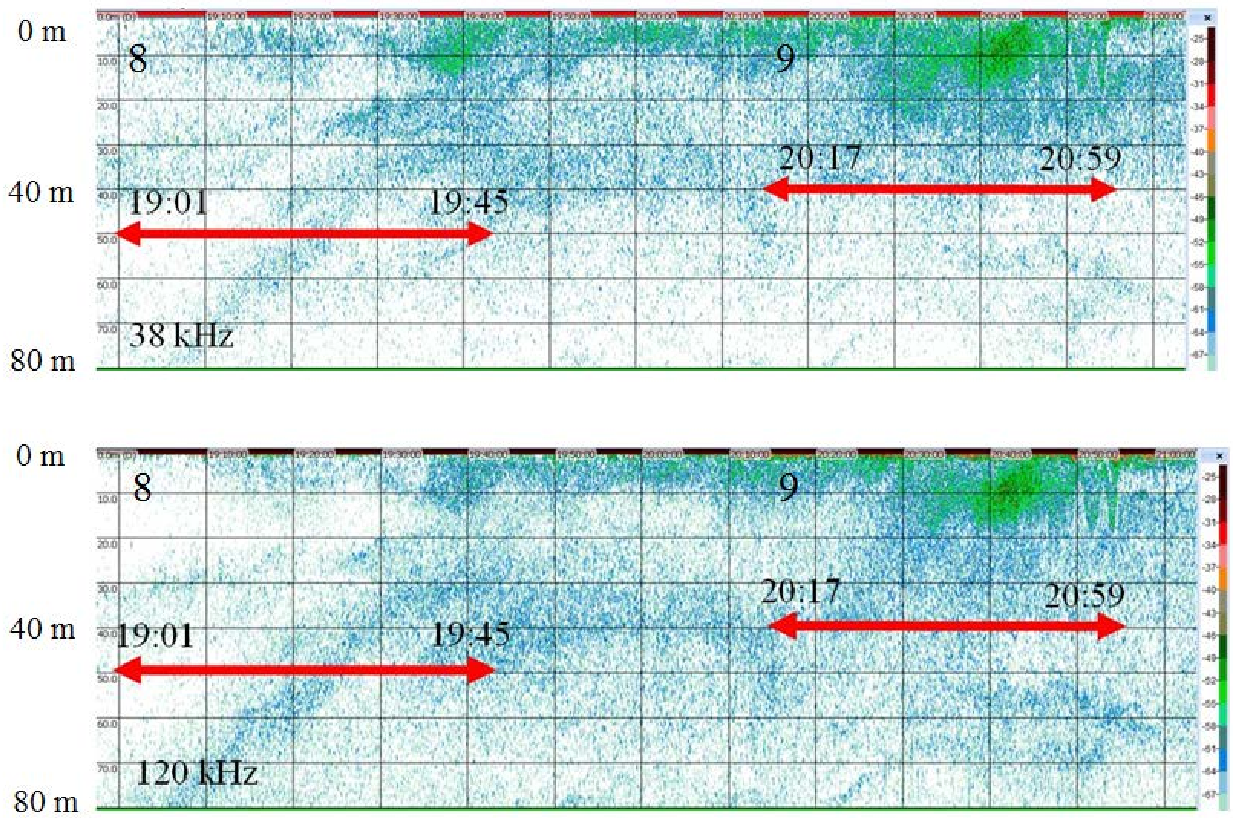

Fig. 6.3 Nighttime echogram recorded passing area in 8 and 9 hauls

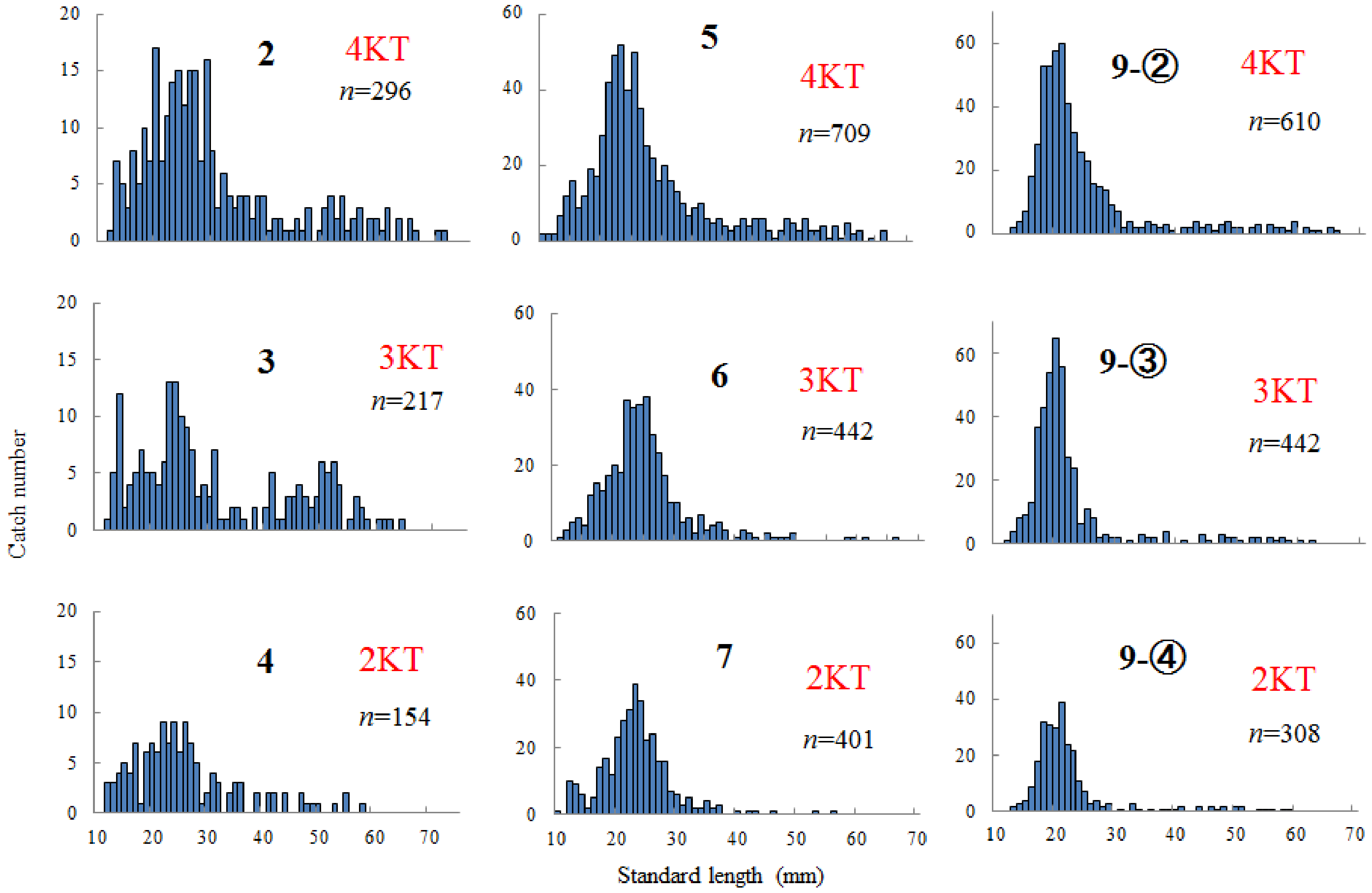

Fig. 6.4 Standard length compositions in lantern fish caught in each codends

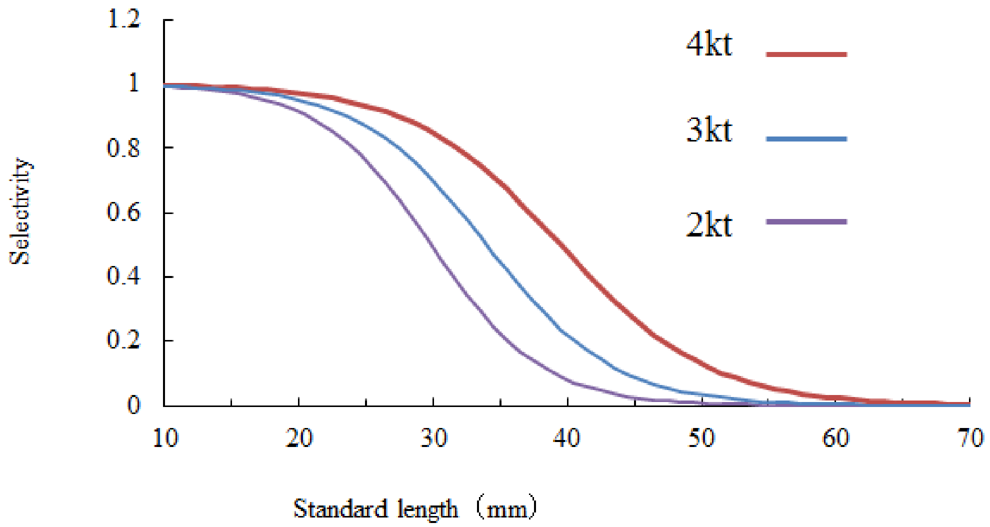

Fig. 6.5 Selection curves of net avoidance for lantern fish

Table 6.1 Length frequency distribution for all species of lantern fish

Standard length (mm)	Towing number								
	2	3	4	5	6	7	9-②	9-③	9-④
10				2		1			
11				2	1	0			
12	1	1	3	2	3	10		1	2
13	7	5	3	7	5	9	2	4	3
14	5	12	4	12	6	6	4	8	4
15	3	2	5	16	4	2	7	9	9
16	8	4	4	9	12	5	20	13	18
17	5	5	7	12	15	14	28	37	32
18	10	7	1	19	13	17	60	43	31
19	7	5	6	17	17	12	55	54	30
20	17	5	7	28	20	23	60	65	39
21	7	4	6	42	18	28	61	56	24
22	11	6	9	49	37	31	42	27	22
23	14	13	7	52	35	39	32	24	11
24	15	13	9	40	36	34	26	6	7
25	12	10	6	50	38	22	23	11	3
26	15	9	9	35	28	24	16	8	4
27	15	7	7	25	23	16	15	2	2
28	7	3	5	22	17	16	14	3	3
29	17	4	1	16	10	7	6	2	
30	8	3	2	20	10	6	7	2	1
31	3	7	4	16	5	3	2		
32	6	1	3	13	6	5	4	1	3
33	4	1		10	2	2	1		1
34	3	2	2	7	7	2	2	3	
35	4	2	3	9	3	4	3	2	1
36	4	1	3	10	4	2	3	2	
37	2			6	5	3	2		1
38	4	2		5	3		1	4	1
39	4		2	6			1		1
40	1	2		4	1	1	1		2
41	2	5	2	3	3		2	1	
42	2	1	2	4	2	1	2		
43	1	1		6	1	1	4		2
44	1	3	2	4			2	3	
45	2	3		6	2		3	1	2
46	1	4		6	1	1	3		1
47	3	3	2	3	1		3	3	2
48		2	1	1	1		3	2	
49	1	3	1	3	2		1	2	2
50	3	6	1	6			2	1	2
51	4	5		5			1		
52	2	6		3			2	2	

53	4	4	1	6		1	2	2	1
54	1			3					1
55	2	1	2	3			1	2	1
56	3	3		4		1		1	
57		2		1			1	2	1
58	2	1	1	4	1		1	1	1
59	2			1	1		4		
60	1	1		5				1	
61	3	1		2	1		1		
62		1		3				1	
63	2						1		
64		1		1					
65	2						2		
66	1			3	1		1		
67		1							
~									
72	1								
Total	265	194	133	649	401	349	540	412	271

Table 6.2 Fish density estimated by MOC-MOHT and acoustic under the influence of net avoidance

Towing number	Towing speed (knot)	MOC-MOHT			Acoustics		
		Catch number (inds.)	Filtered water (m^3)	Density (inds./m3)	<TS> (dB)	<SV> (dB)	Density (inds./m^3)
2	4	296	5628	0.05	-70.23	-66.3	2.5
3	3	217	5160	0.04	-69.51	-65.9	2.32
4	2	154	2305	0.07	-72.71	-65.9	4.77
5	4	709	7843	0.09	-71.46	-64.8	4.61
6	3	442	5831	0.08	-74.2	-65.5	7.34
7	2	394	4898	0.08	-75.7	-65.3	10.93
9-②	4	610	5255	0.12	-73.68	-64.2	8.9
9-③	3	432	5215	0.08	-74.65	-63.3	13.6
9-④	2	307	4206	0.07	-75.01	-65.7	8.45

Table 6.3 Comparison in density between MOC-MOHT and acoustic

Towing number	Towing speed (knot)	MOC-MOHT (inds./m^3)	Acoustics (inds./m^3)	Acoustics / MOC-MOHT
2	4	0.05	2.5	50.0
3	3	0.04	2.32	58.0
4	2	0.07	4.77	68.1
5	4	0.09	4.61	51.2
6	3	0.08	7.34	91.7
7	2	0.08	10.93	136.6
9-②	4	0.12	8.9	74.2
9-③	3	0.08	13.6	170.0
9-④	2	0.07	8.45	120.7

Table 6.4 Fish density estimated by MOC-MOHT and acoustic under no influence of net avoidance

Towing number	Towing speed (knot)	MOC-MOHT			Acoustics		
		Catch number (inds.)	Filtered water (m^3)	Density (inds./m3)	<TS> (dB)	<SV> (dB)	Density (inds./m^3)
2	4	296	5628	0.05	-62.14	-63.48	0.39
3	3	217	5160	0.04	-69.51	-65.85	0.58
4	2	154	2305	0.07	-72.71	-65.93	0.7
5	4	709	7843	0.09	-71.46	-64.83	0.82
6	3	442	5831	0.08	-74.2	-65.54	0.56
7	2	394	4898	0.08	-75.7	-65.31	1.11
9-②	4	610	5255	0.12	-73.68	-64.18	0.99
9-③	3	432	5215	0.08	-74.65	-63.32	1.25
9-④	2	307	4206	0.07	-75.01	-65.74	0.73

Table 6.5 Comparison in density between MOC-MOHT and acoustic

Towing number	Towing speed (knot)	MOC-MOHT (inds./m^3)	Acoustics (inds./m^3)	Acoustics / MOC-MOHT
2	4	0.05	0.39	7.8
3	3	0.04	0.58	14.5
4	2	0.07	0.7	10.0
5	4	0.09	0.82	9.1
6	3	0.08	0.56	7.0
7	2	0.08	1.11	13.9
9-②	4	0.12	0.99	8.2
9-③	3	0.08	1.25	15.6
9-④	2	0.07	0.73	10.4

Chapter 7. General Discussion

7.1 Factors influencing the catching efficiency

Catch efficiency is defined as the ratio of the number of caught fish to the number of fish existing in front of the net. The target fish whether evading the fishing net or escaping through net mesh, would both determine the retention of caught fish. When fishing gear is capturing the target fish, the possibilities of entering and mesh retention would affect the catch efficiency. In this study, we assumed two hypotheses: before entering the net larger individuals tend to evade due to their faster swimming speed, that is, net avoidance; after young fish entering the trawl net, fish having enough small body escape through the mesh space of the net, which is called mesh selectivity. As a result, we clarified factors affecting the catching efficiency such as fish size associated with swimming ability, net mouth dimension, and towing speed. For sampling gears with different mesh size, net with smaller mesh size caught more small sized fish. For various sampling gears with different net mouth, net avoidance more obviously occurred in smaller and unfixed net mouth. For the same sampling gear at various towing speeds of 2, 3 and 4 knots, net avoidance was more prevalent at lower towing speed.

7.2 Mesh selectivity and net avoidance for IKMT and MOHT nets

Comparative experiments were carried out to analyze mesh selectivity of the polyethylene net and size selectivity of net avoidance for small MOHT, IKPT and IKMT nets. In this study for polyethylene net, 50% retention length and selection range were 12.20 and 2.82mm, respectively. MOHT trawl can collected almost all anchovies larger than 15mm. Saiura *et al* (2006) illuminate that in seine fisheries, mesh size of minnow netting was 1.56mm, the similar mesh size as MOHT trawl (1.59mm), which has 50% retention length of 8.34~12.54mm and selection range of 2.40~2.76mm. Hence, our results agree with that of Saiura *et al* (2006). When compared with standard MOHT, large sized fish were not efficiently collected in IKPT, IKMT and small MOHT. It indicated that net avoidance occurred in IKPT, IKMT and small MOHT. When compared small MOHT and standard MOHT, confirming net avoidance of larger anchovies due to the smaller mouth area. When compared IKPT and IKMT, there were no anchovies larger than 25mm collected in IKPT. The filter efficiency may also be lower in smaller mesh size, so we need to discuss the influence of filtered water on different mesh size in the future.

7.3 Effect of towing speed and fish body size on net avoidance

In this study, standard MOHT, multiple layer sampling COC-MOHT and MOC-MOHT were used to evaluate the effect of towing speed on net avoidance. We clarified that net avoidance not only occur at relatively lower towing speed of 2 and 3 knots, but also occur at relatively higher towing speed of 4 knots. Further, we established linear model to obtain the relationship between towing speed and standard length of lantern fish. For specimen of lantern fish, we used length distribution of *Diaphu*s spp for data analysis due to their dominance in retained catch of each MOHT net. The result showed that the 50% retention length of 4, 3 and 2 knots were 38.19, 29.06 and 23.46mm for MOC-MOHT, 42.35, 35.87 and 29.40mm for COC-MOHT, and

27.38, 22.12 and 18.56mm for standard MOHT, respectively. This suggested that the net avoidance was more apparent in standard MOHT than MOC-MOHT and COC-MOHT. The experimental areas were Sagami bay for MOC-MOHT and COC-MOHT, and the East China Sea for standard MOHT. *Diaphus* spp were ranged from 10 to 32mm in standard MOHT, 10 to 40mm in MOC-MOHT and 10 to 44mm in COC-MOHT. As can be seen from the length distribution of lantern fish, *Diaphus* spp collected in standard MOHT were smaller than the other two sampling gears, and the size of *Diaphus* spp were similar in MOC-MOHT and COC-MOHT. Therefore, the different experimental areas might cause the difference in length distribution. For MOC-MOHT and COC-MOHT in Sagami bay, the net avoidance of 4, 3 and 2 knots were larger in MOC-MOHT than COC-MOHT. For these two kinds of sampling gears, they have different mouth dimensions. For MOC-MOHT, it has a frame mouth of 4 m^2 and a main frame with a vertical bar of net stacking structure. In contrast, COC-MOHT has a frame mouth the same as standard MOHT of $5m^2$. The difference in net avoidance between the two fishing gears was probably because smaller mouth exihibit larger net avoidance, and complex frame structure of MOC-MOHT might also cause larger net avoidance.

7.4 Comparison in lantern fish densities between MOC-MOHT sampling and acoustics survey

Under the influence of net avoidance, density estimates by MOC-MOHT was underestimated, found to be about 2 orders of magnitude smaller than that estimates of acoustic. Taking into consideration of net avoidance, large fish with higher swimming ability could not be caught effectively. When we calculate target strength (TS), it would be an underestimation because few larger fish with higher TS were collected. In this study, we used the standard formula of *Diaphus garmani* to express all species of lantern fish. The formula was denoted as TS (dB) = 34.5 × log (Ls)-89.2, where TS is in dB and Ls is standard length in cm. Using this formula, we can see that target strength becomes larger with the increase of standard length. However, large sized fish has higher swimming speed to escape in front of the net. As selection curve was calculated in previous chapter, it indicated that fish with standard length larger than 35, 40 and 55 mm were difficult to be captured at towing speed of 2, 3 and 4 knots. Therefore, TS estimated by observed data using sampling gear was underestimated in state of net avoidance. In order to estimate catch number of lantern fish under no influence of net avoidance, we compensated length distribution of lantern fish using selection curve. As a result, density estimates by MOC-MOHT was 1 order of magnitude less than that of acoustic survey.

This study is the first to use actual sea experimental field data to establish evaluation model of main factors affecting fishing efficiency, including fish size, net mouth dimension, mesh size and towing speed of several sampling trawl gear, and evaluated the effect of net avoidance on fish stock assessment in comparison with the acoustics. The methods and approaches established in this study are useful for many other species to obtain better estimation of fish stock from sampling trawl gear surveys. In understanding of catching efficiency for these sampling gears, we are looking forward to contributing of more precise resource assessments.

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