Doctoral Thesis

Fishery biology of whitespotted conger *Conger myriaster* in the eastern Seto Inland Sea, Japan

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Abstract

The whitespotted conger *Conger myriaster* is a benthic, commercially important marine fish and usually caught by the small trawl fishery in the eastern Seto Inland Sea. The species migrates as leptocephali (transparent willow-leaf-shaped larvae) to this region in early spring, spends a certain period, and then leaves probably for the spawning ground. Since 1993, a survey for the fishery stock management of whitespotted conger has been conducted in the eastern Seto Inland Sea off Hyogo Prefecture. The primary purpose of this study is to clarify biological characteristics of the species in this sea during its life history from larval recruitment to probable spawning migration in order to get knowledge for the fishery stock management.

The occurrence of whitespotted conger leptocephali in the northeastern Harima Nada Sea is described. Their migration to the region was observed from February to May (mainly from March to April) when sea surface temperature measured 8-18°C. The leptocephali occurred mainly in the bottom layer, but they spread to the surface at night. A half of them migrating to the region were found to be at metamorphosing stage.

A large number of whitespotted conger leptocephali were caught as bycatch by the boat seine fishery during their migration. The fishery is likely to give a negative impact on the stock abundance of the species. Bycatch of the leptocephali is not desirable.

The distribution and feeding habits of the newly settled juveniles of whitespotted conger are reported. No juveniles were sampled from the sand bottom, but they occurred on the gravel and sand-mud bottoms. The main stomach contents of the juveniles were crustaceans, polychaetes, and teleosts. Crustaceans were strongly preferred, being the most common and numerically important prey. The juveniles initially fed on amphipods and, with growth, shifted their prey to decapods, polychaetes, and teleosts. The density abundance of the juveniles from the sand-mud bottom was significantly higher than that of the fish from the gravel bottom although the crustacean biomass on the gravel bottom was more abundant than that on the sand-mud bottom. Therefore, it is considered that whitespotted conger juveniles choose their habitat not by the food environment but by the bottom sediment type. The sand-mud bottom is a nursery ground for juvenile whitespotted conger.

The growth of whitespotted conger in captivity is studied for their three stages (leptocephali, newly settled juveniles, and young fish) by feeding them on commercially

available moist pellets or dry pellets. The leptocephali completed metamorphosis without any feeding. Both the newly settled juveniles and young fish could be reared by feeding the pellets of two types. The juveniles grew from less than 100 mm in total length (TL) in May to 300 mm TL in October, and some fish reached over 500 mm TL within a year. It is thus possible that the species is cultured from its juvenile stage and, by short-time rearing, to add a commercial value to those juveniles which are not commercially utilized.

The age and growth of whitespotted conger caught in the eastern Seto Inland Sea are analyzed. Sagittal otoliths were validated for the seasonality of annuli formation and found to be used as an age character. The maximum age of the fish examined was 5. They showed a wide variation in TL in the same year class and also a complicated age composition in the same TL class. The male- and female-biased sex ratios were recorded for the small- and large-sized fish, respectively.

The growth and migration of whitespotted conger are investigated by tagging study. They migrated from the northeastern Harima Nada Sea to Osaka Bay and the Kii Channel through the Akashi Strait from January to August. The TL and gonadosomatic index of the females recaptured in Osaka Bay and the Kii Channel were larger and higher, respectively, than those in the northeastern Harima Nada Sea and the Akashi Strait, which suggests that the females conduct a pre- or spawning migration. Nevertheless, in addition to such migratory fish, the presence of locally resident fish is suggested, and the species may have complicated migratory habits. The fish were recaptured up to 420 days after release and exhibited various growth rates ranging from 0.1-2 mm day^{-1}, which is almost equivalent to about 20 cm year^{-1}.

The average annual catch of whitespotted conger was 1,700 metric tons (mt) from 1984 to 1997 in the eastern Seto Inland Sea off Hyogo Prefecture, but the annual catch decreased to 562 mt in 1999. Subsequently, it slightly recovered during the early 2000’s. The fluctuation of the annual catch is considered to be related to annual changes in abundance of the leptocephali migrating to the region. Whitespotted conger in this sea were mostly caught by the small trawl fishery and ranged from 250-450 mm TL. They recruit to the fishery at 250 mm TL in fall and were continuously caught for a year.

The mesh and artificial selectivities of whitespotted conger in the small trawl fishery are studied in the northeastern Harima Nada Sea, and a possible use of enlarged mesh size for the codend is discussed as an option for the stock management. A 50% mesh selected TL was estimated as 282 mm, and it is desirable to enlarge the codend mesh size from 23 to 26 mm if the conditions are permitted in the region.

Various biological aspects of whitespotted conger caught in the Akashi Strait are described. There were one or two size groups in monthly length frequency distribution, and the large-sized females (>500 mm TL) were dominant in the catch. The Akashi Strait is likely to be one of the important habitats for the growth and maturation of the species. The females seem to spend up to four years there and may begin the pre- or spawning migration by age-5 to other waters.

Based on this study, several measures are proposed to efficiently utilize the stock of whitespotted conger in the eastern Seto Inland Sea as follows: 1) although correlation between the bycatch and stock abundance of the species is yet unclear, we need to minimize the bycatch of the leptocephali by the boat seine fishery, which may also reduce unintentional bycatches of other valuable species; 2) since the sand-mud bottom is an important habitat for the juveniles, it is necessary to conserve such areas as their nursery ground; and 3) we need to consider the effective utilization of the small-sized fish (<300 mm TL), which are mainly caught by the small trawl fishery. Their wholesale price is about as half as that of the medium-sized fish, then by enlarging the codend mesh size in the small trawl fishery, we can reduce the catch of the small-sized fish and expect to increase the catch sales.

While much information has been accumulated through this study on the biology of whitespotted conger in the eastern Seto Inland Sea, we need more work as follows: 1) a monitoring survey to determine the annual abundance of the leptocephali migrating to the region; 2) an investigation into the sex ratio of the species by age (fish size) and region; 3) a study on the reproductive biology and farming of the species; and 4) a survey on the spawning ground of the species, which is totally unknown in Japanese waters.

I. Introduction

The whitespotted conger *Conger myriaster* (Brevoort, 1856) is a bottom-dwelling, marine fish and widely distributed in inshore waters of the Far East Asia, including China, Korea, and Japan (Asano 1984; Park 2001; Tokimura 2001; Tokimura and Yamada 2001). In Japan, this species is a popular cooking ingredient for *Tempura*, *Sushi*, *Yaki-anago* (= grilled conger), and *Ni-anago* (= boiled conger). *Yaki-anago* is preferred in the Kansai area, while *Ni-anago* is popular in the Kanto area. The species migrates as leptocephali (transparent willow-leaf-shaped larvae) to Japanese waters (Kurogi 2008), probably spends a certain period in the coastal sea areas, and then leaves there for a yet unknown spawning ground.

Whitespotted conger are commercially caught using different types of fishing gear in Japanese waters, including trawls, longlines, tube traps, and pots. The catch in Japanese waters declined from 13,000 to 8,200 metric tons (mt) during 1995 to 1999. It decreased gradually from 2000 to 2008 and was 6,339 mt in 2008. The average catch from 1995 to 2008 was 8,900 mt. Among various fishing grounds around Japan, the Seto Inland Sea provides the largest catch of the species (32% of the country catch in 2008), followed by the mid-Pacific Ocean waters (20%). The catch trend in the Seto Inland Sea well coincides with that in Japanese waters: the annual catch was 6,000 mt in 1995, but it decreased gradually and was about 2,000 mt in recent years (Fig. I-1) (Anon. 1997-2010).

The eastern Seto Inland Sea consists of three regions (i.e., the Harima Nada Sea, Osaka Bay, and the Kii Channel) (Fig. I-2). Both in the Harima Nada Sea and Kii Channel, whitespotted conger are mostly caught by the small trawl fishery, while in Osaka Bay, they are mainly taken by the pot fishery (Nabeshima et al. 1995). The catch in the Kii Channel is considerably lower than those in the two other waters (Fig. I-3) (Anon. 1997-2007).

Several studies have been conducted on the biology of whitespotted conger in Japan. Previous works, however, mainly focused on the early life history of the species (Tanaka et al. 1987; Yamano et al. 1991; Lee and Byun 1996; Otake et al. 1997; Kimura et al. 2004). There are only a few fishery biological studies which provide preliminary information on the feeding habit (Takai 1959; Mori and Inoue 1982; Matsumiya and Imai 1987; Fukuda et al. 1997), age and growth (Ishida et al. 2003; Nemoto et al. 2004; Takashima and Takahashi 2006), and ecology (Shimizu 2003; Katayama et al. 2004; Nemoto 2007). In addition, several works currently have focused on the reproductive biology (Okamura and Motonobu

1999; Utoh et al. 2003; Chiba et al. 2005). Although no sexually matured fish have been found to date in inshore waters around Japan, ovulation was induced with hormonal treatment (Horie et al. 2001), and spermiation was observed (Utoh et al. 2004) in captivity. Research on the spawning ground also has been tried. Takai (1959) suggested that a single spawning ground exists in the East China Sea off northern Taiwan. While no significant genetic differentiation was detected among the specimens from off the east coast of central Japan, Kimura et al. (2004) suggested the presence of multi-spawning stocks with different spawning grounds, spawning seasons, and/or migration routes. In contrast to these suggestions, it has been currently inferred that the spawning ground is present in the western North Equatorial Current region and that the larvae are transported westward to the Kuroshio Current and dispersed by it and its branch, the Tsushima Warm Current (Ma et al. 2007; Kurogi 2008). Nevertheless, the exact location of the spawning ground and spawning behavior of whitespotted conger are still unknown.

Like whitespotted conger in East Asian waters, two other related species, the European conger *Conger conger* (Linnaeus, 1758) and the American conger *Conger oceanicus* (Mitchill, 1818), are also commercially important. The European conger is distributed in the Mediterranean Sea to the northeastern Atlantic Ocean, while the American conger occurs off the east coast of North America (Katayama and Kurogi 2008). Various aspects of the biology of European conger have been investigated, including the early life history (Correia et al. 2002a), feeding habits (Cau and Manconi 1984; Morato et al. 1999; O'Sullivan et al. 2004; Vallisneri et al. 2007), age, growth, and reproductive status (Sbaihi et al. 2001, O'Sullivan et al. 2003; Correia et al. 2009). For American conger, the metamorphosis, otolith microstructure, and otolith microchemistry have been studied (Bell et al. 2003; Correia et al. 2004). Further, the distribution, age, growth, and reproduction of the species were discussed (Hood et al. 1988; McCleave and Miller 1994), and the food habit was also reported (Levy et al. 1988). However, knowledge of the spawning ground and spawning behavior is quite limited for both species.

We have very little information on the whitespotted conger population in the eastern Seto Inland Sea. Nabeshima et al. (1994) described the feeding habit of the commercial-sized fish from Osaka Bay. Nishikawa et al. (1994) studied a mesh selectivity in the small otter trawl fishery for the species. Utsumi (2009) reported the fishing status and occurrence of the leptocephali in the eastern Kii Channel.

In 1988, a fishery resource management project started for the four fish species, including marbled flounder *Pseudopleuronectes yokohamae* (Günther, 1877), ridged-eye flounder *Pleuronichthys cornutus* (Temminck & Schlegel, 1846), bastard halibut *Paralichthys olivaceus* (Temminck & Schlegel, 1846), and red seabream *Pagrus major* (Temminck & Schlegel, 1843), in cooperation with the six prefectures (Okayama, Hyogo, Osaka, Wakayama, Kagawa, and Tokushima) facing the eastern Seto Inland Sea (Anon. 1991). Also, since 1993, a survey has been conducted in this sea off Hyogo Prefecture for the resource management of whitespotted conger and other fishes caught by the small trawl fishery (Anon. 1996).

A stock management approach to the tube trap fishery for whitespotted conger has been employed in Tokyo Bay (Shimizu 2003; Uchida et al. 2005; Harada et al. 2007). A management also has been conducted for the species in Ise-Mikawa Bay for various fisheries, including the small trawl fishery, pot fishery, and boat seine fishery (Anon. 2010).

As shown in Fig. I-3, the current catch of whitespotted conger in the eastern Seto Inland Sea remains at a low level, and an efficient utilization of the fishery stock is very important during such a low catch period. The stock management for optimum utilization of whitespotted conger should be done based on the accurate stock assessment and sufficient biological knowledge of the species, and the stock estimation can be completed using the accurate catch data. Much information on the life history of whitespotted conger in the eastern Seto Inland Sea is necessary for the stock management approach.

The primary purpose of the present study is to clarify various aspects of the biology of whitespotted conger in the eastern Seto Inland Sea from their larval recruitment to probable spawning migration in order to implement an efficient stock management of the species. Part of the results presented in this thesis was published earlier by me and my colleagues (Gorie and Ohtani 1997, 1998a, 1998b; Gorie and Tanda 2004; Gorie et al. 2004, 2010; Gorie and Nagasawa 2010).

Following this introduction (Chapter I), the migration of whitespotted conger leptocephali into the Harima Nada Sea is reported in Chapter II. Biological information on whitespotted conger juveniles during a period from post-settlement to recruit is provided in Chapter III. In Chapter IV, the age and growth are analyzed using the aquarium-reared and wild-caught fish, and the migration and growth of the species are also given based on a tagging study. In Chapter V, the catch and fishing status of the species in the eastern Seto

Inland Sea are analyzed, and a possible use of an enlarged mesh size is discussed for future resource management. In Chapter VI, monthly changes in length frequency distribution and catch per unit effort (CPUE) of whitespotted conger in the Akashi Strait through a pot survey are reported, and some biological aspects, including changes in gonadosomatic index, relative condition factor, and age composition of the species, especially the large-sized females, in this area are also discussed. This thesis concludes a general discussion in Chapter VII, which contains suggestions for the stock management and proposals for future work of whitespotted conger in the eastern Seto Inland Sea.

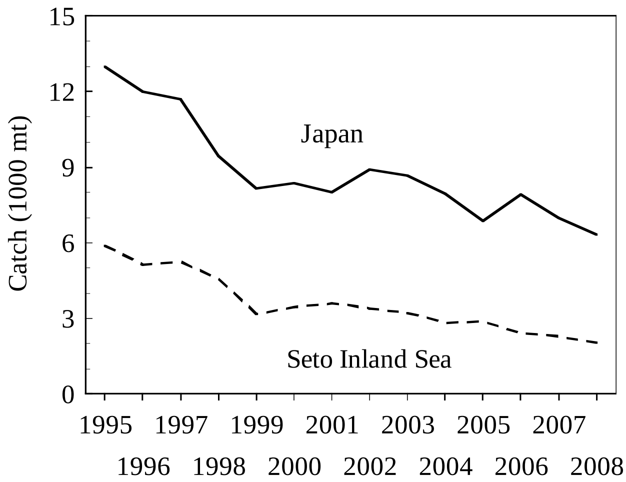

Fig. I-1. Annual changes in catch of whitespotted conger in Japanese waters and the Seto Inland Sea from 1995 to 2008.

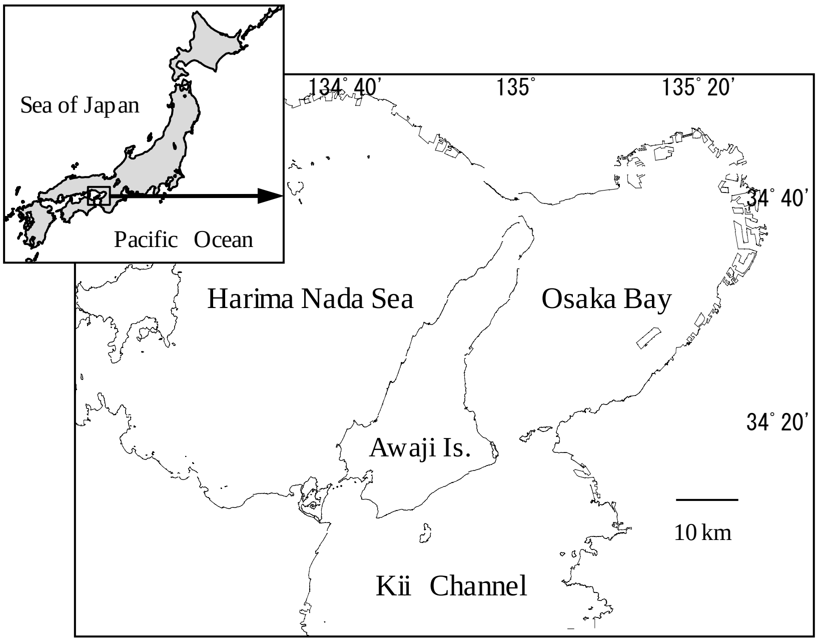

Fig. I-2. The eastern Seto Inland Sea, a study area in this study.

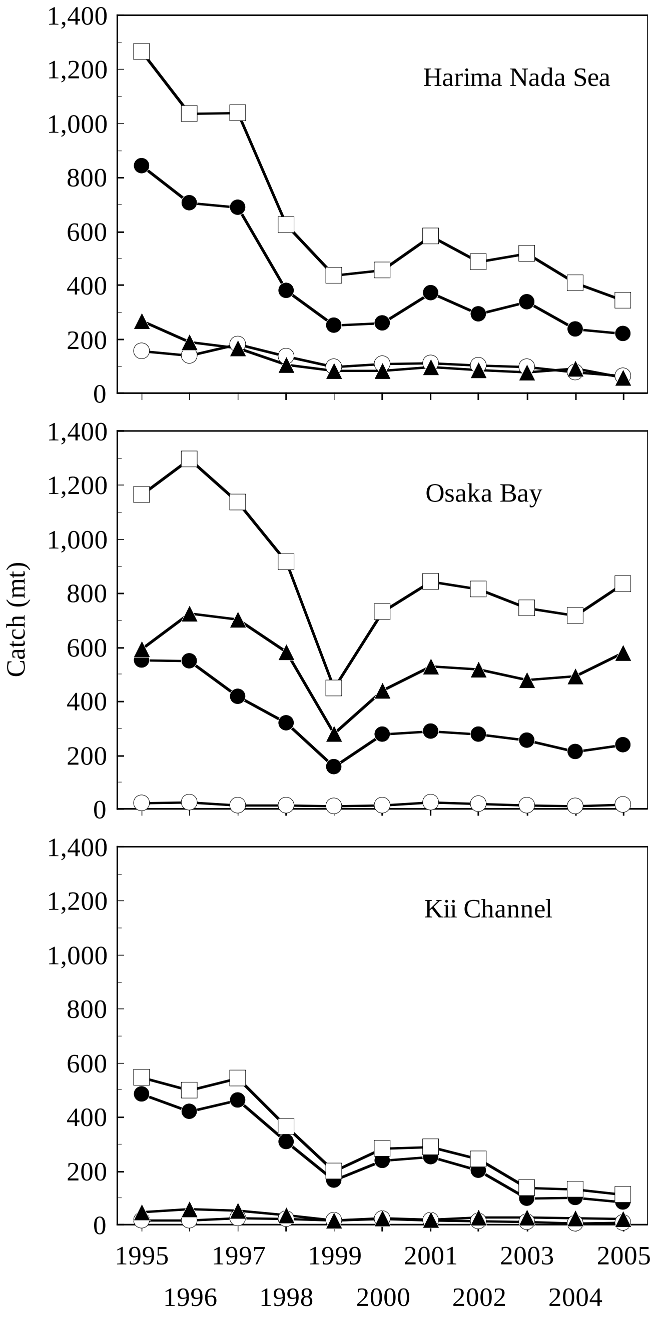

Fig. I-3. Annual changes in catch of whitespotted conger by various fisheries in the Harima Nada Sea, Osaka Bay, and the Kii Channel from 1995 to 2005. Open squares, total catch; closed circles, catch by small trawl fishery; open circles, catch by longline fishery; closed triangles, catch by other fisheries.

II. Migration of whitespotted conger leptocephali to the eastern Seto Inland Sea

Whitespotted conger occur as leptocephali (transparent willow-leaf-shaped larvae) in inshore waters around Japan. Both the pre- and metamorphosing leptocephali have been recorded from various regions in different seasons: the Suo Nada Sea from October to June (Takai 1959), the Kii Channel from November to April (Utsumi 2009), both Ise and Suruga bays from February to May (Kubota 1961; Mochioka et al. 2006), and the southern Tohoku waters from January to July (Onuma 1995; Katayama and Shimizu 2006). Based on these information, it is evident that whitespotted conger leptocephali tend to emerge earlier at the lower latitudes of Japan. They also have been considered to conduct multiple migrations intermittently (Shimizu 2005; Katayama and Shimizu 2006; Mochioka et al. 2006; Kurogi 2008).

Clarifying their migration ecology can provide basic knowledge to choose options for the stock management (e.g., conservation of the leptocephali), but we have only limited information on the migration and its duration in the eastern Seto Inland Sea.

In this chapter, I report the occurrence of whitespotted conger leptocephali in the northeastern Harima Nada Sea. I also describe unintentional bycatch of the leptocephali by the boat seine fishery.

1. Occurrence of whitespotted conger leptocephali

In this section, various aspects of the migration of whitespotted conger leptocephali, such as migrating duration, vertical distribution, and metamorphic stage are presented based on a fishing survey in the northeastern Harima Nada Sea and PAL/TL (preanal length/total length) analysis of the sampled leptocephali.

Materials and Methods

Fish collection

A survey was conducted from January to May in 2003 and February to May in 2004-2009 (except for 2005 and 2007) at depths of 20-25 m near Kami Island in the northeastern Harima Nada Sea (Fig. II-1-1).

Whitespotted conger leptocephali were collected by a small midwater beam trawl net with a 2.4 mm mesh aperture of a codend (Fig. II-1-2). The net was towed in the middle and bottom layers for 30 min at a speed of 1-2 knots using a small boat (9.1 mt) in the daytime. In 2003, three layers (surface, middle, and bottom) were towed both in the daytime and night. All the night surveys were conducted from 30 min lag time after sunset. The net was held in each layer during the net towing by monitoring the position of a net recorder unit (Type CN-8: Furuno Electric Co., Ltd., Nishinomiya, Japan) attached on the square net. In the surface, middle, and bottom layer samplings, the net recorder unit was kept 2-3 m down from the surface, at an intermediate depth, and 3-4 m up from the sea bottom, respectively. The ground rope was usually 1-2 m above the sea bottom when towing the bottom layer. The catch per unit effort (CPUE) was expressed as mean number of the leptocephali collected per 30 min towing.

Before the net was towed, oceanographic data, such as water temperatures, salinities, and depths, were collected using STD (JFE Advantech Co., Ltd., Nishinomiya, Japan).

Fish measurements and determination of metamorphic stage

Whitespotted conger leptocephali were fixed in 5-10% buffered formalin solution on board immediately after capture and then brought to the laboratory, where they were measured for total length (TL) and preanal length (PAL) (i.e., length from the tip of the snout to the posterior margin of the anus). All measurements were taken in millimeters. In this study, those larvae with a value of PAL/TL<0.88 were identified as being of metamorphosing stage, based on a preliminary analysis (see the Discussion section).

Statistical analysis

Statistical difference between CPUEs in each towing layer as well as sampling time (daytime vs. night) was analyzed by Kruskal-Wallis test. Difference in PAL/TL between the daytime and night was determined by *t*-test.

Results

Occurrence and distribution

Whitespotted conger leptocephali were collected in the northeastern Harima Nada Sea from February through May with being abundant especially between March and April. The leptocephali were sampled when sea surface temperature (SST) ranged from 8-18°C (Fig. II-1-3). They were usually collected in the bottom and middle layers but not in the surface layer in the daytime. CPUEs in the bottom layer were higher than those in the middle layer. Night CPUEs were also higher than those in the daytime, and the leptocephali were caught even in the surface layer at night (Table II-1-1). There was a significant difference (P=0.037, Kruskal-Wallis test) between CPUEs in each towing layer in the daytime, but not in the night.

Total length and metamorphic stage

The pre-metamorphosing leptocephali (PAL/TL>0.88) ranged from 94-132 mm TL, and the latter size was the largest recorded in this study (Fig. II-1-4). The mean TL (MTL) tended to decease from March to May although no particular tendency in TL was observed between the towing layers in the daytime and night. A half of the leptocephali caught in March were already at metamorphic stage, and the rate of pre-metamorphic leptocephali decreased coincidentally with decrease in TL (Fig. II-1-4). While almost all the leptocephali caught in the daytime in May were at metamorphosing stage (98%, N=43), the rate of the metamorphic leptocephali caught in the night was only 44% (N=9). In addition, PAL/TL values in the leptocephali taken at night were significantly higher (P<0.001) than those in the daytime, indicating that the pre-metamorphosing leptocephali spread more widely in the night (Fig. II-1-5).

Discussion

To differentiate the metamorphic stage of whitespotted conger leptocephali, PAM/TM (number of preanal myomere/number of total myomere) ratio has been used in the studies of leptocephalus development (Lee and Byun 1996; Otake et al. 1997; Utsumi 2009), and PAM/TM<0.8 was employed as a criterion for metamorphosing stage (Katayama and Shimizu 2006; Mochioka et al. 2006). Meanwhile, like in the present study, PAL/TL ratio also has been successfully used in classifying the metamorphic stage for whitespotted conger (Yamano et al. 1991) and two other related species, European conger *Conger conger* (Correia et al. 2002a, 2002b, 2003) and American conger *C. oceanicus* (Bell et al. 2003;

Correia et al. 2004). In this study, I used PAL/TL=0.88 instead of PAM/TM=0.80 as a criterion for metamorphic stage, based on the analysis between PAL/TL and PAM/TM. In my preliminary study (Gorie unpublished), PAL/TL was found to be strongly correlated with PAM/TM: [PAL/TL=0.986×(PAM/TM)+0.087, r^2=0.98, N=361]. Therefore, as an indicator of the developmental stage of whitespotted conger, PAL/TL has a higher advantage than PAM/TM in easily obtaining measurement data and avoiding myomere counting errors, especially when formalin preserved specimens are examined. In addition, although PAL/TL=0.88 was used as a threshold of metamorphic stage in this study, it should be noted that the threshold must be determined based on both external and physiological events. Further study is needed to determine the metamorphic stage based on PAL/TL.

This study has revealed that whitespotted conger leptocephali migrate to the northeastern Harima Nada Sea from February to May (abundantly from March to April), when SST ranged from 8-18°C. In the nearby, southerly-located Kii Channel, the leptocephali appeared from November to April with SST ranging from 8.8-20.0°C and were most abundant when SST was at 10°C (Utsumi 2009). Although no data were presented, Nabeshima et al. (1995) mentioned that the leptocephali were found also in the nearby Osaka Bay from January to April. Further, in the northeastern Harima Nada Sea, the leptocephali were not collected in January and June (Gorie unpublished). These results suggest that whitespotted conger leptocephali are drifted from the offshore Pacific waters to the Kii Channel in November, when SST are between 8 and 20°C, and are transferred and/or move to the northeastern Harima Nada Sea through Osaka Bay with lag time. Unfortunately, I cannot refer to the possibility that the leptocephali reach the Harima Nada Sea through the western Seto Inland Sea and/or the Naruto Strait because no survey has been conducted both in the western and southeastern Harima Nada Sea. It is, however, reasonable to infer that the leptocephali migrate through the Naruto Strait as well.

Multiple migrations have been suggested for whitespotted conger leptocephali in Tokyo Bay (Shimizu 2005), the southern Tohoku area (Katayama and Shimizu 2006), Suruga Bay (Mochioka et al. 2006), and Sagami Bay (Kurogi 2008). It also has been assumed that the migration is not continuous but intermittent. In this study, length frequency distribution of the leptocephali and their rate of pre-metamorphic stage did not fluctuate but decreased consistently from March to May (Fig. II-1-4), which suggests that, unlike in other regions, the migration of the leptocephali into the Harima Nada Sea was not multiple. Also, it might be possible that the intermittent migration was hidden by buffering effects of the waters because, as above discussed, the leptocephali are thought to pass through the Kii Channel and Osaka Bay to reach the northeastern Harima Nada Sea.

This study has shown for the first time that whitespotted conger leptocephali do not occur in the surface layer but in the bottom and middle layers in the daytime. They, however, spread their distribution to the surface layer in the night (Table II-1-1). Also, both the pre- and early-metamorphosing leptocephali may stay just above the sea bottom because the pre-metamorphosing individuals were collected at night in May (Fig. II-1-4, right) and PAL/TL in the leptocephali caught in the night is significantly higher (P<0.001, t-test) than that in the daytime (Fig. II-1-5). Consequently, these results may suggest that the pre-metamorphosing leptocephali migrate intermittently into the Harima Nada Sea even in May and/or that such leptocephali stay just above the sea bottom in the daytime but spread widely in the night.

It is known that almost all the leptocephali caught in the southern Tohoku area (Katayama and Shimizu 2006), Suruga Bay (Mochioka et al. 2006), and the Kii Channel (Utsumi 2009) were at pre-metamorphic stage. However, the results obtained in this study was different form those in such regions. A half of the leptocephali caught during the early migration period (February-March) were already at metamorphic stage, which implies that many of the leptocephali migrate to the northeastern Harima Nada Sea with metamorphosing. The difference in migration period and metamorphic stage between the Harima Nada Sea and Kii Channel can be explained by the following reasons: 1) the former region is slightly more northerly located than the latter region in the eastern Seto Inland Sea; and 2) when the leptocephali are about to arrive in the Harima nada Sea after migrating from the Kii Channel, they may recognize that they have reached appropriate waters to begin metamorphosis (Kurogi 2008).

The leptocephali caught in this study ranged from 91-132 mm TL. In other inshore waters around Japan, the similarly sized leptocephali (80-140 mm TL) were captured (Shimizu 2005; Mochioka et al. 2006; Utsumi 2009), and a specimen of up to 155 mm TL was collected in the open waters facing the Pacific Ocean (Katayama and Shimizu 2006). The largest size of the species at pre-metamorphic stage may vary between the regions, and, as Kurogi (2008) suggested, the leptocephali appear to continue growing until they are drifted to appropriate waters to settle down.

More information is needed on the relationship between horizontal distribution of the leptocephali and oceanographic environment to clarify their occurrence patterns in the eastern Seto Inland Sea. Also, for forecasting the fishing conditions of the species there, it is important to assess the abundance of the migrating leptocephali near the Kii Channel. We need more work to understand the migration ecology of the leptocephali for the efficient stock management of the species.

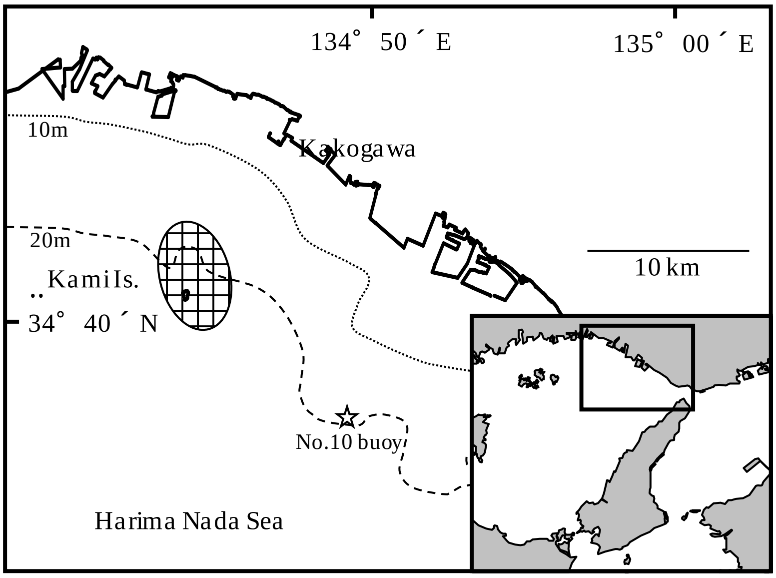

Fig. II-1-1. A survey area (crosshatched) to collect whitespotted conger leptocephali in the northeastern Harima Nada Sea.

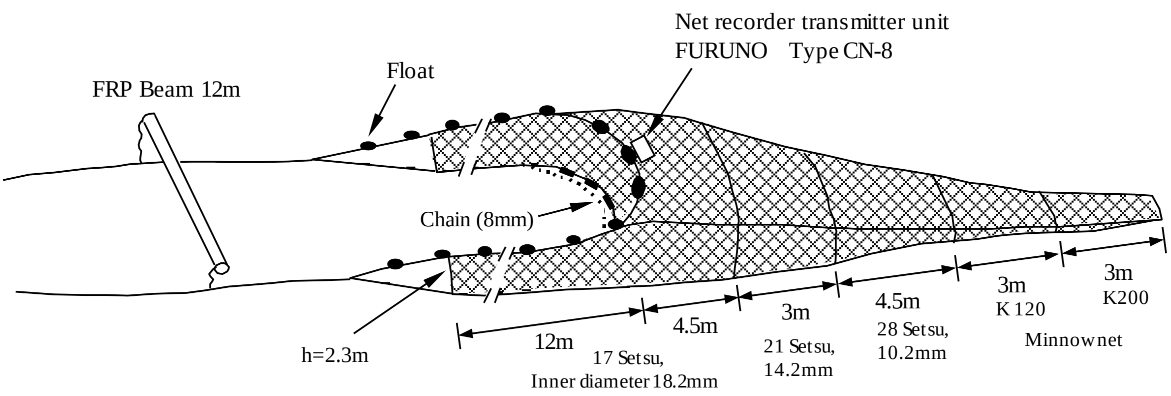

Fig. II-1-2. Diagram of a midwater beam trawl net to collect whitespotted conger leptocephali in the northeastern Harima Nada Sea.

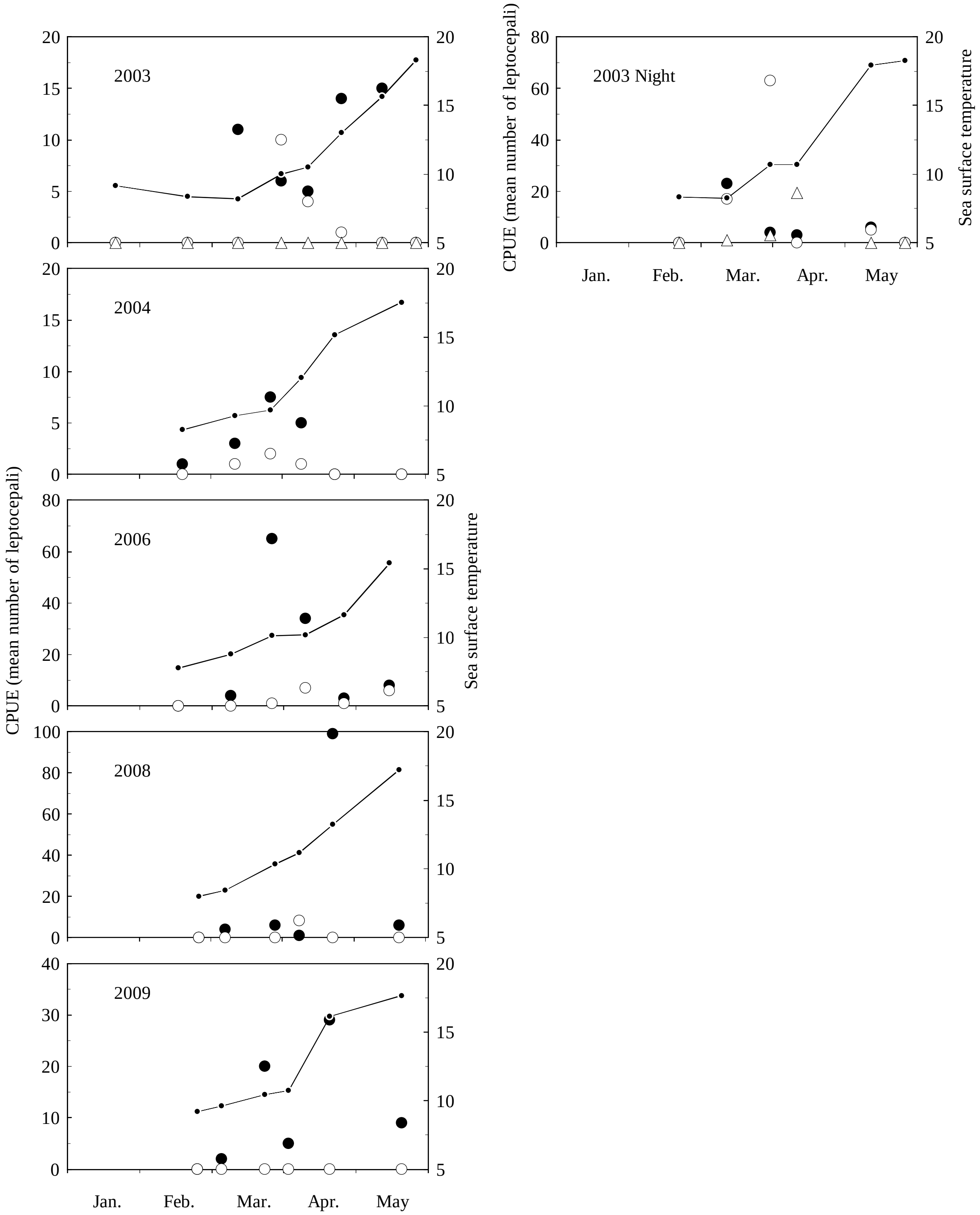

Fig. II-1-3. Monthly changes in CPUE (mean number of whitespotted conger leptocephali caught per haul for 30 min) using a midwater beam trawl net in the northeastern Harima Nada Sea in the daytime (left) and night (right) from 2003 to 2009 (except for 2005 and 2007). Open triangles, surface layer; open circles, middle layer; closed circles, bottom layer; line with dots, sea surface temperature (°C).

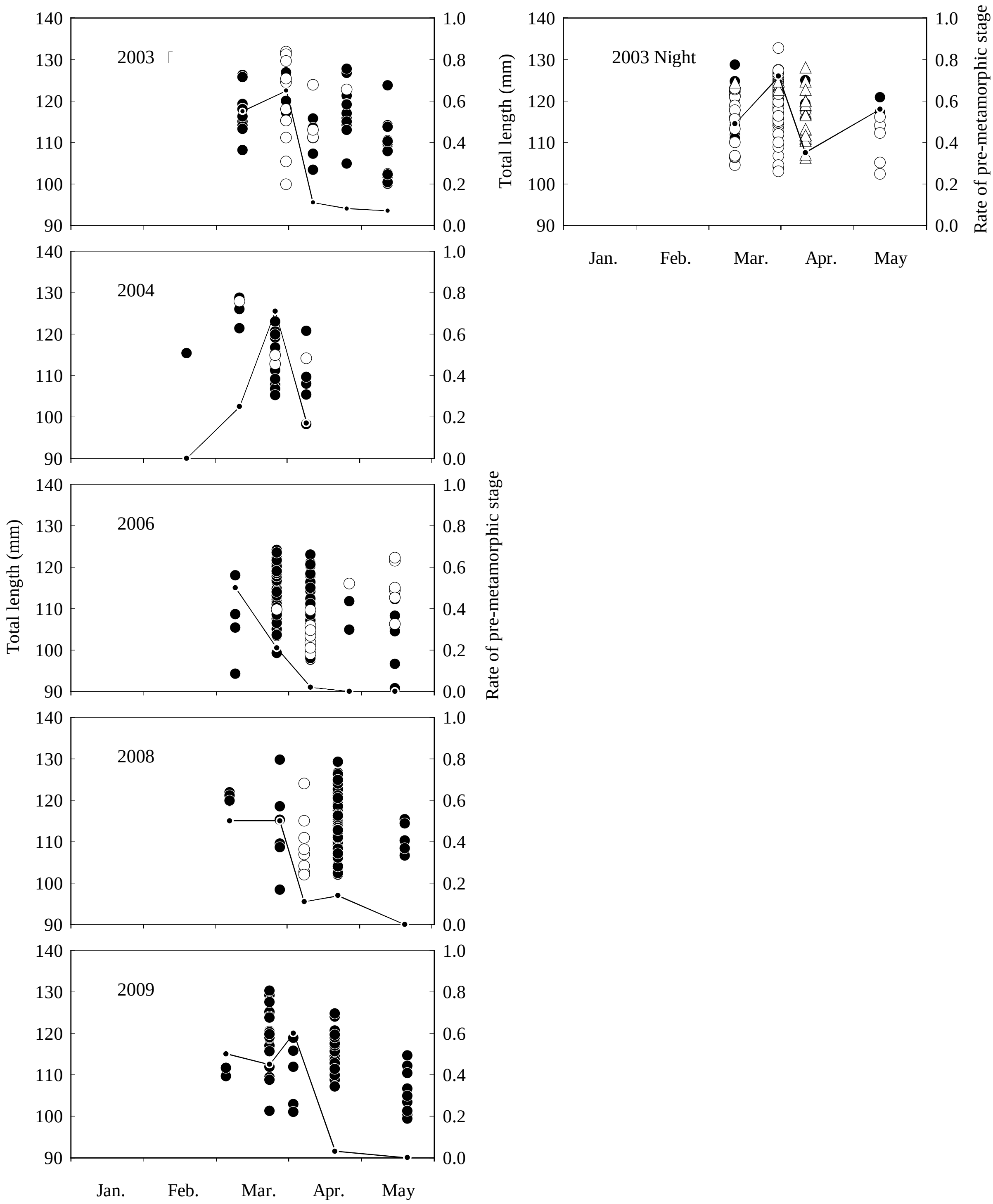

Fig. II-1-4. Monthly changes in total length distribution and rate of pre-metamorphic stage in whitespotted conger leptocephali caught with a small midwater beam trawl net in the northeastern Harima Nada Sea in the daytime (left) and night (right) from 2003 to 2009 (except for 2005 and 2007). Open triangles, surface layer; open circles, middle layer; closed circles, bottom layer; line with dots, rate of pre-metamorphic stage (PAL/TL>0.88).

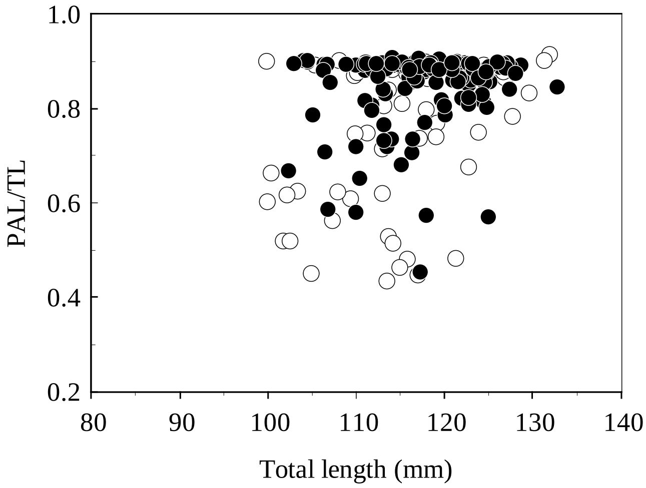

Fig. II-1-5. Relationship between total length and PAL/TL of whitespotted conger leptocephali caught in the northeastern Harima Nada Sea in the daytime and night in 2003. The value of PAL/TL less than 0.88 is used as a criterion for metamorphosing stage. Open circles, daytime caught specimens (*N*=64); closed circles, night caught specimens (*N*=142).

Table II-1-1. CPUE of whitespotted conger leptocephali caught with a midwater beam trawl net in the daytime and night in the northeastern Harima Nada Sea in 2003

Date in 2003	Bottom				Middle				Surface			
	Daytime		Night[1]		Daytime		Night		Daytime		Night	
	CPUE	WT	CPUE	WT	CPUE	WT[2]	CPUE	WT[2]	CPUE	WT	CPUE	WT
13 Mar.	11	8.3	23	8.3	0	8.1	17	8.3	0	8.2	1	8.3
31 Mar.	6	9.0	4	9.2	10	9.5	63	9.4	0	10.0	3	10.7
11 Apr.	5	10.4	3	10.4	4	10.4	0	10.6	0	10.5	19	10.7
12 May	15	13.7	6	13.7	0	14.6	5	14.3	0	15.7	0	18.0
25 May	0	14.9	0	14.9	0	15.4	0	16.1	0	18.3	0	18.3

CPUE, mean number of leptocephali per haul for 30 min. [1] The night surveys were conducted from 30 min lag time after sunset.

[2] Water temperature at 10 m in depth.

2. Unintentional bycatch of whitespotted conger leptocephali by the boat seine fishery

In the eastern Seto Inland Sea, the boat seine fishery commonly operates from February through December. This fishery is conducted by a lot of fishing unities commonly consisting of three boats (two towing boats and a carrying boat). While two boats are towing the net, a carrying boat transports the catch to land it at fish markets.

The juveniles of the Pacific sandlance *Ammodytes personatus* Girard, 1856 are the main target of the boat seine fishery from February through April which is just the period when whitespotted conger leptocephali abundantly migrate to the eastern Seto Inland Sea (see Chapter II-1).

When Pacific sandlance juveniles are auctioned at fish markets, purity of product with less contamination of other organisms is strongly important for a high auction price. To avoid contamination of non-target animals in the catch, fishermen usually use a filtration system attached to the fishing net. This filtration system has a powerful effect on both removing non-target organisms and selecting the high-valued juveniles of appropriate size. Unfortunately, however, the filtration system is not perfect but still catches non-target organisms as bycatch (= unintentional capture of non-target species), which becomes a major problem in fishery resource management in the eastern Seto Island Sea. Numerous valuable larvae and juveniles of other marine animals are caught but discarded dead or dying back into the sea because bycatches are usually released only when retrieved by the carrying boat.

So far, there has been no information on bycatch of whitespotted conger leptocephali by the boat seine fishery in the eastern Seto Inland Sea. Since the bycatch is implied to waste stocks of other commercially important organisms, including whitespotted conger, it is essential to clarify the present status of bycatch to estimate its impact on the population of whitespotted conger and to improve the fishing equipment for avoiding bycatch.

In this section, the bycatch of whitespotted conger leptocephali through the boat seine fishery is described.

Materials and Methods

Sample collection

The surveys were conducted from February to April in 2003-2007 when the boat seine fishery operated in the eastern Seto Inland Sea with targeting Pacific sandlance juveniles. I requested some of the fishermen engaged in the fishery in the Harima Nada Sea and Osaka Bay to preserve a haul of bycatches found in the filtration net before they released the bycatches from the net. These bycatch samples were taken from the carrying boats, fixed in 5-10% buffered formalin solution, and preserved until analysis.

Identification and measurements of bycatch species

The collected animals were identified and counted by species. They were classified into one of the five abundant species: rockfish inferred as *Sebastes cheni* Barsukov, 1988, fat greenling *Hexagrammos otakii* Jordan & Starks, 1895, whitespotted conger leptocephali *Conger myriaster*, marbled rockfish *Sebastiscus marmoratus* Cuvier, 1829, Japanese flying squid *Todarodes pacificus* (Steenstrup, 1880), and others. Total length (TL, mm) or mantle length (ML, mm) and body weight (BW, g) were recorded for individuals of the major five species.

Results

Rockfish (7-35 mm TL) and fat greenling (21-73 mm TL) were abundantly found in the bycatch, accounting for 15-85% and 29-44%, respectively, of the annual bycatch in number although there was no bycatch of the latter species in 2003 and 2007 (Table II-2-1). Whitespotted conger leptocephali (72-135 mm TL) followed these two species and accounted for 5-21% in the annual bycatch. Marbled rockfish (6-33 mm TL) and Japanese flying squid (9-117 mm ML) were caught only in two years of the five years surveyed.

Discussion

This study has shown for the first time that a certain number of larvae and juveniles of commercially important organisms were unintentionally caught in the eastern Seto Inland Sea by the boat seine fishery targeting Pacific sandlance juveniles. It has been already recognized in other Japanese waters that the bycatch can affect the stock of whitespotted conger. Ishida et al. (2003), who surveyed coastal fisheries of the Tohoku region, found that the boat seine fishery selectively caught the leptocephali of the species and gave a negative impact on its resource. Since 2006, in Ise-Mikawa Bay, a stock management has been actually performed in the boat seine fishery by setting a catch limit for the leptocephali (Anon. 2010). It is, however, difficult to accurately estimate an actual impact of bycatch on the fishery resources.

While whitespotted conger leptocephali may be found at fish markets, it is yet unknown whether the leptocephali are selectively caught in the eastern Seto Inland Sea. It may be also possible that fishermen sell the incidentally caught leptocephali of the species by themselves. This study has revealed that a numerous number of the leptocephali were caught as bycatch, which suggests that the boat seine fishery is likely to give a negative impact on the stock of whitespotted conger in the eastern Seto Inland Sea. Under this situation, at least the selective catch of whitespotted conger leptocephali should be prohibited.

Since we have very limited information on the unintentional bycatch of marine animals, including whitespotted conger leptocephali, further study is desirable. Research to estimate a negative impact of the bycatch on the fishery resources will provide the basic knowledge for the stock management of whitespotted conger and all other bycatch species in the eastern Seto Inland Sea.

Table II-2-1. Number percentage of unintentional bycatches with a boat seine fishery in the eastern Seto Inland Sea from 2003 to 2007

English name/Year	2003	2004	2005	2006	2007	Mean
Number of samples	16	12	8	13	5	
Number of species occurred	35	40	34	43	19	
Rockfish[1]	84.8	32.2	14.8	15.2	61.3	50.8
Fat greenling	0.0	28.7	42.7	44.1	0.0	15.1
Whitespotted conger leptocephalus	11.7	20.7	13.8	4.6	11.7	12.4
Marbled rockfish	0.0	0.0	0.0	17.5	10.8	5.9
Japanese flying squid	0.7	0.0	24.4	0.0	0.0	4.2
Others	2.8	18.5	4.3	18.6	16.2	11.6
Total number of bycatch species[2]	11,465	5,709	8,036	5,088	18,066	9,673

[1] Inferred as *Sebastes cheni*; [2] mean number of fish per a haul. All the bycatches were larvae or juveniles.

III. Habitat preference and feeding habits of whitespotted conger juveniles

In Japanese waters, larval whitespotted conger are spread by the Kuroshio Current and its branch, the Tsushima Warm Current. When the leptocephali reach appropriate coastal waters, they actively move into inshore waters and begin metamorphosis (Kurogi 2008). In the northeastern Harima Nada Sea, whitespotted conger occur as leptocephali from February to May and complete metamorphosis. They display shrinkage in total length with metamorphosis, settle down to the ground, and begin the demersal life (see Chapters II-1, IV-1).

There are a few studies on the feeding habits of commercial-sized whitespotted conger (Mori and Inoue 1982; Matsumiya and Imai 1987; Nabeshima et al. 1994; Fukuda et al. 1997): this species preys mostly on teleosts, crustaceans, and mollusks. Similar results were reported for two related species: European conger *Conger conger* (Cau and Manconi 1984; Morato et al. 1999; O'Sullivan et al. 2004; Vallisneri et al. 2007) and American conger *Conger oceanicus* (Levy et al. 1988). On the other hand, very little is known about the feeding habits and habitat during the juvenile stage of these three species. In Japan, Takai (1959) reported that juvenile whitespotted conger occurred at 1-17 m in depth on the sand-mud to mud bottoms, but detailed data have not been published. He also mentioned that the juveniles of 100-200 mm in total length fed on shrimps, fishes, crabs, and polychaetes. In Korea, Huh and Kwak (1998) found that the juveniles of the same species fed mainly on fishes, shrimps, and crabs in a *Zostera* bed and showed a very constant prey selection. Previously, I reported that the diet of whitespotted conger changed with fish size (Gorie and Tanda 2004). Nevertheless, information on the habitat and food habit of their juveniles is quite limited, and there have been no studies on relations between prey fauna and the stomach contents of the juveniles.

In this chapter, I report: 1) where the newly settled juveniles of whitespotted conger are distributed in the northeastern Harima Nada Sea; and 2) what environmental conditions are related to their habitats. I also discuss the feeding habits of the juveniles and their relation to the fauna of prey.

Materials and Methods

Fish sampling

The study was conducted in the northeastern Harima Nada Sea (Fig. III-1). The survey region was divided into four areas: Area A (depth: 13 m), Area B (10 m), Area C (17 m), and Area D (18 m).

Juvenile whitespotted conger were sampled using a small trawl net and pots. The trawl survey was performed from April to September in 2003-2008 with a 2.4 mm mesh aperture of a codend (Fig. III-2). Since no juvenile was caught during the daytime and few juveniles were obtained within 30 min after sunset in the trawl survey, sampling was carried out at night (30 min lag time after sunset). The net was towed for 10-20 min at a speed of 2 knots using a small boat (9.1 mt). Catch per unit effort (CPUE) was expressed as mean number of the juveniles per haul for 20 min.

The pot survey was conducted using commercially available pots (Fig. III-3: nominal mesh size, 18 *setsu*; mesh size of the upper and bottom parts, 18 and 15.9 mm, respectively) in October and December from 2004 to 2008. The survey was carried out from evening to night in Areas A and B. After thawed from a deep freezer, sardines were put as bait inside the pots. The pots were usually devoted into the sea before 1 hour of sunset and allowed the fish to trap for 4 hours. The effective numbers of the pots for the survey was 35 in each survey area. Catch per unit effort (CPUE) was expressed as mean number of the fish caught for 4 hours dipping time per pot.

Before the surveys were conducted in each survey area, oceanographic data, including water temperatures (WT), salinities, and depths, were recorded with STD (JFE Advantech Co., Ltd., Nishinomiya, Japan).

Bottom sediment sampling and grain size analysis

Bottom sediments were sampled with a SK Type bottom sampler (Rigo Co., Ltd., Tokyo, Japan) in Areas B-D on 3 July 2003 and in Area A on 22 August 2003. Grain sizes were analyzed based on the Japanese Geotechnical Society Standard (JSF T 131-1990) and sorted by the Wentworth grain size scale. Losses on ignition were measured after the sediments were heated at 600°C for 2 hours.

Benthos sampling and their composition

Benthos were sampled before towing the trawl net in 2004 with a Smith-MacIntyre bottom sampler (22×22 cm, Rigo Co., Ltd., Tokyo, Japan) and with a sledge net (Fig. III-4) for 1 min towing at a speed of 2 knots. The samples caught using the bottom sampler were sieved with a 1 mm mesh aperture size and stored in 5-10% buffered formalin solution. The benthos composition in these samples was expressed as numerical and weight percent for five categories: polychaetes, gastropods, bivalves, crustaceans, and cephalochordates. Since these animals accounted for more than 95% of the total, other organisms were excluded from the analysis. The benthos sampled with the sledge net were categorized into one of eight groups: nematodes, polychaetes, gastropods, bivalves, crustaceans, chaetognaths, ophiuroids, and teleosts.

Stomach content analysis

The juveniles were fixed soon after caught in 5-10% buffered formalin solution from May to August in 2004. For stomach content analysis, 30, 106, and 120 juveniles were selected randomly from Areas A-C, respectively (Table III-1). These juveniles were measured for total length (TL, mm) and body weight (BW, g), and the stomachs were removed and examined for contents. Prey items from each stomach were identified to one of four groups (polychaetes, crustaceans, teleosts, and others) and expressed as numerical and weight percent by sampling date and fish size. Moreover, crustaceans were classified into amphipods, decapods, or others.

Ivlev's selectivity index (E_i) (Ivlev 1955) was calculated as follows: $E_i = (r_i\text{-}p_i)\cdot(r_i+p_i)^{-1}$, where r_i is the percentage of prey item i in the fish stomachs, and p_i is the percentage of item i in the benthos samples collected with the Smith-MacIntyre bottom sampler. The index can take values between -1 and 1. A value between 0 and 1 means that a fish has a positive preference for the prey item i, while a value between 0 and -1 shows a negative preference. If a value is 0, a fish has no preference to the item i.

Statistical analysis

Differences in CPUE and prey density were explored using the Steel-Dwass test or Mann-Whitney's U test between the survey areas where the juveniles were collected.

Results

Juvenile distribution and oceanographic features

In the trawl survey, whitespotted conger juveniles were collected in Areas A-C, but no juvenile was taken in Area D. The juveniles were collected from May to September (Table III-2). CPUEs in Areas B and C were significantly higher than that in Area A ($P \approx 0.003$, Steel-Dwass test), but no significant difference was observed between Areas B and C.

In the pot survey, the CPUE in Area B was significantly higher than that in Area A (P=0.01, U test) (Table III-3).

Bottom WTs and salinities where the juveniles were caught ranged from 14.6-27.4°C and 30.2-32.7, respectively (Tables III-2, III-3).

Bottom sediment type

The grain size composition of the bottom was different among the survey areas (Fig. III-5). Gravel and pebbles were the major components in Area A, but their proportions were low in Areas B and C, where medium-coarse sand predominated. A small amount of gravel and pebbles were also found in Area D, where medium sand was abundant. Some silt and clay were found in Areas B and C, but they were not observed in Area D. Both median and maximum size of particles were the largest in diameter in Area A and the smallest in Area D (Table III-4). Losses on ignition ranged from 2.0-2.9% in the four survey areas. Although the depths were different, the bottom of Areas B and C was similar, and the bottom types of each survey area were classified as follows: gravel bottom in Area A, sand-mud bottom in Areas B and C, and sand bottom in Area D.

Benthos composition

There were some differences in composition of the benthos collected by the Smith-MacIntyre bottom sampler between Areas A-C, where whitespotted conger juveniles were collected (Fig. III-6). In Area A, crustaceans were the most numerous, but cephalochordates (lancelet *Branchiostoma belcheri*) and bivalves were the major components by weight. In Areas B and C, polychaetes predominated by both number and weight. The biomasses of polychaetes were similar in these three areas and that of crustaceans in Area A was more abundant than those in the other areas although significant difference was not observed ($P \approx 0.05$, Steel-Dwass test, Table III-5).

A wide variety of the benthos was collected by the sledge net (Fig. III-7). In Area A, crustaceans were dominant by number, but bivalves and teleosts were also important by weight. In Areas B and C, the proportions of four groups (bivalves, crustaceans, polychaetes, and nematodes) were high by number, whereas those of crustaceans and ophiuroids were high by weight in these areas, respectively. The composition considerably fluctuated by sampling date.

Based on the bottom sediment type and benthos composition, Area A is characterized by gravel bottom with abundant crustaceans and bivalves, and both Areas B and C by sand-mud bottom with high abundance of various groups of the benthos, such as polychaetes, bivalves, crustaceans, and ophiuroids. Areas B and C are considered to have a similar benthos composition and bottom sediment type.

Stomach contents

A total of 256 juveniles were examined for their stomach contents (Table III-1). Throughout the survey period, crustaceans were very common by number in Areas A-C (Fig. III-8). Both polychaetes and teleosts were also important by weight in Areas B and C, where polychaetes showed the highest percentage in June.

The stomach contents varied between the survey areas and with fish size (Fig. III-9). Crustaceans were highly predominant in all fish sizes in Area A. They were also abundantly preyed on in Areas B and C, but the importance of polychaetes and teleosts increased by weight in these areas. Polychaetes were found in the juveniles of 80-210 mm TL but not observed in the stomach contents of the juveniles over 220 mm TL. Teleosts as prey were detected in the juveniles over 90 mm TL. Of the crustaceans found, both amphipods and decapods were very dominant, but their importance was different by size: the proportion of amphipods and decapods declined and increased, respectively, with an increase in fish size (Fig. III-10). This trend was found in all survey areas.

The main amphipods preyed on were podocerids, aorids, and pontogeneiids by number. Oedicerotids were also detected by weight. As for the decapods, three groups (penaeids, crangonids, and processids) mainly occurred by number but pasiphaeids were important by weight. The teleosts eaten were gobiids and callionymids by number, but engraulids were also important by weight. The polychaetes that were preyed on consisted of errantians and sedentarians, and the former predominated (83% by number). Sand grains were rarely observed.

Based on the Ivlev's selectivity index, the juveniles showed a strong preference for crustaceans (Table III-6). Crustaceans showed a high value throughout the period, regardless of the survey areas. The percentage of empty stomachs ranged from 10-72% in the small-sized juveniles (<100 mm TL), but few empty stomachs were found in the juveniles larger than 100 mm TL. No particular trend in percentage of empty stomachs was observed among the three survey areas.

To summarize these results, whitespotted conger juveniles fed mainly on crustaceans, polychaetes, and teleosts and showed a strong preference for crustaceans. The juveniles preyed on amphipods after beginning their demersal life and shifted their prey, with growth, from amphipods to decapods, polychaetes, and teleosts.

Discussion

This study has shown for the first time that the newly settled juveniles of whitespotted conger occurred at 10-20 m in depth on the gravel (Area A) and sand-mud bottoms (Areas B and C). They were not sampled from the sand bottom (Area D).

This study also suggests that whitespotted conger juveniles exhibit a higher preference for the sand-mud bottom than gravel bottom because CPUEs from the sand-mud bottom were significantly higher than that from the gravel bottom (Area A). There was no significant difference in CPUE between Areas B and C in the trawl survey. Water depths in these areas were slightly different (10 and 17 m each), but both the environmental conditions and benthic fauna were very similar to each other. The observed difference in water depth may give no impact on the distribution and abundance of the juveniles in these areas.

As for the benthic fauna of the survey areas, polychaetes, crustaceans, and mollusks (gastropods and bivalves) were most commonly sampled (Figs. III-6, III-7). The biomass of polychaetes was similar in Areas A-C and that of crustaceans was abundant in Area A (Table III-5). The stomach contents of the juveniles, however, did not accord with the benthic fauna: the juveniles showed a strong preference for crustaceans (Table III-6) and preyed mainly on crustaceans, polychaetes, and teleosts, indicating that the juveniles show selective feeding habits for prey animals (Fig. III-8). Crustaceans are numerically important, while polychaetes and teleosts are quantitatively significant. The juveniles also shifted their food items, with growth, from amphipods to decapods, polychaetes, and teleosts (Figs. III-9, III-10). Crustaceans were heavily preyed on in Area A, whereas polychaetes were fed on in Areas B and C (Figs. III-8, III-9). In these areas, crustaceans and/or polychaetes were the most abundant, and the stomach contents of the juveniles correlated with the available crustacean-polychaete composition (Figs. III-6, III-8). These results suggest that the juveniles feed on crustaceans and polychaetes in the areas, where these animals are more abundant than other prey animals.

Although nothing has been reported on the specific feeding behavior of whitespotted conger, epifaunal polychaetes were commonly found in the juvenile's stomachs and sand grains were rarely observed. This implies that the juveniles have a foraging behavior for epifaunal animals rather than buried infaunal animals.

CPUEs of juvenile whitespotted conger were higher in Areas B and C than in Area A (Tables III-2, III-3) although crustaceans predominated in Area A and their biomass was more abundant than in other areas (Fig. III-6, Table III-5). These results suggest that the juveniles choose their habitats not by the food environment but by the bottom sediment type.

I previously reported the food habits of juvenile whitespotted conger from the northeastern Harima Nada Sea (Gorie and Tanda 2004). Huh and Kwak (1998) also reported the stomach contents of the juveniles of the same species caught in an eelgrass (*Zostera*) bed in Korean waters. The results of these studies are slightly different from those in the present study. A higher variation in percentage of prey items was observed in the northeastern Harima Nada Sea (Gorie and Tanda 2004), and the juveniles in Korean waters consumed fishes, crustaceans, and gastropods but did not feed on polychaetes. These differences may be due to the environment of sampling locations between Japanese (sand-mud bottom) and Korean (*Zostera* bed) waters and/or the smaller sample size [N=1-18 (mean: 6) for each 10 mm size class] in this study than in the previous one [N=1-26 (mean: 12)] (Gorie and Tanda 2004).

In conclusion, the newly settled juveniles of whitespotted conger were collected from the gravel and sand-mud bottoms, where crustaceans and bivalves commonly occurred and various types of the benthos were abundant, respectively. The sand-mud bottom was preferred by the juveniles, being considered to be an important nursery ground. The juveniles showed a strong preference for crustaceans and selective feeding habits for crustaceans, polychaetes, and teleosts. They potentially choose their habitats by the bottom sediment type rather than the food environment. Further clarification of the habitat requirements and feeding habits is needed at the different depths and under various environmental conditions in the Seto Inland Sea to identify the key habitats used by whitespotted conger.

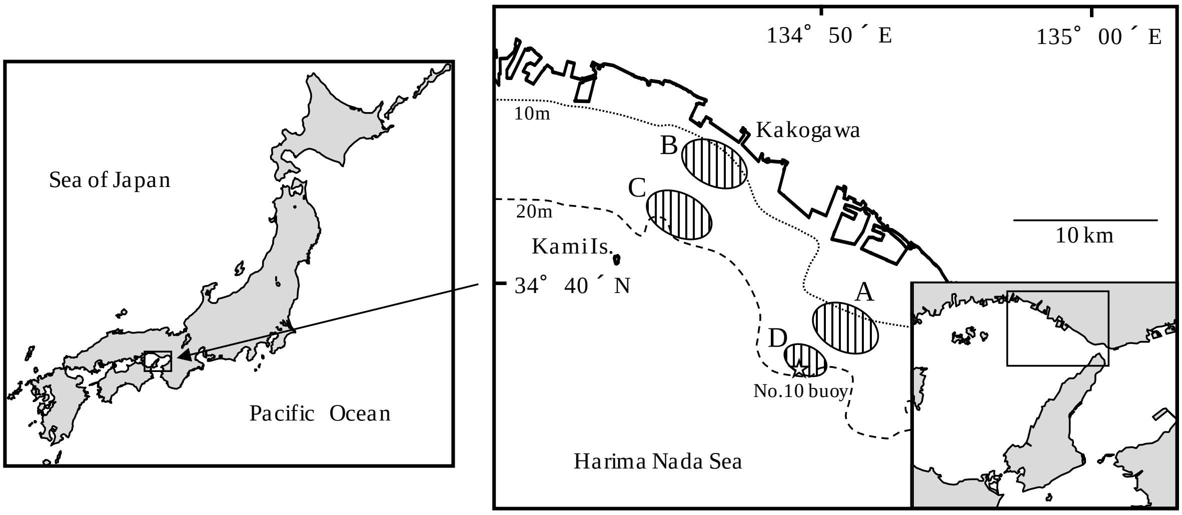

Fig. III-1. A location of the survey areas (hatched) in the northeastern Harima Nada Sea.

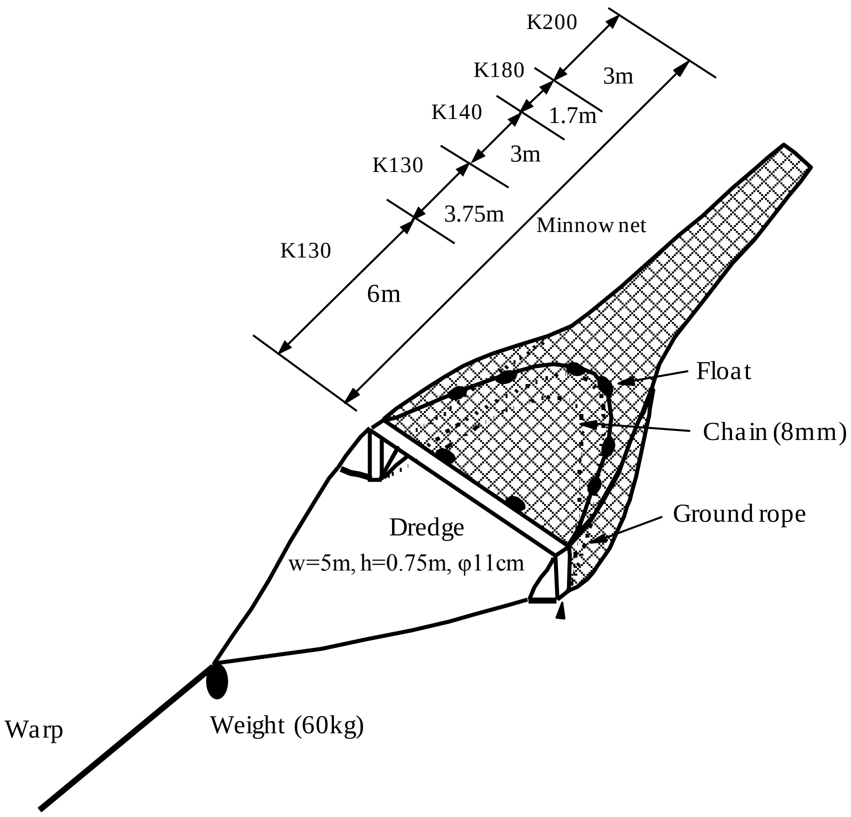

Fig. III-2. Diagram of a bottom trawl net to collect newly settled whitespotted conger in the northeastern Harima Nada Sea.

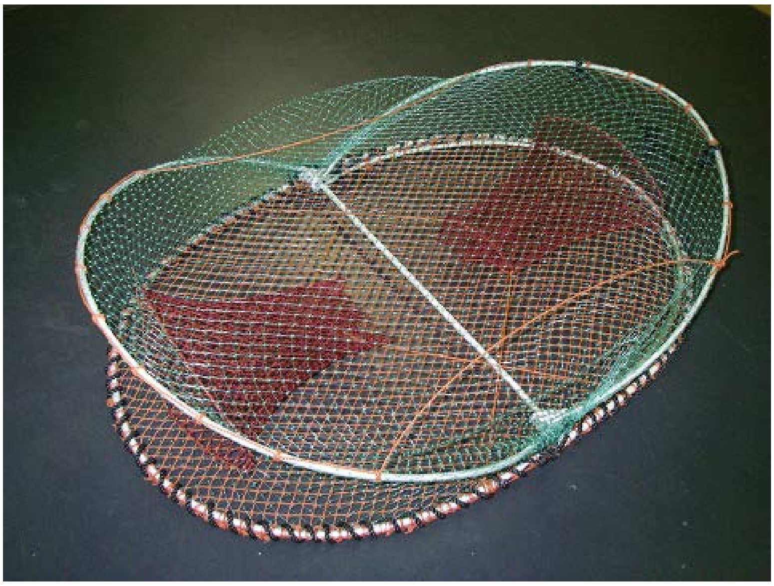

Fig. III-3. A commercially available pot used for the pot survey in the northeastern Harima Nada Sea from 2004 to 2008. Nominal mesh size: 18 *setsu*; mesh size of the upper and bottom parts, 18 and 15.9 mm, respectively.

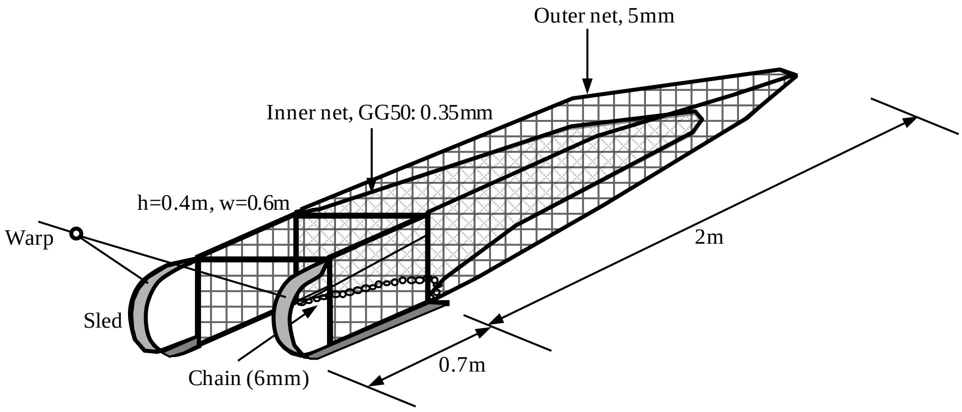

Fig. III-4. Diagram of a sledge net used to collect epifaunal benthos in the northeastern Harima Nada Sea.

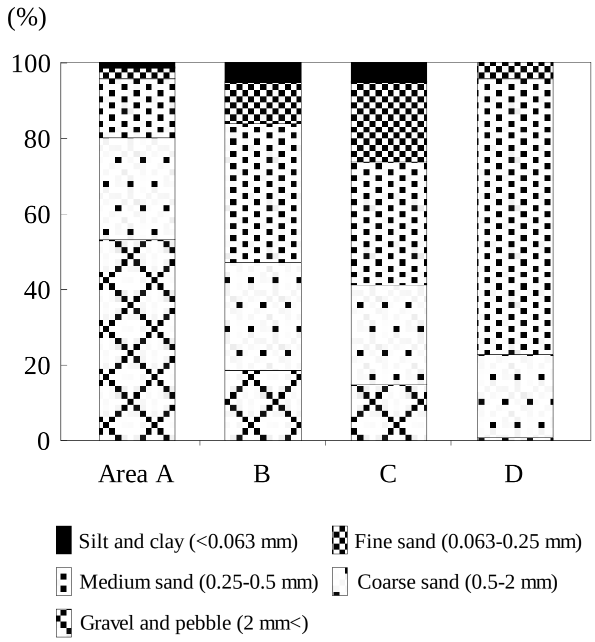

Fig. III-5. Grain size compositions of the survey areas in the northeastern Harima Nada Sea.

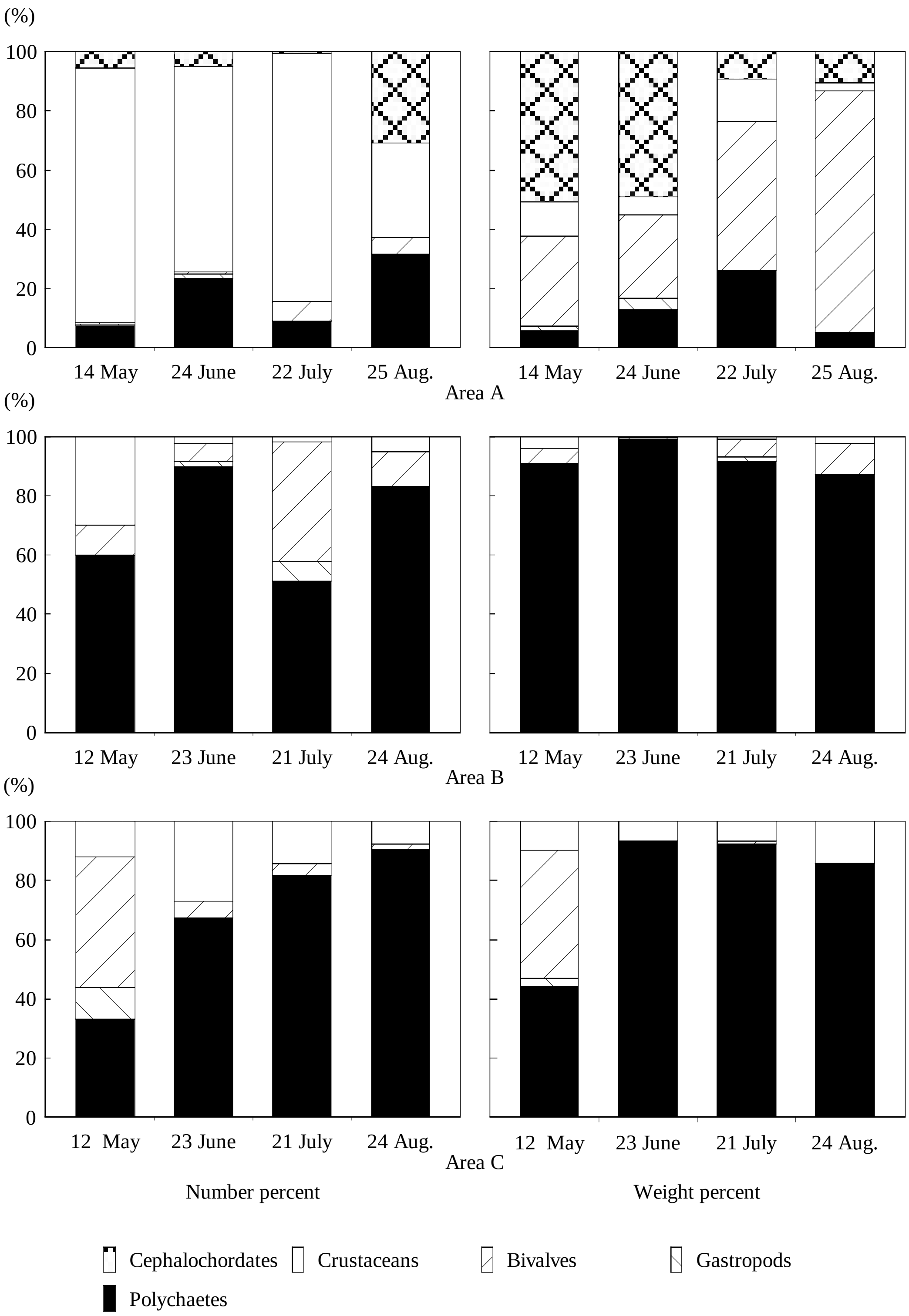

Fig. III-6. Compositions of various groups of benthos collected with the Smith-MacIntyre bottom sampler. Left, number percent; right, weight percent.

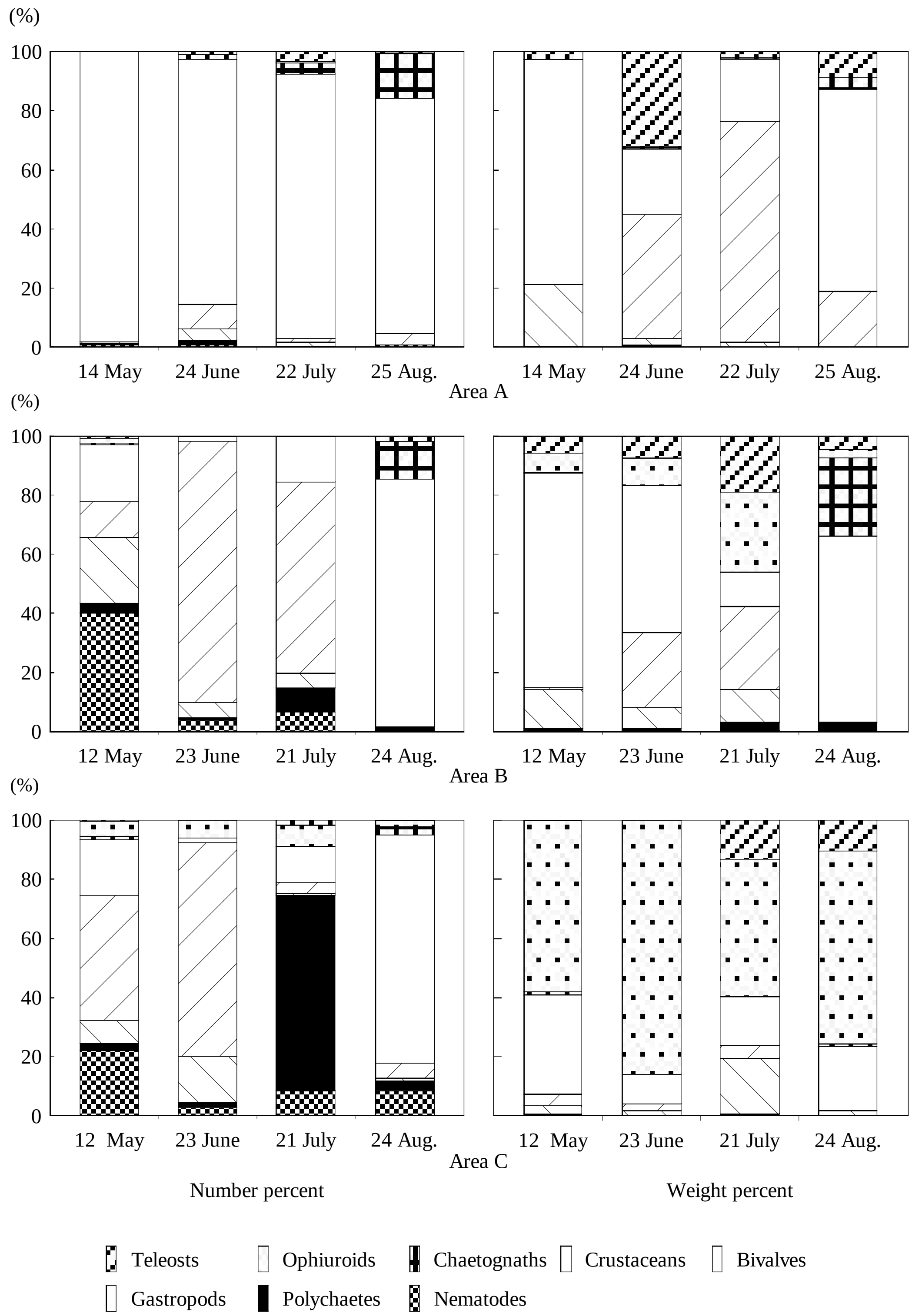

Fig. III-7. Compositions of various groups of benthos collected with the sledge net. Left, number percent; right, weight percent.

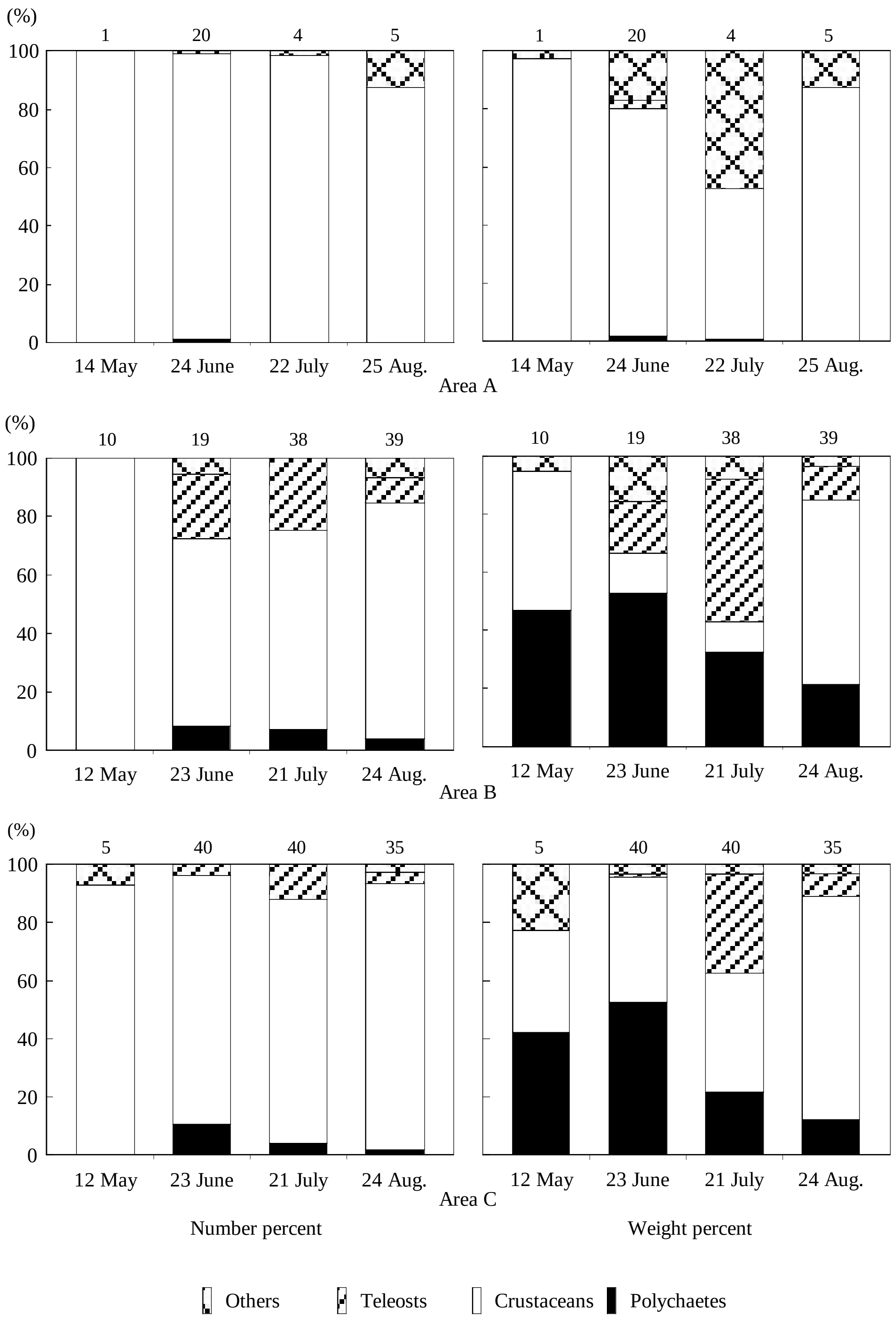

Fig. III-8. Compositions of stomach contents of juvenile whitespotted conger. Left, number percent; right, weight percent. Sample size is given for each sampling date.

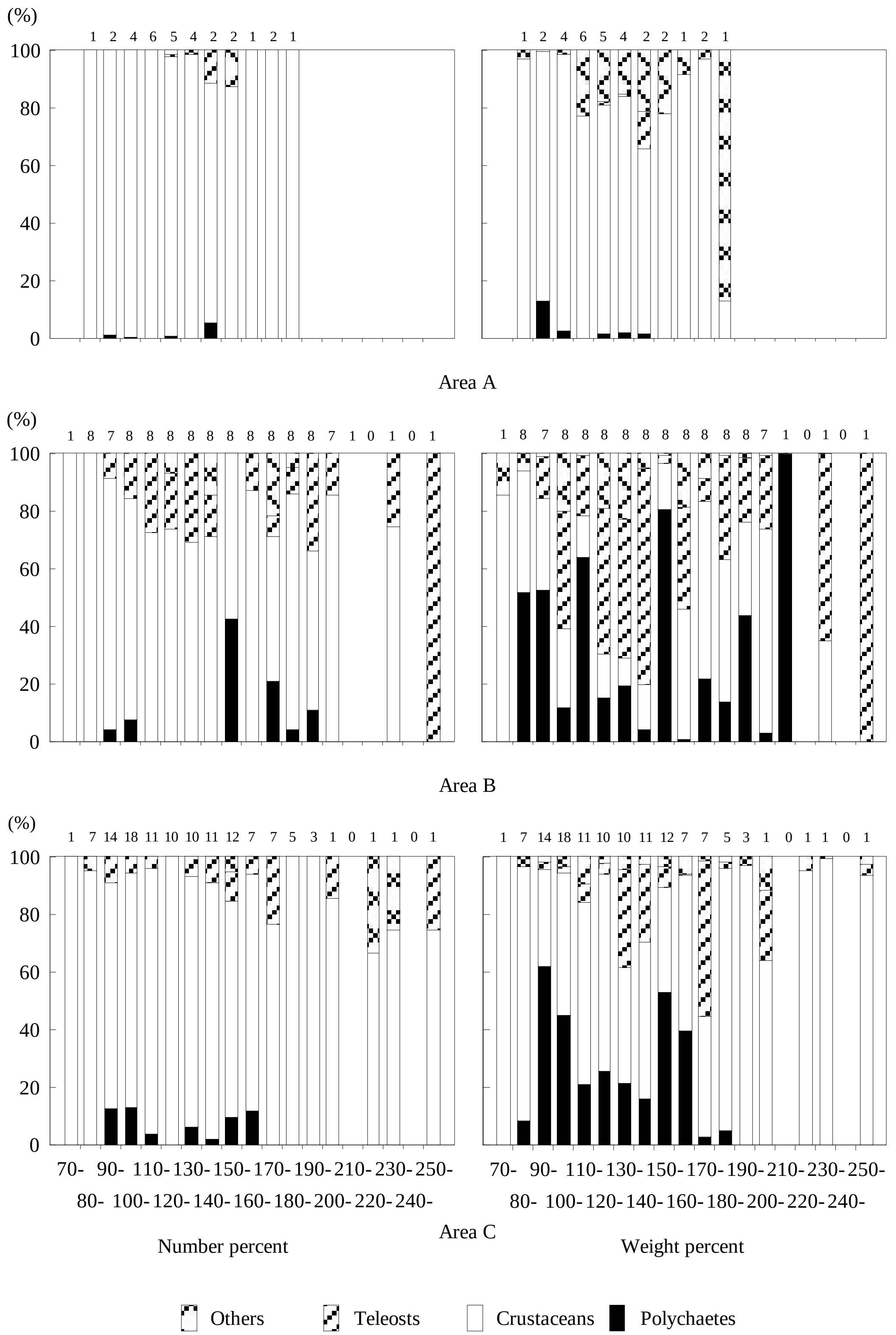

Fig. III-9. Compositions of stomach contents of juvenile whitespotted conger of different total length classes. Left, number percent; right, weight percent. Sample size is given for each size class.

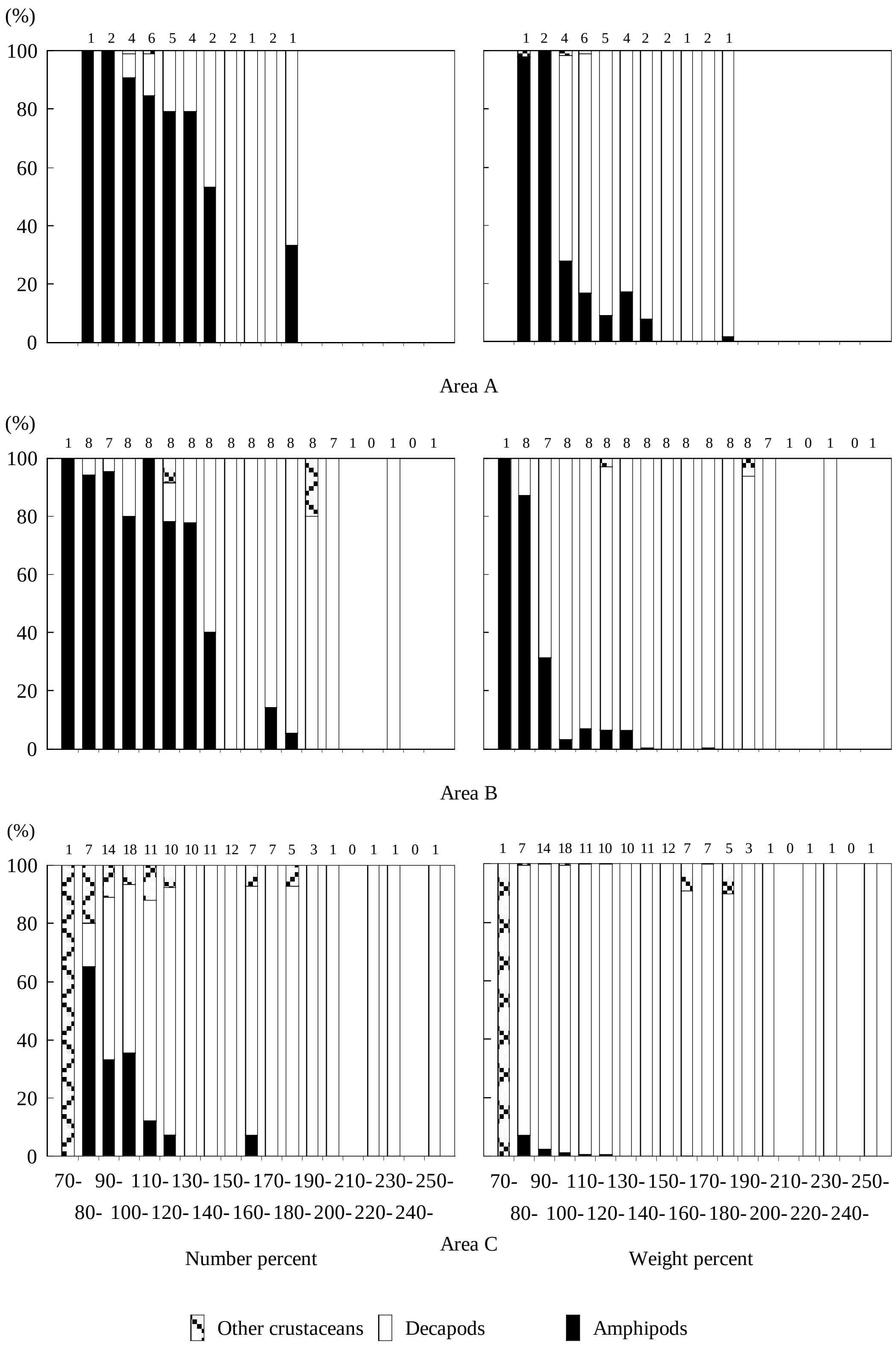

Fig. III-10. Compositions of amphipods, decapods, and other crustaceans in the stomach contents of juvenile whitespotted conger of different total length classes. Left, number percent; right, weight percent. Sample size is given for each size class.

Table III-1. Number and size of fish examined for stomach contents

Date in 2004	Area A			Area B			Area C		
	N caught	TL (SD, range)	*N* examined	*N* caught	TL (SD, range)	*N* examined	*N* caught	TL (SD, range)	*N* examined
12, 14 May	7	86 (3.5, 81-91)	1	97	85 (3.7, 76-95)	10	18	84 (3.4, 77-91)	5
23, 24 June	91	120 (13.4, 94-152)	20	181	112 (13.6, 86-151)	19	146	104 (10.5, 85-147)	40
21, 22 July	9	152 (22.8, 128-188)	4	374	139 (19.7, 84-195)	38	154	135 (21.5, 100-195)	40
24, 25 Aug.	15	164 (18.6, 133-208)	5	231	169 (20.7, 105-262)	39	142	167 (23.7, 124-258)	35
Total	122		30	883		106	460		120

N, sample size; TL, mean total length (mm); SD, standard deviation (mm).

Table III-2. Mean CPUE, WT, and salinity of the bottom net surveys

Year	Date	Area A			Area B			Area C			Area D		
		CPUE	WT (°C)	Salinity	CPUE	WT (°C)	Salinity	CPUE	WT (°C)	Salinity	CPUE	WT (°C)	Salinity
2003	9 Apr.				0			0	10.3	32.9			
	22 Apr.	0	11.7	32.8							0		
	16 May				2	15.6	32.2	9					
	13 June				11	19.5	32.0	8	18.3	32.3	0	19.3	32.4
	10 July				94	21.8	31.5	52	21.3	31.9	0	22.3	31.9
	25 Aug.				57	25.5	31.0	47	25.0	31.3	0	25.7	31.3
2004	12, 14 May	4	16.7	32.2	97	15.6	32.2	18	15.2	32.4			
	23, 24 June	44	20.6	31.8	181	20.8	31.6	146	20.0	31.9			
	21, 22 July	5	24.3	31.7	374	24.2	31.6	154	23.8	31.7			
	24, 25 Aug.	8	26.5	32.0	231	27.2	31.5	142	26.9	31.7			
2005	30, 31 May	3	17.2	31.8	11	16.6	31.7	58	16.2	31.7	0	16.7	31.8
	24 Aug.	7	25.3	32.2	82	25.7	32.1	294	25.0	32.1			
	21, 22 Sep.	12	26.0	32.1	342	26.1	32.1	180	25.9	32.2	0		
2006	18 May				0	13.9	32.1	0	13.9	32.2			
	5 June	8	17.7	31.8	16	16.9	31.7	38	16.2	31.9			
	19, 20 July	362	23.0	30.4	103	22.0	31.2	129	21.3	31.5			
	14, 15 Sep.	29	26.2	31.5	212	26.6	30.9	102	26.5	31.0			
2007	23, 24 May	0	16.7	32.4	25	15.8	32.5	31	15.8	32.5			
	25, 26 July	9	23.1	31.5	262	23.2	31.7	89	23.0	32.1			
	27 Sep.	20	27.3	31.9	210	27.4	31.7	40	27.3	31.6			
2008	26, 26 May	9	16.4	32.2	78	16.4	32.2	23	15.8	32.3			
	25 June	36	17.7	31.8	58	20.0	31.7	40	19.3	31.9			
	24, 25 Sep.	16	25.5	32.6	242	26.1	32.4	42	26.0	32.5			

CPUE, mean number of fish caught per 20 min towing; blank, no data.
WT and salinity profiles express the data near the sea bottom.
All of the surveys were conducted at night (30 min lag time after sunset).

Table III-3. CPUE, WT, and salinity of the pot surveys

Year	Date	Area A			Area B		
		CPUE	WT (°C)	Salinity	CPUE	WT (°C)	Salinity
2004	26 Oct.	0.1	22.6	30.8	2.1	22.9	30.9
	22 Dec.	1.6	15.6	31.1	1.2	15.6	30.2
2005	25 Oct.	0.3	22.4	32.4	2.2	21.2	31.8
2006	24 Oct.	0.5	23.0	31.5	2.9	23.0	31.3
	22 Dec.	3.0	14.6	31.7	8.8	14.2	31.5
2007	23 Oct.	0.0	22.9	32.0	4.1	23.1	32.0
2008	21 Oct.	0.0	23.3	32.6	1.8	23.5	32.3
	9 Dec.	0.1	14.9	32.7	1.3	14.1	32.4

CPUE, mean number of fish caught per 4 hour dipping time per pot.
WT and salinity profiles express the data near the sea bottom.
All of the surveys were conducted at night.

Table III-4. Bottom sediment of the survey areas

	Area A	B	C	D
Median particle diameter (mm)	2.39	0.47	0.41	0.38
Max diameter (mm)	26.5	19.0	19.0	9.5
Loss on Ignition (%)	2.9	2.3	2.3	2.0

Table III-5. Benthos density of the survey areas

Date in 2004		Polychaetes		Crustaceans	
		N/m^2	W/m^2	N/m^2	W/m^2
Area A	14 May	3,079	16,419	35,310	34,244
	24 June	3,574	16,959	10,496	8,281
	22 July	1,033	3,963	9,897	2,163
	25 Aug.	579	5,901	579	2,754
Area B	12 May	826	3,112	413	138
	23 June	4,566	6,182	124	23
	21 July	4,773	3,886	165	43
	24 Aug.	2,748	44,727	165	1,128
Area C	12 May	682	839	248	184
	23 June	723	4,585	289	314
	21 July	1,281	919	227	68
	24 Aug.	1,426	2,713	124	450

N, number; W, weight (mg).

Table III-6. Ivlev's selectivity index

Date in 2004			Polychaetes Number	Polychaetes Weight	Crustaceans Number	Crustaceans Weight	N
Area A	14 May	r_i	0.0	0.0	100.0	97.1	1
		p_i	7.3	5.2	83.7	10.8	
		E_i	-1.00	-1.00	0.09	0.80	
	24 June	r_i	1.0	2.0	98.3	77.9	20
		p_i	23.1	12.1	67.8	5.9	
		E_i	-0.92	-0.72	0.18	0.86	
	22 July	r_i	0.0	0.6	98.7	52.1	4
		p_i	8.5	23.7	81.0	13.0	
		E_i	-1.00	-0.95	0.10	0.60	
	25 Aug.	r_i	0.0	0.0	87.5	87.5	5
		p_i	28.3	5.3	28.3	2.5	
		E_i	-1.00	-1.00	0.51	0.94	
Area B	12 May	r_i	0.0	47.0	100.0	47.7	10
		p_i	54.8	65.3	27.4	2.9	
		E_i	-1.00	-0.16	0.57	0.89	
	23 June	r_i	8.3	52.9	63.9	13.5	19
		p_i	87.0	14.2	2.4	0.1	
		E_i	-0.83	0.58	0.93	0.99	
	21 July	r_i	7.2	32.6	68.1	10.3	38
		p_i	49.1	35.0	1.7	0.4	
		E_i	-0.74	-0.04	0.95	0.93	
	24 Aug.	r_i	4.1	21.1	80.8	63.7	39
		p_i	76.9	82.3	4.6	2.1	
		E_i	-0.90	-0.59	0.89	0.94	
Area C	12 May	r_i	0.0	42.3	92.9	34.9	5
		p_i	30.0	40.0	10.9	8.8	
		E_i	-1.00	0.03	0.79	0.60	
	23 June	r_i	10.7	52.6	85.7	43.2	40
		p_i	61.4	47.0	24.6	3.2	
		E_i	-0.70	0.06	0.55	0.86	
	21 July	r_i	4.3	21.7	83.9	41.1	40
		p_i	77.5	41.3	13.8	3.1	
		E_i	-0.89	-0.31	0.72	0.86	
	24 Aug.	r_i	1.9	12.2	91.6	77.1	35
		p_i	86.3	84.2	7.5	14.0	
		E_i	-0.96	-0.75	0.85	0.69	

r_i, percent of prey item i from the fish stomachs; p_i, percent of item i in the benthos samples with the Smith-MacIntyre bottom sampler; E_i, Ivlev's selectivity index; N, number of fish examined.

IV. Age, growth, and movement of whitespotted conger

For efficient fishery resource management; information on the age, growth, and movement of target fishes is essential. The relation between age and total length of fishes is one of the basic knowledge, which can provide us useful information (e.g., growth patterns, growth difference between male and female, and fishing status). The most valuable advantage of getting these parameters may be collection of the information on age at recruitment and age composition of catch. These parameters enable us to estimate the catch in number by age, which is important information for stock estimation.

Some approaches are possible to study the age and growth of whitespotted conger by: 1) rearing experiments; 2) chasing changes in total length distribution; 3) age determination; and 4) release and recovery of tagged fish. Rearing experiments are practicable in the laboratory, while the other works must be done using wild fish.

In this chapter, the age and growth of aquarium-reared and wild-caught whitespotted conger are analyzed. The movement and growth of this species in the wild are also studied through a tagging survey.

1. Growth of whitespotted conger in captivity

Data from rearing experiments are likely to provide us with estimation of the growth of whitespotted conger inhabiting the sea. Recently, a few studies have been conducted on the growth of the species in captivity. The fish were reared experimentally by feeding commercial dry pellets (Nemoto et al. 2004) or dry pellets combined with fresh foods (Takashima and Takahashi 2006). The growth process of the species, unfortunately, was yet poorly understood in these studies, so that our knowledge of the growth is limited, especially from the viewpoint of fish farming.

In this section, the growth of whitespotted conger in the laboratory tank is studied during their three stages, leptocephali (pelagic phase), newly settled juveniles (demersal phase), and young fish (demersal phase), by feeding moist pellets or commercial dry pellets in order to help estimating the growth of the species in the wild and to search for the feasibility of fish farming.

Materials and Methods

Leptocephali

Whitespotted conger leptocephali were obtained on 8 April 1997 from a commercial fishing boat operating in the northeastern Harima Nada Sea. The leptocephali were transferred alive to the laboratory and released to a 0.5 *kl* round-shaped, black-colored FRP tank. Although many of the leptocephali died from injury and/or damage on their body surface within a few days after transfer, the experiment was continued using the surviving leptocephali. Sand-filtered seawater was supplied to the tank by an open flow system with a flow rate of 2-10 *kl* per day (Fig. IV-1-1). Based on a preliminary experiment (Gorie unpublished), the rearing seawater temperature (WT) was kept below 26°C from July to September because high WT might actually cause a negative effect, and also no juveniles were found to be fed until they finished metamorphosis and settled to the bottom. After almost all the leptocephali completed metamorphosis, a moist pellet was fed every evening from 23 April 1997. The moist pellet was a commercial formula powder feed, originally for Japanese eel *Anguilla japonica* Temminck & Schlegel, 1847 ("*Tokai*", mash for adult eel, Marubeni Nisshin Feed Co., Ltd., Tokyo), added with equal quantity of tap water (w/w). The powder feed and water were well mixed, flattened thinly (easy to bite), and then fed. A few polyvinyl chloride (PVC) pipes (75 mm in nominal diameter and 30-50 cm in length) were set in the water. The feeding trial finished on 26 December 1997 (Day 262).

Newly settled juveniles

The newly settled juveniles of whitespotted conger were caught by a small trawl net (see Fig. III-2) on 18 May and 5 June 2006 and also on 18-19 May 2009 in the northeastern Harima Nada Sea. The net was towed for 10-20 min at a speed of 1.5-2.5 knots using a small boat (9.1 mt) with a 2.4 mm mesh aperture of a codend, and the juveniles were transferred alive to the laboratory.

The first feeding experiment started on 23 June 2006 using 46 juveniles and ended on 28 September 2007 (Day 462). After the juveniles were acclimated in an aquarium for several days, they began to feed a commercial diet (dry pellets). The second feeding experiment started on 19 May 2009 with 47 fish and finished on 14 July 2010 (Day 420). This experiment was conducted without feeding acclimation because the first experiment demonstrated that no feeding acclimation was necessary for the juveniles. The fish were initially reared in a 0.2 *kl* round-shaped, polycarbonate aquarium, then, with growth, transferred to a 0.5 *kl* round-shaped, black-colored FRP tank, and finally released to a 1 *kl* tank. A few PVC pipes (40 or 75 mm in nominal diameter, 10-50 cm in length) were set in the water. Sand-filtered seawater was supplied to the tank every hour with an equal volume of the effective storage capacity. In these feeding experiments, commercial dry pellets, originally for Japanese amberjack *Seriola quinqueradiata* Temminck & Schlegel, 1845 ("*Marin*" No. 1-6, Hayashikane Sangyo Co., Ltd., Shimonoseki), were fed every hour during the night from 6 p.m. to 6 a.m. using an automatic feeder. The feed dosage was controlled every day to avoid residual pellets. After the fish were anesthetized in 0.04% 2-Phenoxyethanol (ethylene glycol monophenyl ether), they were usually measured monthly for total length (TL, mm) and body weight (BW, g). In some cases, total BW of all surviving fish was also measured.

Young fish

Young whitespotted conger were sampled on 25 August 1995 from a small trawl fishing boat which commercially operated in the northeastern Harima Nada Sea. The fish were transferred alive to the laboratory and released to a 0.5 *kl* round-shaped, black-colored FRP tank. Forty-four fish were acclimated but were not fed until 1 September 1995. A feeding trial started on 2 September 1995 and finished on 12 August 1996 (Day 346). Three PVC pipes (75 mm in nominal diameter, 30-50 cm in length) were set in the water of the tank, which was covered by a transmissive clear PVC board (4 mm thick) to prevent the fish from escapement. A total of 10 *kl* sand-filtered seawater was supplied to the tank a day. In this feeding experiment, moist pellets with the same component as that for the leptocephali were fed in the evening every two days. The feed dosage was determined each time to avoid residual pellets. At monthly intervals, all the fish were anesthetized with 0.01% ethyl 3-aminobenzoate methanesulfonic acid salt and measured for TL and BW.

Evaluation of rearing experiments

In the experiments conducted in 1995 and 2006, the following characteristic values of the feeding trials were calculated: body weight gain (W, g) = $W_2+W_3-W_1$, feed conversion efficiency (%) = $W \cdot F^{-1} \cdot 100$, daily growth rate (%) = $(X_2-X_1) \cdot [(X_1+X_2)/2 \cdot t)]^{-1} \cdot 100$, and daily feeding rate (%) = $F \cdot [(N_1+N_2)/2 \cdot (X_1+X_2)/2 \cdot t]^{-1} \cdot 100$, where W_1 = initial total BW, W_2 = final total BW, W_3 = BW of dead and missing fish, F = amount of feeding, X_1 = initial mean BW, X_2 = final mean BW, N_1 = initial number of fish, N_2 = final number of fish, and t = feeding period. The feeding amounts were assumed to be equal to the food intakes by the fish.

Results

Leptocephali

The initial mean TL (MTL) of the leptocephali was 110 mm on 8 April 1997. With metamorphosing, they exhibited their body shrinkage and showed a minimum size (69 mm MTL) on 2 May 1997 (Day 24). Although WT was controlled below 26°C, they increased their length and reached 365 mm MTL at the end of the experiment on 26 December 1997 (Day 262) (Fig. IV-1-2, Table IV-1-1).

Many leptocephali died for a short period around 21 April 1997, when metamorphosis was in progress and the settled juveniles emerged. The leptocephali schooled marginally from the surface to the bottom, preferred the dark side, and moved near the tank bottom with metamorphosing. After finishing metamorphosis, they tended to hide themselves in PVC pipes.

The settled juveniles were observed to bite the edge of the flattened moist pellets, roll quickly their body, and then pluck the diet. Cannibalization was commonly found: the settled juveniles swallowed the leptocephali from its head, especially at night.

Newly settled juveniles

In the first experiment conducted in 2006, the juveniles were 108 mm initial MTL in June, grew linearly during the summer, and attained 344 mm MTL on 26 October 2006 (Day 125) (Fig. IV-1-3, Table IV-1-2). Although TL increments remained low during a low WT period, the juveniles slightly grew in 2007 and finally reached 454 mm MTL (range: 361-607 mm) on 28 September 2007 (Day 462). The total feed eaten was 25.5 kg and the body weight gain was 8.0 kg. The cumulative feed conversion efficiency, daily growth rate, and daily feeding rate were 31.2, 0.4, and 1.3%, respectively. The overall survival rate was 89% (Table IV-1-3).

In the second experiment conducted in 2009, the juveniles were 88 mm initial MTL and grew to 406 mm MTL in a year (Day 363). These fish attained 422 mm MTL on 14 July 2010 (Day 420), measuring 346-605 mm TL. All the fish survived until Day 363 (Table IV-1-4).

During the daytime, almost all the juveniles hid themselves in PVC pipes. When being fed, they came all together from the pipes and ate the diet. During the night, almost all the fish stayed outside of the pipes, swam around, and foraged.

Young fish

The young fish took about two weeks to begin feeding well on the moist pellets after starting the experiment. The fish of 239 mm initial MTL in September 1995 grew 325 mm MTL in December 1995 (Day 91). They reached 422 mm MTL (range: 353-528 mm TL) in August 1996 (Day 346) (Fig. IV-1-4, Table IV-1-5). Although a high growth rate was recorded in the fall (September to November) and spring (April to July) months, it remained low in winter and summer months when WTs were below 14°C and over 23°C, respectively. The feed conversion efficiency, daily growth rate, and daily feeding rate were 31.1, 0.4, and 1.5%, respectively. The overall survival rate was 82% (Table IV-1-6).

Discussion

I found in this study that whitespotted conger leptocephali completed metamorphosis without any feeding. Takashima and Takahashi (2006) also observed that the leptocephali of the species did not feed before finishing metamorphosis. Mochioka et al. (1993), however, reported the food intake action of larval whitespotted conger. Mochioka and Iwamizu (1996) also found that the leptocephali fed selectively on larvacean houses of *Oikopleura* spp., their and other zooplankters' fecal pellets. In addition, a mass mortality occurred in this study during the final phase of metamorphosis which may have been associated with non-feeding during metamorphosis. Anyway, there are two different results regarding the feeding of whitespotted conger leptocephali. Further study is needed to clarify whether or not the feeding is essential for metamorphosis.

In this study, the leptocephali spent about two weeks at 13°C to transfer them to the demersal phase. It is known that the metamorphic duration of whitespotted conger ranges from 10 to 70 days (Kubota 1961; Asano et al. 1978; Lee and Byun 1996, Otake et al. 1997;

Takashima and Takahashi 2006). This large variation in the duration of metamorphosis may depend on differences in initial stage of the larvae used for the experiments and in rearing WT. Also, differences in criteria (e.g., TL shrinkage or otolith increment analysis) to judge the metamorphic duration may have effect on the results. Since it is difficult and ambiguous to identify the beginning and completion of metamorphosis, it is highly desirable to establish the standardized criteria in order to determine the metamorphic duration of whitespotted conger leptocephali.

This study has revealed that whitespotted conger can be reared by feeding on commercial dry pellets or moist pellets: the newly settled juveniles (88-108 mm MTL) grew up to over 420 mm MTL in a year and attained as large as 607 mm TL on Day 462 (Tables IV-1-2, IV-1-4). From the experiments using the moist pellets for the young fish in 1995 and the dry pellets for the juveniles in 2006, similar results were observed in the feed conversion efficiency (30%), daily growth rate (0.4%), and daily feeding rate (1.4%) (Tables IV-1-3, IV-1-6). These values may be a normal value when the commercial incorporated diets are used. It is also considered that the optimum WT range is between 14 and 23°C. The fish showed a wide range of variation in TL at the end of the feeding trials, and this may be caused by differences in growth rate between individuals and between sexes because the female of the species grows faster significantly than the male for the first one and a half year of its life (Nemoto et al. 2004).

It is evident that whitespotted conger can be reared in captivity from the pelagic leptocephalus stage to the commercial size. This study also has given us the following suggestions: 1) the species probably can be farmed commercially; 2) experimental works to require rearing are feasible; and 3) rearing the juveniles may be one of the options for future stock management of the species. It may be possible that those non-commercial sized juveniles caught in the fishery are reared until they grow to the commercial size, without releasing them back to the sea from fishing boats. Because fresh fish and bivalves are also utilizable as feed for rearing the juveniles (Takashima and Takahashi 2006), even fishermen may use part of the discards from the haul.

While there is greater advantage in workability to use commercial dry pellets than both moist pellets and fresh food, it was quite difficult to rear the wild-caught young fish over 200 mm TL by dry pellets (Gorie unpublished). This is probably because the wild fish more than 200 mm TL are completely imbued with fresh food. It may be easier to make the smaller fish take commercial dry pellets. In addition, it is very difficult to rear the fish from leptocephalus stage because most of the leptocephali die within a few days after capture, and loss of the fish due to cannibalization is inevitable during the rearing.

In conclusion, this study has clarified that whitespotted conger leptocephali finished metamorphosis without any feeding. The newly settled juveniles and young fish could be reared by feeding commercial dry pellets and moist pellets. The fish of less than 100 mm TL caught in May grew 300 mm TL in October, some of which reached over 500 mm TL within a year. Therefore, the species has a potential to be cultured commercially and to add a value to its juveniles by a short-term rearing as an alternative option to utilize the stock efficiently in the eastern Seto Inland Sea.

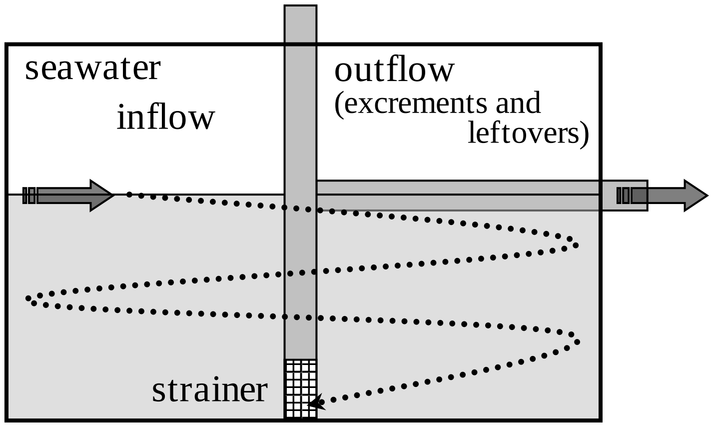

Fig. IV-1-1. Diagram of a rearing tank for the leptocephali, newly settled juveniles, and young whitespotted conger. Water flow (dotted line) entrains waste materials.

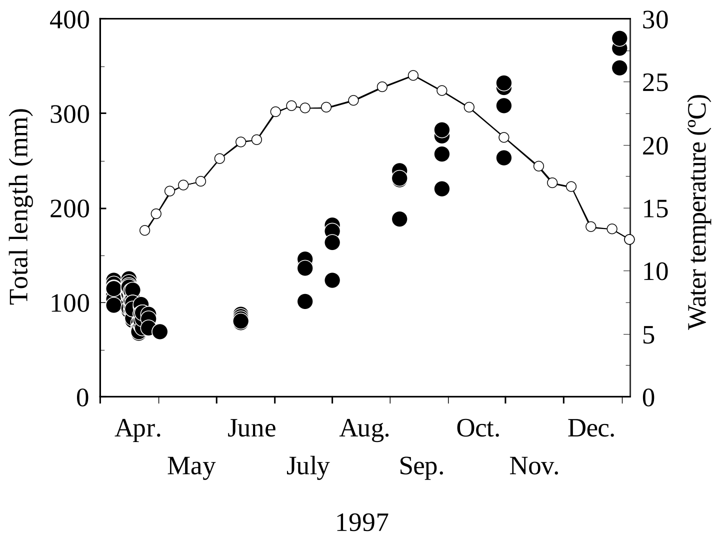

Fig. IV-1-2. Changes in total length of whitespotted conger leptocephali in captivity fed with moist pellets and in water temperature in the tank. Open circles, water temperature; closed circles, total length.

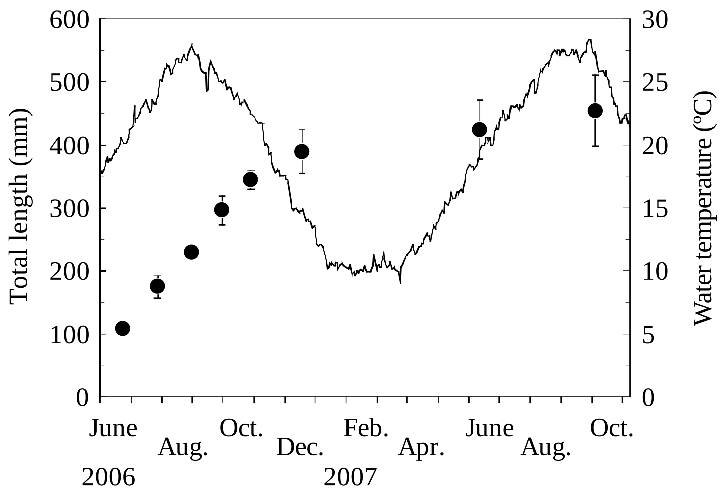

Fig. IV-1-3. Changes in total length of juvenile whitespotted conger in captivity fed with commercial dry pellets and in water temperature. Line, water temperature; closed circles, total length. Vertical bars indicate the standard deviation.

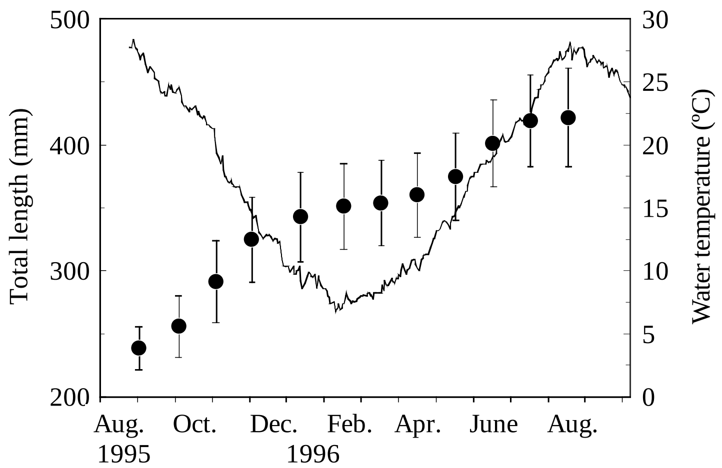

Fig. IV-1-4. Changes in total length of young whitespotted conger in captivity fed with moist pellets and in water temperature. Line, water temperature; closed circles, total length. Vertical bars indicate the standard deviation.

Table IV-1-1. Growth of whitespotted conger leptocephali fed with moist pellets in 1997

Date in 1997 (Days)		TL (SD)		WT	*N*
8 Apr.	(Day 0)	110	(6.0)	11.6	70
18 Apr.	(Day 10)	95	(7.3)	12.1	18
26 Apr.	(Day 18)	81	(7.1)	13.1	3
2 May	(Day 24)	69	(0.0)	14.6	2
13 June	(Day 66)	83	(2.8)	20.2	11
16 July	(Day 99)	132	(20.8)	22.9	4
30 July	(Day 113)	161	(26.4)	23.2	4
3 Sep.	(Day 148)	222	(23.0)	25.4	4
25 Sep.	(Day 170)	259	(27.9)	24.3	4
27 Oct.	(Day 202)	305	(36.2)	20.6	4
26 Dec.	(Day 262)	365	(15.8)	12.9	3

TL, mean total length (mm); SD, standard deviation; WT, water temperature; *N*, number of fish examined.

Table IV-1-2. Growth of juvenile whitespotted conger fed with commercial dry pellets from 2006 to 2007

Date (Days)		TL (SD, range)	BW (SD, range)	*N*
23 June 2006	(Day 0)	108 (6.2)	1 (0.2)	9
27 July	(Day 34)	175 (17.0)	8 (2.3)	10
29 Aug.	(Day 67)	229 (10.7)	18 (2.8)	10
28 Sep.	(Day 97)	296 (23.0)	39 (10.7)	10
26 Oct.	(Day 125)	344 (14.2)	72 (12.8)	10
15 Dec.	(Day 175)	389 (35.1, 283-450)	107 (32.4, 35-176)	45
7 June 2007	(Day 349)	424 (46.7, 332-552)	129 (65.5, 50-346)	45
28 Sep.	(Day 462)	454 (55.8, 361-607)	187 (97.9, 45-450)	41

TL, mean total length (mm); BW, mean body weight (g); SD, standard deviation; *N*, number of fish examined.

Table IV-1-3. Results of the rearing experiment in juvenile whitespotted conger fed with commercial dry pellets from 2006 to 2007

Period	Days	Amount of feeding (g)	Total body weight gain (g)	Feed conversion efficiency (%)	Daily growth rate (%)	Daily feeding rate (%)	*N* dead	*N* missing	Survival rate (%)
23 June 2006-26 July	34	551	275	49.9	4.2	7.8	0	0	100
27 July-28 Aug.	33	832	545	65.5	2.4	4.3	0	1	98
29 Aug.-27 Sep.	30	901	713	79.1	2.4	2.3	0	0	100
28 Sep.-25 Oct.	28	1,360	1,359	99.9	2.1	1.9	0	0	100
26 Oct.-14 Dec.	50	2,705	1,740	64.3	0.8	1.3	0	0	100
15 Dec.-6 June 2007	174	11,090	1,144	10.3	0.1	1.2	0	0	100
7 June-27 Sep.	113	8,100	2,193	27.1	0.3	1.1	4	0	91
23 June 2006-27 Sep. 2007	462	25,539	7,967	31.2	0.4	1.3	4	1	89

N, number of fish examined.

Table IV-1-4. Growth of juvenile whitespotted conger fed with commercial dry pellets from 2009 to 2010

Date (Days)		TL (SD, range)	BW (SD, range)	*N*
19 May 2009	(Day 0)	88 (5.6)	1 (0.1)	12
17 July	(Day 59)	183 (12.6, 153-210)	10 (2.2, 2-5)	47
15 Sep.	(Day 119)	296 (17.4, 256-339)	39 (8.3, 25-57)	47
18 Nov.	(Day 183)	357 (22.9, 295-421)	70 (16.5, 27-107)	47
16 Mar. 2010	(Day 301)	396 (34.4, 295-490)	102 (34.5, 25-198)	47
17 May	(Day 363)	406 (45.1, 292-520)	113 (54.3, 18-288)	47
14 July	(Day 420)	422 (62.1, 346-605)	139 (97.9, 50-507)	45

TL, mean total length (mm); BW, mean body weight (g); SD, standard deviation; *N*, number of fish examined.

Table IV-1-5. Growth of young whitespotted conger fed with moist pellets from 1995 to 1996

Date	(Days)	TL	(SD, range)	BW	(SD, range)	*N*
1 Sep. 1995	(Day 0)	239	(16.7, 194-271)	15	(3.0, 9-22)	44
3 Oct.	(Day 32)	256	(24.1, 193-298)	22	(8.4, 6-39)	43
2 Nov.	(Day 62)	291	(32.8, 216-353)	31	(11.6, 8-59)	43
1 Dec.	(Day 91)	325	(33.6, 248-381)	50	(17.3, 17-81)	42
9 Jan. 1996	(Day 130)	343	(35.3, 258-404)	66	(22.0, 20-105)	41
13 Feb.	(Day 165)	351	(34.3, 260-413)	65	(21.4, 18-102)	40
14 Mar.	(Day 195)	354	(34.0, 262-416)	67	(21.1, 19-112)	40
12 Apr.	(Day 224)	360	(33.5, 268-427)	72	(22.2, 23-129)	40
13 May	(Day 255)	375	(34.4, 284-448)	82	(25.6, 28-144)	40
12 June	(Day 285)	401	(34.5, 321-478)	111	(36.4, 44-188)	40
12 July	(Day 315)	419	(36.4, 354-518)	120	(37.9, 62-218)	38
12 Aug.	(Day 346)	422	(39.3, 353-528)	116	(40.5, 56-221)	36

TL, mean total length (mm); BW, mean body weight (g); SD, standard deviation; *N*, number of fish examined.

Table IV-1-6. Results of the rearing experiment in young whitespotted conger fed with moist pellets from 1995 to 1996

Period	Days	Amount of feeding (g)	Total body weight gain (g)	Feed conversion efficiency (%)	Daily growth rate (%)	Daily feeding rate (%)	*N* dead	*N* missing	Survival rate (%)
2 Sep. 1995-2 Oct.	31	500	277	55.3	1.1	2.0	0	1	98
3 Oct.-1 Nov.	30	900	399	44.4	1.2	2.6	0	0	100
2 Nov.-30 Nov.	29	1,270	791	62.3	1.6	2.6	0	1	98
1 Dec.-8 Jan. 1996	39	1,850	682	36.8	0.7	2.0	0	1	98
9 Jan.-12 Feb.	35	740	-37	-	-0.1	0.8	1	0	98
13 Feb.-13 Mar.	30	510	87	17.0	0.1	0.6	0	0	100
14 Mar.-11 Apr.	29	630	217	34.5	0.3	0.8	0	0	100
12 Apr.-12 May	31	1,065	375	35.2	0.4	1.1	0	0	100
13 May-11 June	30	2,120	1,182	55.7	1.0	1.8	0	0	100
12 June-11 July	30	2,200	273	12.4	0.3	1.6	2	0	95
12 July-11 Aug.	31	1,390	-149	-	-0.1	1.0	1	1	95
2 Sep. 1995-11 Aug. 1996	345	13,175	4,096	31.1	0.4	1.5	4	4	82

N, number of fish examined.

2. Growth of whitespotted conger in the wild

In the previous section, the growth of whitespotted conger in captivity from the pelagic, larval stage to the young stage is studied. While the absolute relationship between fish age and size in the wild cannot be identified only through the laboratory work, it is also important to examine wild-caught specimens in order to clarify the growth of the species. The aim of this section is thus to study characteristics of the age and growth of wild whitespotted conger in the eastern Seto Inland Sea. The growth is estimated by studying changes in total length distribution in a single cohort from continuous fishing surveys and by age determination. To determine the age of the fish, a new aging technique of UV observation of burnt otoliths (Katayama et al. 2002) is employed, and the seasonality of annuli formation in the otolith is validated. The age-total length relationship is determined, and the male-female ratio is also examined. In addition, the movement and growth of the species in this region are discussed based on the data from a tagging study.

1) Growth of whitespotted conger based on the fishing survey

To date, no study has been conducted to examine the growth of whitespotted conger by chasing changes in total length distribution from the pelagic leptocephali to those individuals recruited to the fishery.

In this section, the growth process of whitespotted conger in the wild is estimated by the fishing survey.

Materials and Methods

The survey area was located in the northeastern Harima Nada Sea (see Figs. II-1-1, III-1). Sampling of whitespotted conger was conducted from February to December in 2001, 2003, 2004, and 2008. The leptocephali (pelagic stage) were caught using a midwater beam trawl net (see Fig. II-1-2) from February to May, while the juveniles and young fish (demersal stage) were taken with a bottom trawl net (see Fig. III-2) from April to September and with pots (see Fig. III-3) in October and December, respectively. The midwater beam trawl and bottom trawl surveys were conducted in the daytime and 30 min lag time after sunset, respectively. Sampling using pots were carried out from evening to night.

The specimens caught were fixed immediately after capture on board in 5-10% buffered formalin solution and preserved until analysis. They were examined for total length (TL, mm) and body weight (BW, g).

Results

Whitespotted conger leptocephali were collected from February to May. The juveniles and young fish were caught in April and afterwards. The leptocephali ranged from 85-132 mm TL, and the juveniles and young fish measured 68-417 mm TL. Although the newly settled juveniles were only 82-86 mm mean TL (MTL) in May, they grew to 183-189 mm MTL in September and attained 301-340 mm MTL in December, when some large-sized fish reached over 400 mm TL (Fig. IV-2-1, Table IV-2-1).

Discussion

No study has ever been tried to examine the growth of whitespotted conger in the wild during the period from newly settled juveniles to individuals recruited to the fishery. Through the continuous sampling at sea, this study is the first to successfully show that whitespotted conger reached up to 400 mm TL within a year after they changed from the pelagic to demersal phase. Although the age of the fish was not determined in the study, monthly changes in length frequency distribution strongly suggest that all the fish examined are age-0 (Fig. IV-2-1).

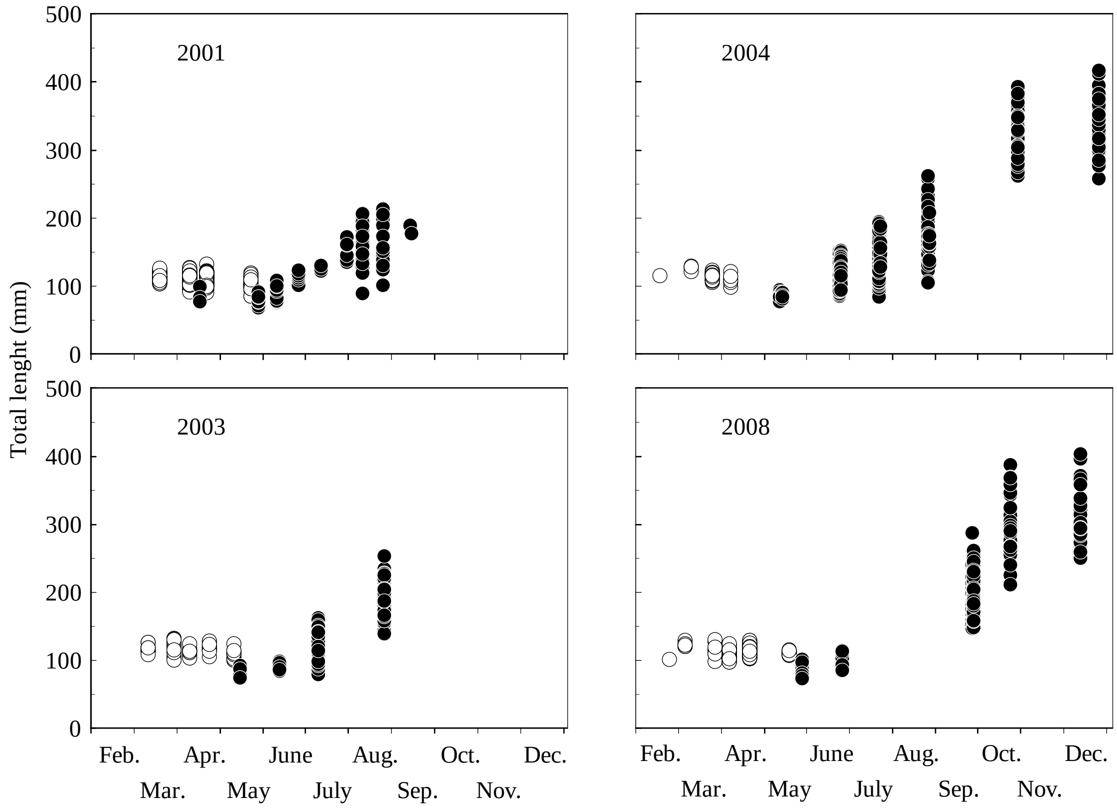

Fig. IV-2-1. Monthly changes in total length of whitespotted conger collected in the northeastern Harima Nada Sea in 2001, 2003, 2004, and 2008. Open circles, leptocephali (pelagic phase); closed circles, juveniles and young fish (demersal phase).

Table IV-2-1. Change in mean total length of wild-caught whitespotted conger in 2001, 2003, 2004, and 2008

	Date	TL	(SD)	*N*	Stage
2001	21 Mar.	113	(6.3)	33	P
	11 Apr.	112	(6.9)	93	P
	23 Apr.	109	(6.0)	204	P
	24 May	104	(7.3)	52	P
	18 Apr.	83	(10.6)	4	D
	29 May	82	(6.6)	14	D
	11 June	90	(9.9)	18	D
	26 June	113	(7.0)	7	D
	12 July	126	(3.9)	3	D
	30 July	150	(14.1)	7	D
	10 Aug.	158	(25.7)	35	D
	24 Aug.	167	(33.3)	18	D
	12, 13 Sep.	183	(8.6)	2	D
2003	13 Mar.	117	(5.4)	11	P
	31 Mar.	120	(8.9)	17	P
	11 Apr.	113	(5.7)	9	P
	25 Apr.	118	(6.1)	13	P
	12 May	108	(6.6)	14	P
	16 May	82	(5.4)	11	D
	13 June	92	(4.9)	19	D
	10 July	125	(16.5)	146	D
	25 Aug.	186	(21.4)	104	D
2004	18 Feb.	115	-	1	P
	11 Mar.	126	(3.3)	4	P
	26 Mar.	114	(5.0)	17	P
	8 Apr.	109	(7.7)	6	P
	12, 14 May	85	(3.7)	122	D
	23, 24 June	111	(13.9)	418	D
	21, 22 July	138	(20.4)	537	D
	24, 25Aug.	168	(22.3)	388	D
	26 Oct.	307	(30.1)	70	D
	22 Dec.	340	(32.0)	98	D
2008	25 Feb.	101	-	1	P
	7 Mar.	123	(3.2)	7	P
	28 Mar.	116	(9.5)	9	P
	7 Apr.	108	(7.1)	29	P
	21 Apr.	116	(6.1)	102	P
	19 May	111	(2.8)	11	P
	28 May	86	(6.8)	18	D
	25 June	103	(10.0)	11	D
	24, 25 Sep.	189	(26.2)	193	D
	21 Oct.	290	(36.9)	52	D
	9 Dec.	301	(38.0)	47	D

TL, mean total length (mm); SD, standard deviation; P, pelagic phase (leptocephalus); D, demersal phase (juvenile or young); *N*, number of fish examined.

2) Growth of whitespotted conger based on otolith reading

The absolute age and growth of whitespotted conger in Japanese waters are still poorly understood. Only several works were conducted based on otolith reading of the material from the Suo Nada Sea (Takai 1959), Ise Bay (Kubota 1961), and the Kumano Nada Sea (Kubota 1961). This paucity of research in otolith reading for age determination of whitespotted conger was due to the fact that a good age character had not been found until recently. A new method using burnt otoliths was currently developed by Katayama et al. (2002) to estimate the age of the species. Using this new method, Ishida et al. (2003) reported the age and growth of the species collected from the Joban Sea off the Pacific coast of Ibaraki Prefecture. No information is, however, available on the age and growth of whitespotted conger in the eastern Seto Inland Sea.

In this section, the growth of whitespotted conger in the eastern Seto Inland Sea is investigated using the newly developed technique by reading sagittal otoliths. The validity of sagittal otoliths as an age character is evaluated, and the relationship between total length and body weight of the species is presented. The sex ratio of the fish is also discussed.

Materials and Methods

For age determination, whitespotted conger were sampled between 1999 and 2009 from small trawl fishing boats operating in the Harima Nada Sea and Osaka Bay and from the pot survey conducted in the Akashi Strait and Harima Nada Sea. A total of 730 fish were examined for age determination. In addition, the fish from the pot survey collected in 2006 and 2007 in the Harima Nada Sea (Areas A and B, see Fig. III-1) were used for sex identification.

After measuring total length (TL, mm) and body weight (BW, g), the fish were sexed. Sagittal otoliths were removed from each fish, washed with tap water, wiped dry, and then stored in small sealable plastic bags until treatment. After otoliths were burnt and serially sectioned, they were observed under UV light by the method of Katayama et al. (2002). The year of birth and age were determined for each fish by counting annuli of the otoliths. As the hatch period of the species is inferred to continue for a long period, from August through February (Lee and Byun 1996; Mochioka 2001), a chronologic age (hatch in January) is adopted in this study. The sex was identified based on observations by the naked eye of the gonad (Table IV-2-2).

Results

Otolith observation

The year of birth and sex were obtained from 446 out of 730 fish. Seasonal changes in proportion of otoliths with a bright or dark zone at their margin under UV light are shown in Fig. IV-2-2. The margin of otoliths from the fish collected in October and February possessed the dark zone. The bright zone was observed between April and August with a peak of the proportion being in June. The proportion of the bright zone increased and decreased before and after June, respectively.

Age and growth

Whitespotted conger examined from the eastern Seto Inland Sea were found to be mostly age-1 to 4 (Fig. IV-2-3). The fish showed a wide variation in TL in the same year class and had a complicated age composition in the same TL class. Age-1, 2, 3, and 4 females measured 326-793 (mean: 579, N=105) mm TL, 301-895 (592, N=162) mm TL, 473-890 (665, N=35) mm TL, and 661-851 (782, N=8) mm TL, respectively. Also, the females of about 400 mm TL consisted of age-1 to 3 fish. While over 800 mm TL was recorded even for age-1 and age-2 females, most of the males were less than 400 mm TL (85%, N=134) and age-1 (85%). In the TL-BW relationship, dispersion of BW increased for the females larger than about 600 mm TL (Fig. IV-2-4).

Sex ratio

The number of males and females used for age determination was 134 and 312, respectively (Table IV-2-3). The age of the males ranged from 0-2 (mostly age-1), while that of the females was up to 5 (age-2 fish were the most abundant, followed by age-1 fish). The males and females ranged from 284-470 (mean: 376, N=134) mm TL and 301-895 (601, N=312) mm TL, respectively. However, most of the specimens from the pot survey in 2006 and 2007 were males (91%, N=507) (Table IV-2-4).

Discussion

It has been shown in this study that the bright zone at the margin of burnt sagittal otoliths from whitespotted conger captured in the eastern Seto Inland Sea was formed from April to August. While the percentage of the bright zone did not reach 100%, it is reasonable to consider that this zone was formed once a year during the period from April to August. Similarly, Katayama et al. (2002) found that the bright zone was formed from April to October in the same species from the coastal Pacific waters off northern Honshu Island, Japan. Thus, this study has confirmed that the sagittal otoliths can be used as an age character for whitespotted conger.

Whitespotted conger exhibited a wide variation in TL in the same year class and had a complicated age composition in the same TL class. While an age-TL relationship was not displayed, Ishida et al. (2003) found similar results in the fish caught in the Pacific waters off the coast of Ibaraki Prefecture. In addition, although the male sample size was small in the present study, it is likely that difference in growth existed between sexes in the wild (i.e., the females grow faster than males) as Nemoto et al. (2004) reported for the captive fish. In addition, Egusa (1970) reported a growth difference between sexes in European eels *Anguilla anguilla* in freshwater ponds. Further, the females have a potential to mature at age-2 (Horie et al. 2001), but the males attained sexual maturity even at age-1 in captivity (Gorie unpublished). Thus, the growth difference between sexes may be derived from the ages at maturity and/or life spans. Therefore, whitespotted conger in the wild also show high diversity in growth not only between individuals but also sexes, as stated for the captive fish (see Chapter IV-1), which may be a characteristic of the life history of the species.

The lack of a clear correlation between the age and TL means that the age composition of whitespotted conger cannot be accurately estimated only using data of length frequency distribution. In this study, the method using burnt otoliths was found useful to determine the age of whitespotted conger, which suggests us to apply age-length key method for the analysis of population dynamics of the species in the future. In addition, the TL-BW relationship found in this study will contribute to conversion from the total amount of catch into the number of catch of whitespotted conger in the eastern Seto Inland Sea.

Based on microscopic observations of the whole otoliths, Takai (1959) and Kubota (1961) previously reported the age and growth of whitespotted conger from the Suo Nada

Sea, Ise Bay, and the Kumano Nada Sea. The results of these authors were somewhat different from those found in this study. The range of TL in their fish of the same age class was at most about 200 mm. In contrast to it, the fish I examined showed a very wide variation in TL, for example, from 301-895 mm (594 mm in difference) for age-2 fish. It is unknown at present whether the difference between their and my results is due to the methods employed, the number of the fish examined, and/or the fluctuation in growth pattern of the species between years and regions.

Whitespotted conger examined for age determination in this study were mostly females (70%, Table IV-2-3) as previously reported (Takai 1959; Kubota 1961; Okamura et al. 2000; Katayama et al. 2002; Ishida et al. 2003). In 2006 and 2007, nonetheless, a large number of males appeared in the same length class (91%, Fig. IV-2-5, Table IV-2-4), and most of them were considered to be age-0 or 1 (see Chapters IV-1, IV-2-1). A similar male-biased sex ratio has been reported for the individuals in a specific enclosed lagoon (Nemoto 2007) and for the fish less than 450 mm TL in the eastern Seto Inland Sea (Takemori et al. 2004). To date, no adequate explanation is possible for the biased sex ratio (e.g., the absence of males more than 450 mm TL or over age-2 and the male-biased sex ratio in the young fish). As the large-sized fish are supposed to be females (Fig. IV-2-3), the sex ratio in commercially caught, large whitespotted conger may be female-biased. Alternatively, the males may conduct a migration to an unknown spawning ground earlier than females. It may be also possible that the females have already moved somewhere out of the survey area before they recruit to the fishery as their recruitment is earlier than the males'. Consequently, it is likely that the biased sex ratio may be caused by differences in growth, habitat utilization, and movement between sexes of the species.

In conclusion, sagittal otoliths could be used as an age character for whitespotted conger. This species showed a wide variation in TL in the same year class and had a complicated age composition in the same TL class, which suggests that age-length key method is more suitable than length-frequency analysis for future research on the population dynamics of whitespotted conger. More work is needed in various waters of Japan to determine the causes responsible for the biased sex ratio of the species.

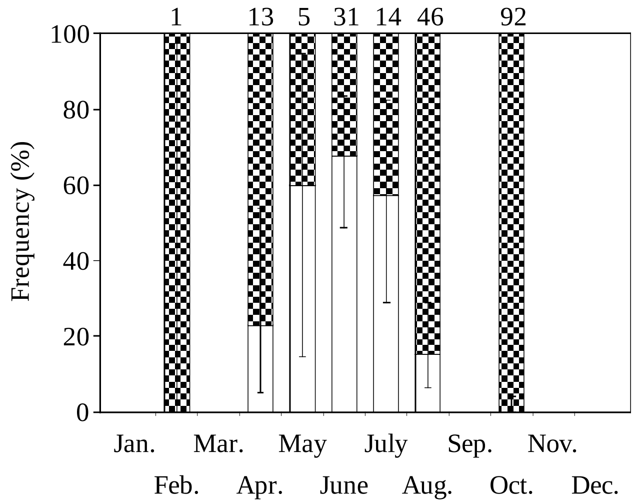

Fig. IV-2-2. Seasonal changes in proportion of otoliths with a bright or dark zone at their margin under UV light. Open bars, bright zone; shaded bars, dark zone. Sample size is given for each month. Vertical bars mean 95% confidence interval.

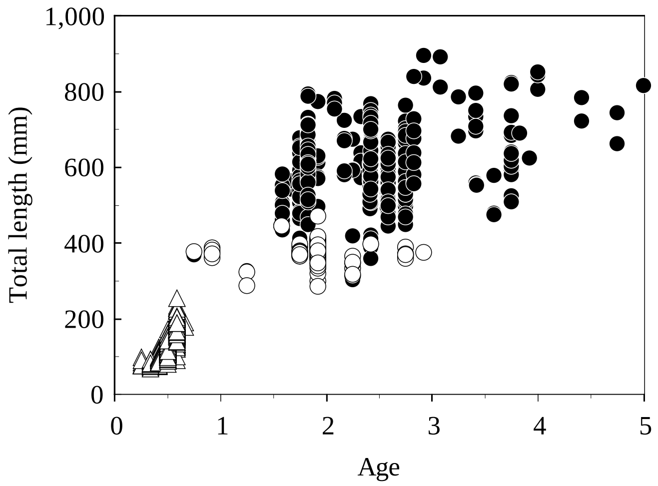

Fig. IV-2-3. Age-total length relationship of whitespotted conger collected in the eastern Seto Inland Sea from 1999 to 2009. Open circles, males (*N*=134); closed circles, females (*N*=312); open triangles, fish of unknown sex and probably age-0 (*N*=475).

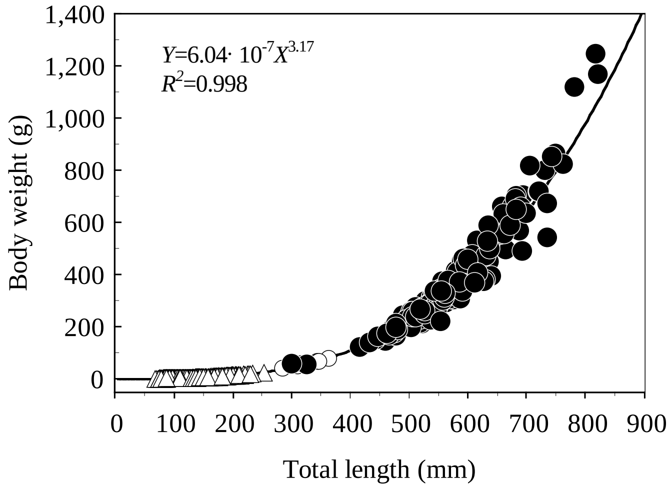

Fig. IV-2-4. Relationship between total length and body weight of whitespotted conger collected in the eastern Seto Island Sea. Allometric relationship regressed with all data overlaid. Open circles, males (N=8); closed circles, females (N=162); open triangles, fish of unknown sex and probably age-0 (N=475).

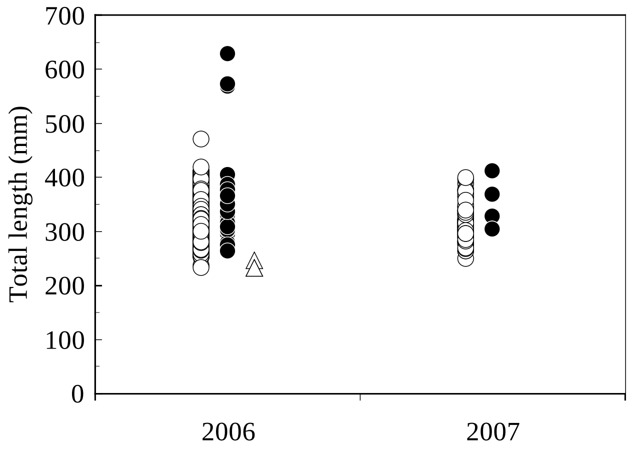

Fig. IV-2-5. Sex of whitespotted conger collected in the eastern Seto Inland Sea in 2006 and 2007. Open circles, males (*N*=460); closed circles, females (*N*=45); open triangles, fish of unknown sex (*N*=2).

Table IV-2-2. Criteria to differentiate the sex of whitespotted conger based on the gross morphology of the gonad

Male	Female
Testes barely visible as thin strands or visible as cord	Ovary cleary visible as a lamellar structure and dull white
Ventrolateral to the swim bladder	Individual oocytes barely visible to the naked eye
Very smooth and dull white	Subtle granular appearance and bright white
Can be easily pulled out with tweezers	Fragile tender tissue, easy to be pieces when pulled out

Table IV-2-3. Sex composition in each age group of whitespotted conger collected in the eastern Seto Inland Sea from 1999 to 2009

Age	Male	Female
0	6	1
1	114	105
2	14	162
3		35
4		8
5		1
Total	134	312

Table IV-2-4. Sex composition in whitespotted conger collected in the eastern Seto Inland Sea in 2006 and 2007

Date	Male	Female	unidentified	Total
22 Dec. 2006	357	40	2	399
23 Oct. 2007	103	5	0	108
Total	460	45	2	507

3) Movement and growth of whitespotted conger determined by tagging study

Information on the growth and migration of wild whitespotted conger is quite limited. The species may have a sex-biased migratory habit (see Chapter IV-2-2), and the females tend to move to deeper waters with maturation (Okamura et al. 2000). They also exhibit a seasonal loop migration driven by the avoidance of cold waters (Katayama et al. 2004). A tag and release survey must be a powerful tool to investigate the movement of whitespotted conger in the wild. So far, a few tagging studies have been conducted for young whitespotted conger. Based on the fact that the tag-released young fish tended to return to the release site in Tokyo Bay, they are considered to have homing behavior (Shimizu 2003). In contrast, however, the young fish [30 cm in total length (TL)] may remain near the release site in the eastern Seto Inland Sea (Takemori et al. 2004). To date, however, there have been no studies using tagging on the growth of the large-sized fish (>50 cm TL).

In this section, the movement and growth of large-sized whitespotted conger is shown based on a tagging study conducted in the eastern Seto Inland Sea. Also, based on the hypothesis that the females leave from the eastern Seto Inland Sea for a yet unknown spawning ground, new findings that may infer their pre- or spawning migration are presented.

Materials and Methods

Tagging and release

The study area was located in the eastern Seto Inland Sea (Fig. IV-2-6). Most of the whitespotted conger used for tagging were captured in the Akashi Strait using pots, and some were obtained from a commercial small trawl fishery operating near the strait. All the tagged fish were released at a single site in coastal waters of the northeastern Harima Nada Sea (Fig. IV-2-6, 34°41’N, 134°52’E). Before tagged, the fish were anesthetized in 0.04% 2-Phenoxyethanol (ethylene glycol monophenyl ether) and measured for total length (TL, mm) and body weight (BW, g). Conventional T-bar anchor tags (20 mm long), yellow or red in color and individually numbered, were used from 1997 to 2002. Anchor tags were inserted with a tag gun into the midpoint of the caudal muscle just above the lateral line between the anus and the posterior end of the caudal fin. Also, in 2003 to 2008, a double-tagging method was employed. After anchor tags were introduced, an individually numbered yellow tube (25 mm long, 1.75 mm in diameter), which was cut off the dart tag, was inserted into the abdominal cavity near the anus using a scalpel. In this double-tagging method, it was expected that highly visible, external anchor tags could attract fishermen's attention, and recaptured fish could be exactly identified by internal dart tubes. Especially, as the number on an anchor tag tended to vanish within 2 months, this double-tagging method was quite useful to identify individual fish.

Almost all the tagged fish were estimated to be females because their overall mean TL (MTL) was 519 mm (Table IV-2-5, see Chapter IV-2-2). A small number of the tagged and non-tagged fish were kept in a laboratory aquarium for 2 months, but there was no tag loss from these fish, and no significant differences in TL and mortality were observed between the two groups.

Growth and movement analysis

Growth was determined using the fish specimens whose tag numbers and dates at recapture were available. Freshly-caught specimens were received from fishermen and measured for TL, BW, and gonad weight (GW, g). Absolute growth rate (G) was calculated as follows: $G = (TL_r - TL_i) \cdot d^{-1}$, where TL_r is total length at recapture, TL_i is total length at release, and d is the number of days that the fish were at liberty. When frozen fish specimens were received, their TL was compensated because those specimens shrank to 97.3% of their initial TL in my preliminary test (N=38) when they were thawed. No data were used when a fish size at recapture is lower than that at release.

Gonadosomatic index (GSI) was calculated as follows: GSI (%) = $GW \cdot BW^{-1} \cdot 100$. In addition, following Katayama et al. (2002), age determination was conducted using sagittal otoliths.

Recapture locations and movement distances were determined when veracious locations were available. All recapture locations were plotted and visually validated. Although some fish were recaptured very shortly after release near the release site, the locations within 5 km from the release site were eliminated from movement analysis. The movement distance was calculated as a linear feasible distance from the release site. However, when a straight line was impossible due to the presence of Awaji Island, the detours were calculated assuming that the fish passed through the central region in one of the three straits (Akashi, Naruto, and Yura Seto straits, Fig. IV-2-6).

Annual catch survey at a fisheries cooperative association

In 2002 to 2008, monthly catch data of whitespotted conger by brand size were collected at Fisheries Cooperative Association in Kariya, where most of the fishermen are engaged in the small trawl fishery in Osaka Bay off Hyogo Prefecture (Fig. IV-2-6). The fish are usually marketed as one of the three fish sizes: small (<30 cm TL), medium-large (30-50 cm TL), and extra large (>50 cm TL).

Statistical analysis

Differences in TL and GSI were explored by Mann-Whitney's *U* test between the two waters (Harima Nada Sea-Akashi Strait waters vs. Osaka Bay-Kii Channel waters) where the fish were recaptured. Differences in age composition and recaptured waters were explored by χ^2 test.

Results

Tag-release and recapture

In 1997 to 2008, a total of 2,439 fish were tagged and released. The overall MTL was 519 mm (Table IV-2-5). No mortality was observed during the tagging and release operations. Of the 2,439 fish released, 181 were recaptured. Of these recaptured fish, 63 were single tagged, while 118 were double tagged. A half of the recaptured fish were caught during the pot surveys in the Akashi Strait. The remaining recaptures were mostly caught by the small trawl fishery and reported from fishermen, but a few specimens were sent by fish brokers. When a tag was identified by these people, only information on the date and location of recapture or the tag number was sometimes obtained. Of the 100 specimens closely examined, 4 fish were found to have lost internal tubes. The recaptured fish could be individually identified up to 420 days after the release, using the numbers on the internal tubes.

Growth and biological aspects

The growth rates were determined from 131 recaptured fish. As the number of days at liberty was longer, the growth increment of the fish at recapture was bigger. The fish exhibited various growth rates ranging from 0.25-2 mm day^{-1} during May to September (month at release) and from 0.1-1 mm day^{-1} during November to March (Fig. IV-2-7). The fish released from May to September showed larger growth rates than those released from November to March. The growth rate of the fish, which were recaptured over 300 days after release ranged from 0.3-0.6 mm day^{-1} (mean: 0.5, N=5). One fish showed as large as 233 mm growth increment for 394 days (from 502 mm TL at release to 735 mm TL at recapture). The females recaptured in the Osaka Bay-Kii Channel waters were larger than those in the Harima Nada Sea-Akashi Strait waters (P=0.009, U test), but no significant difference was found in the males (Fig. IV-2-8).

GSIs of the females were correlated with their size (Fig. IV-2-9, P<0.001, r=0.59, N=90). The fish with more than 4 in GSI were caught only in the Osaka Bay-Kii Channel waters (Fig. IV-2-10).

The age of the recaptured fish varied from 1-3 (Table IV-2-6). The males recaptured in the Harima Nada Sea and Osaka Bay were age-1. There was no significant difference between female age composition and displacement waters (χ^2 test) although the age of the recaptured females ranged from 1-2 in the Harima Nada Sea, from 1-3 in the Akashi Strait, and from 2-3 in Osaka Bay, respectively.

Movement

The recapture locations were plotted and validated using the data of 144 fish. The fish moved to Osaka Bay and the Kii Channel from the Harima Nada Sea through the Akashi Strait. Most of the fish that exhibited the eastward movement were recaptured near the Akashi Strait. In January to August, the fish were recovered widely from Osaka Bay (Fig. IV-2-11). Of the fish recovered in the Osaka Bay-Kii Channel waters, the females were recaptured from January to August, while a few males were from August to October (Table IV-2-7). The recapture with the longest movement (about 60 km from the release site) was collected in the Kii Channel. A few fish were recaptured in the waters west of the release site, and one fish was near the Naruto Strait.

Not all the released fish passed through the Akashi Strait, nor they did always move to Osaka Bay through the strait even when they were at liberty for a long period. Some large-sized fish remained in the Akashi Strait (Fig. IV-2-8). Some fish moved to Osaka Bay soon after the release, but others remained around the Akashi Strait. The recaptured fish were divided into two groups by displacement waters (Fig. IV-2-12): a locally resident group in the Harima Nada Sea-Akashi Strait waters and a migratory group in the Osaka Bay-Kii Channel waters, which indicates that these groups have different migratory habits.

Seasonal catch of whitespotted conger

Extra large-sized fish (>50 cm TL) were caught in Osaka Bay off Hyogo Prefecture from January to July with a peak in April (Fig. IV-2-13). Such fish were not caught from August.

Discussion

A double-tagging method, using conventional, external anchor tags and individually numbered internal tubes, was employed in this study. The numbers printed on the anchor tags were subject to vanish because whitespotted conger usually hide in the bottom and rub their body against the burrow wall. Due to this, it was often difficult to identify individual fish only by the external anchor tags. On the other hand, since the numbers printed on the internal tags were well preserved in the fish’s abdominal cavity and clearly identifiable more than one year, the double-tagging method is highly recommended to study the biology of whitespotted conger.

This study has shown that whitespotted conger moved to Osaka Bay and the Kii Channel from the northeastern Harima Nada Sea through the Akashi Strait (Fig. IV-2-11). This movement may be a pre- or spawning migration to a yet unknown spawning ground. In addition, a new hypothesis that such movement begins in January and continues until August is herein proposed based on the following information: 1) most of the tagged fish were females and reached to a sexually maturing size (based on an experiment of Horie et al. 2001); 2) the spawning season of whitespotted conger is estimated to be from August to February (Tanaka et al. 1987; Lee and Byun 1996; Mochioka 2001; Kurogi et al. 2002), and the individuals tagged and released in this study moved to Osaka Bay and the Kii Channel from January to August, which is before the estimated spawning season; 3) both TL and GSI of the females recaptured in the Osaka Bay-Kii Channel waters were significantly higher than those in the Harima Nada Sea-Akashi Strait waters (Figs. IV-2-8, IV-2-9, IV-2-10). In

January to April, GSIs of the females recaptured in the Osaka Bay-Kii Channel waters were also significantly higher than those of the females caught with pots in the Akashi Strait (see Chapter VI), indicating that the fish had more developed gonads in the Osaka Bay-Kii Channel waters; and 4) no fish of extra large size was caught in Osaka Bay from August by the small trawl fishery (Fig. IV-2-13), which implies that such fish left Osaka Bay for other waters.

During the survey, no spawning evidence of whitespotted conger in the eastern Seto Inland Sea was obtained, which is the same as in other inshore waters of Japan (Takai 1959; Okamura et al. 2000; Ishida et al. 2003). It is thus reasonable to consider that the fish begin a pre- or spawning migration to the North Pacific before the estimated spawning season.

Of the 181 fish recaptured, 110 (61%) were taken in the Akashi Strait, where the fish were originally caught for the tagging study. This high recapture rate was partially due to the fishing efforts there, but some fish are thought to have exhibited a kind of homing behavior, as is inferred with the young fish (Shimizu 2003). The Akashi Strait may be one of the favorite and important habitats for the large-sized fish in the eastern Seto Inland Sea.

A west-southward detour to the Kii Channel through the Naruto Strait was not considered in this study. Such movement, however, may be possible because one fish was recaptured near the strait (Fig. IV-2-11, mid-left). While no obvious explanation is possible at present why there were few recaptures in the waters west of Awaji Island, this may be due to quite a low fishing activity and/or the lack in notification to fishermen about the tagging study.

Judging from their TL, almost all the tagged and released fish were females. A few males were recovered in Osaka Bay in August and October (Fig. IV-2-8, Table IV-2-7), but this study cannot refer to the movement of the males because of their small sample size. The absence of the males or large-sized males of whitespotted conger from coastal waters of Japan has been reported to date (Okamura et al. 2000; Ishida et al. 2003). A similar phenomenon is also known for European conger *Conger conger* (Cau and Manconi 1983; O'Sullivan et al. 2003). It has, however, been recently found that whitespotted conger males occurred at a higher rate in a specific enclosed, brackish-water lagoon (percentage of males, 55%) than in inshore waters (1%) along the Pacific coast of northeastern Japan (Nemoto 2007). The male-biased occurrence was also reported for the fish less than 45 cm TL in the eastern Seto Inland Sea [see Chapter IV-2-2 (percentage of males, 91%); Takemori et al.

2004 (73%)]. Differences in various biological aspects between sexes may be a specific character of congrid fishes.

This study has shown for the first time the growth rate of wild whitespotted conger in the eastern Seto Inland Sea. The recaptured fish exhibited various growth rates from 0.1-2 mm day^{-1} (about 20 cm $year^{-1}$). The fish released from May to September showed a larger growth rate than those released from November to March (Fig. IV-2-7). This is due to differences in WT in the habitat because the fish reared in aquaria showed WT dependent growth (see Chapter IV-1). These growth rates are higher than those of two related species, American conger *Conger oceanicus* and European conger *C. conger* (about 10 cm $year^{-1}$ for both species, Hood et al. 1988; Sbaihi et al. 2001). In addition, whitespotted conger in the eastern Seto Inland Sea showed a wide variation in TL within the same year class and had a complicated age composition in the same TL class (see Chapter IV-2-2). Similar results were found for the same species caught off Joban, northeastern Japan (Ishida et al. 2003), *C. oceanicus* in the western Atlantic off North America (Hood et al. 1988), and *C. conger* in the European waters (O’Sullivan et al. 2003). Whitespotted conger reared in aquaria also show various differences in growth (see Chapter IV-1; Nemoto et al. 2004). This wide variation in growth rate is probably another specific aspect of congrid fishes, suggesting that age-length key method is more reliable for the stock estimation of the fish than length-frequency analysis.

No data on the factors to trigger the launch of the movement were taken in this study. There was no significant difference between the female age composition and displacement waters where the fish were recaptured (Table IV-2-6). Some large-sized fish remained in the Akashi Strait for a long period after release. Two types of groups were identified in the study area by the displacement waters (Fig. IV-2-12): a locally resident group to stay for a certain period near the Akashi Strait and a migratory group to move to Osaka Bay and the Kii Channel. The species may have complicated migratory habits in the eastern Seto Inland Sea. Since the individuals caught in the Osaka Bay-Kii Channel waters were larger than those in the Harima Nada Sea-Akashi Strait waters, the species may conduct a size-dependent migration. Alternatively, the pre- or spawning migration of the locally resident group of the fish may begin by age-5 in the eastern Seto Inland Sea because the fish collected in this sea were up to age-5 (see Chapters IV-2-2, VI). However, as an age-13 specimen was taken in the Joban waters (Ishida et al. 2003), the migration of the species is still a complicated biological issue for further research. More information on the age composition and other biological aspects of whitespotted conger in various regions are needed.

In conclusion, whitespotted conger moved to Osaka Bay and the Kii Channel from the Harima Nada Sea through the Akashi Strait in the eastern Seto Inland Sea. The observed displacement suggests their pre- or spawning migration, which is considered to begin in January and continue until August. This species is likely to have two groups showing different migratory habits. The fish exhibited various growth rates ranging from 0.1-2 mm day^{-1}, which is almost equivalent to about 20 cm $year^{-1}$.

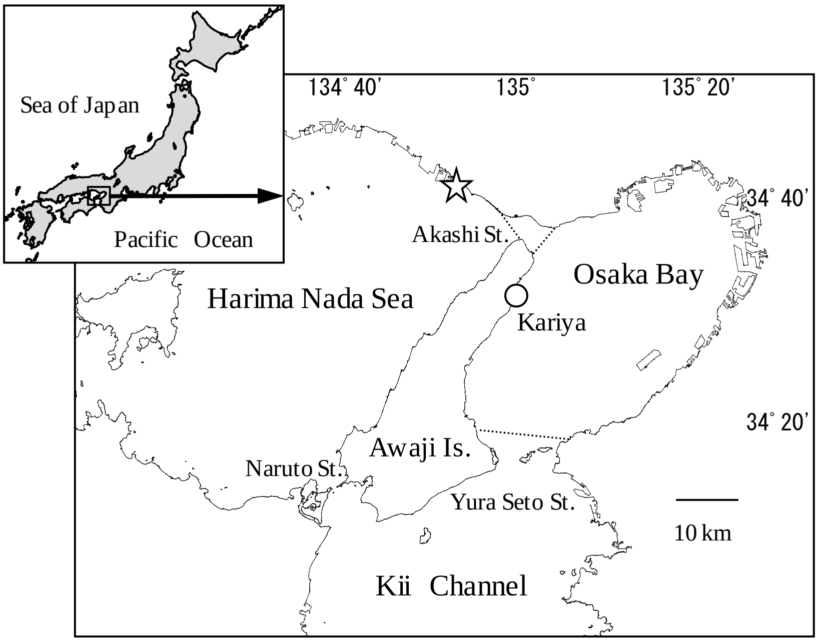

Fig. IV-2-6. A study area in the eastern Seto Inland Sea, Japan. The release site is shown by an open star. The location of Fisheries Cooperative Association in Kariya, where the catch data of whitespotted conger were obtained is indicated by an open circle. The regional boundaries are shown by dotted lines.

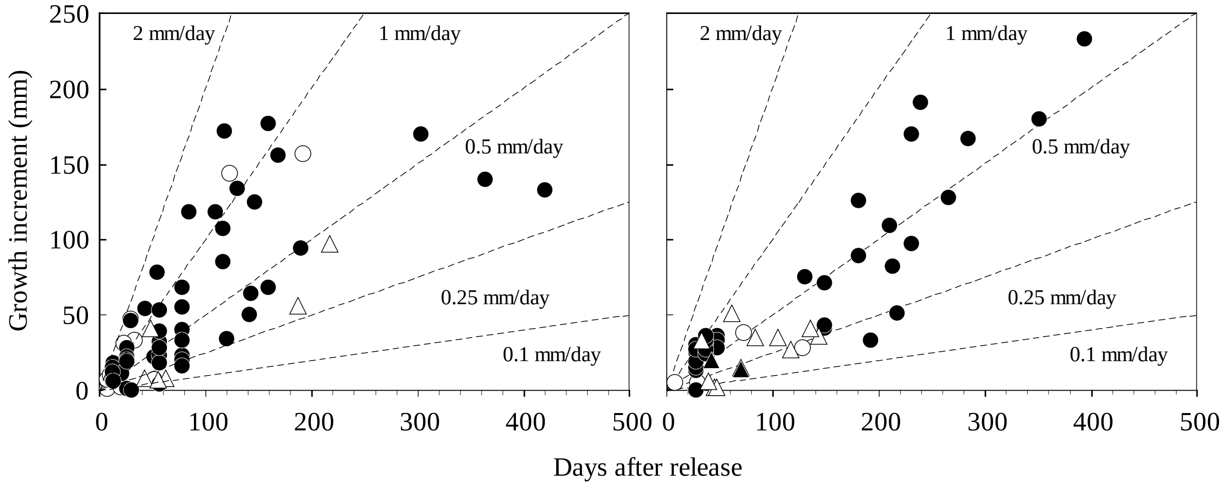

Fig. IV-2-7. Growth increments of whitespotted conger recaptured in four regions of the eastern Seto Inland Sea. Left, released in May, June, July, and September; right, released in November, December, and March. Dotted lines show guide growth increments day^{-1} (mm). Open circles, recaptures in the Harima Nada Sea; closed circles, recaptures in the Akashi Strait; open triangles, recaptures in Osaka Bay; closed triangles, recaptures in the Kii Channel.

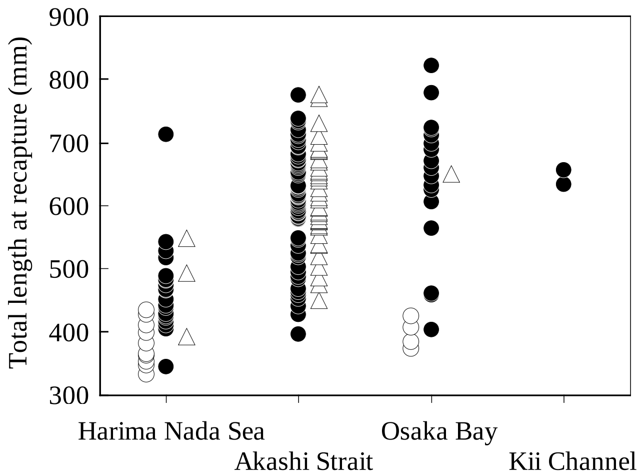

Fig. IV-2-8. Total length at recapture of male and female whitespotted conger from four regions of the eastern Seto Inland Sea. Open circles, males; closed circles, females; open triangles, fish of unknown sex.

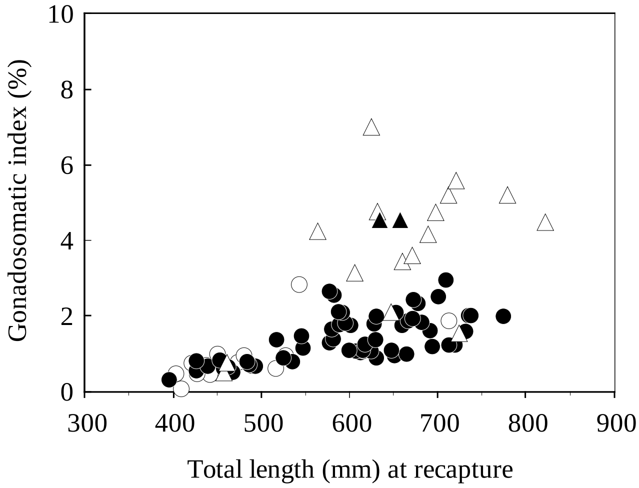

Fig. IV-2-9. Relationship between total length and gonadosomatic index at recapture of female whitespotted conger from four regions of the eastern Seto Inland Sea. Open circles, recaptures in the Harima Nada Sea; closed circles, recaptures in the Akashi Strait; open triangles, recaptures in Osaka Bay; closed triangles, recaptures in the Kii Channel.

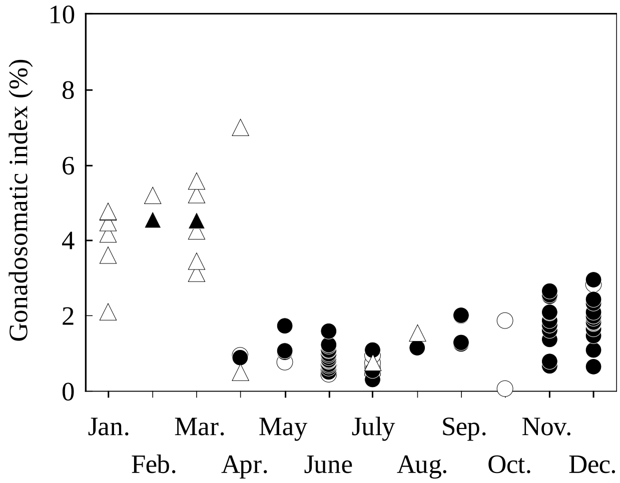

Fig. IV-2-10. Monthly changes in gonadosomatic index at recapture of female whitespotted conger from four regions of the eastern Seto Inland Sea. Open circles, recaptures in the Harima Nada Sea; closed circles, recaptures in the Akashi Strait; open triangles, recaptures in Osaka Bay; closed triangles, recaptures in the Kii Channel.

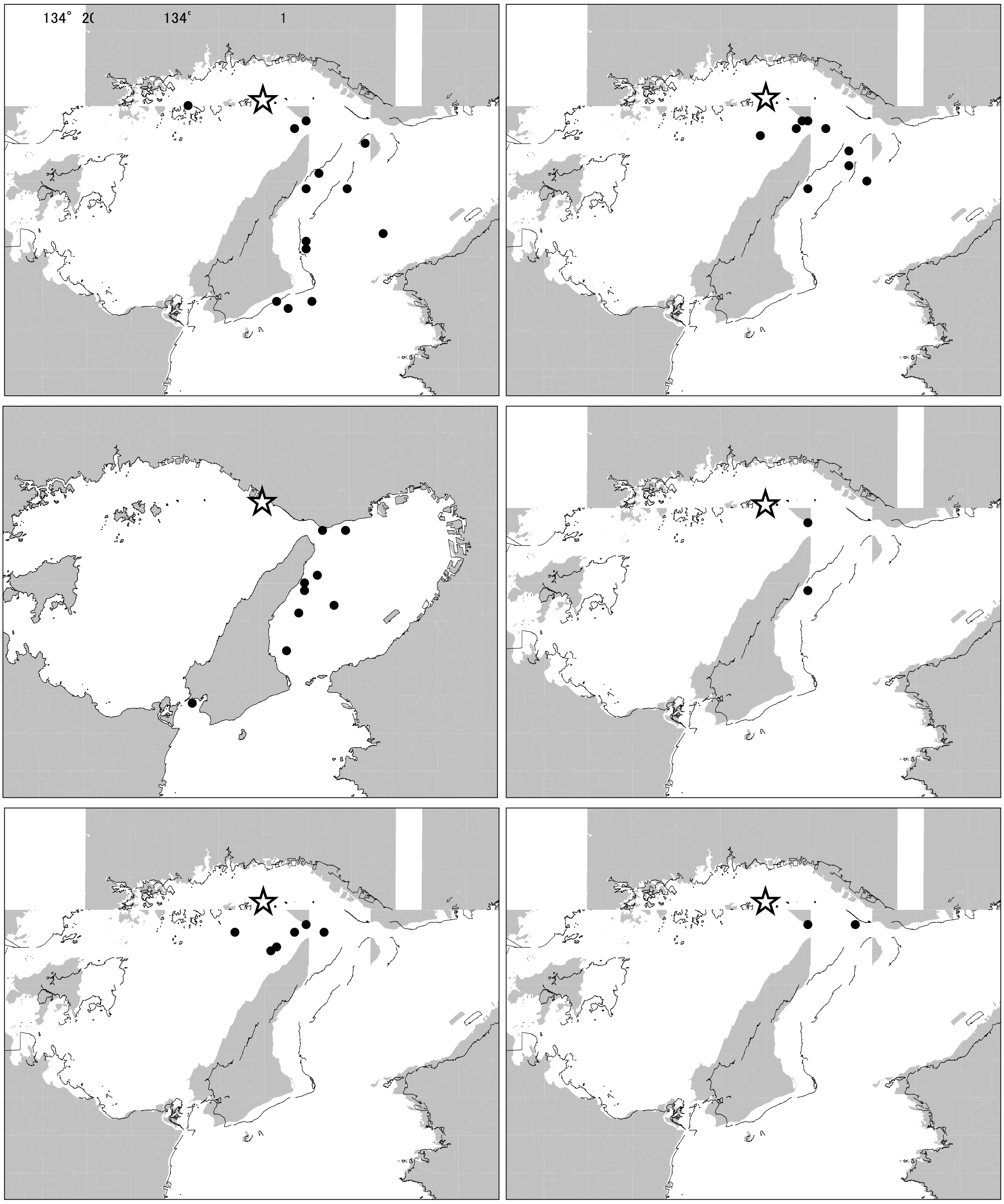

Fig. IV-2-11. Bimonthly recapture positions (dots) of whitespotted conger released at a single site (an open star) in the northeastern Harima Nada Sea. The number of fish recaptured is shown at recapture positions where more than one fish were collected.

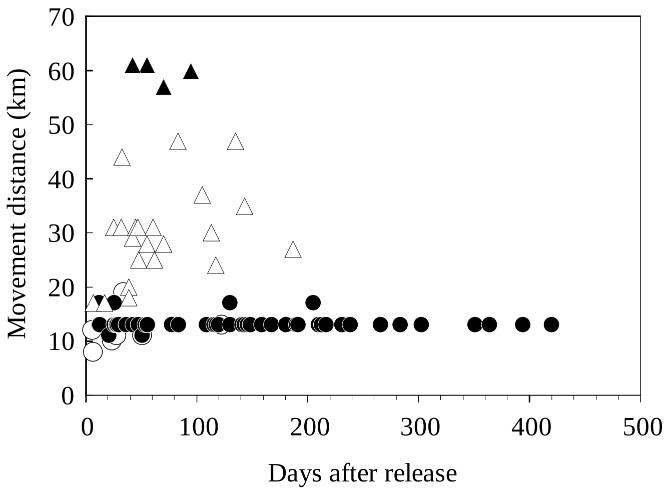

Fig. IV-2-12. Movement distance from the release site of whitespotted conger from four regions of the eastern Seto Inland Sea. Open circles, recaptures in the Harima Nada Sea; closed circles, recaptures in the Akashi Strait; open triangles, recaptures in Osaka Bay; closed triangles, recaptures in the Kii Channel.

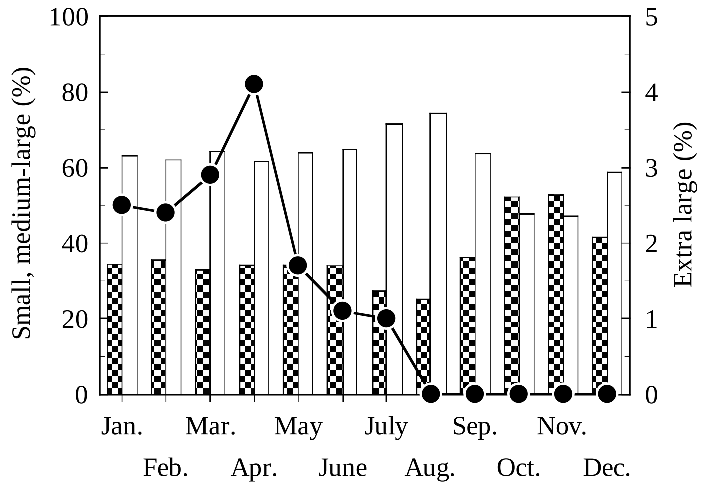

Fig. IV-2-13. Monthly composition of three size classes of whitespotted conger landed at Fisheries Cooperative Association in Kariya. The fish were caught in a small trawl fishery in Osaka Bay off Hyogo Prefecture. Data are shown using total catch for 7 years from 2002 to 2008. Shaded bars, small fish; unshaded bars, medium-large fish; closed circles, extra large fish.

Table IV-2-5. Number and total length of whitespotted conger tagged and released in the northeastern Harima Nada Sea from 1997 to 2008

Year	Month of release	*N*	TL (mm)	SD (mm)
1997	June	90	440 (277-749)	87.3
	July	262	513 (279-784)	93.9
1998	June	40	535 (354-771)	82.8
	July	14	598 (434-657)	60.0
	Aug.	7	645 (573-704)	45.6
1999	May	45	417 (344-516)	39.1
	June	90	506 (382-755)	75.0
	July	66	532 (421-760)	68.3
	Nov.	63	571 (289-758)	126.6
	Dec.	89	686 (547-943)	72.8
2001	Nov.	104	584 (382-818)	83.0
	Dec.	63	609 (385-880)	87.2
2002	June	45	441 (368-543)	47.9
	Nov.	53	575 (411-777)	98.9
	Dec.	129	618 (376-891)	88.5
2003	June	63	440 (326-613)	70.6
	Sep.	81	517 (390-693)	77.0
	Dec.	107	614 (354-815)	89.6
2004	Mar.	5	552 (436-725)	107.6
	May	46	457 (334-708)	87.3
	June	96	479 (328-802)	92.9
	Sep.	41	561 (413-682)	63.1
	Nov.	42	613 (478-770)	60.6
2005	June	134	478 (346-743)	74.7
	Nov.	58	605 (377-754)	85.1
2006	June	203	454 (318-720)	68.7
	Nov.	46	524 (298-749)	102.5
2007	June	116	441 (302-642)	68.9
	Nov.	19	466 (338-607)	77.1
2008	June	97	462 (330-685)	75.6
	July	80	460 (320-763)	87.4
	Nov.	45	474 (286-731)	111.8
Total/Mean		2,439	519 (277-943)	107.9

N, number of fish tagged and released; TL, mean total length (range); SD, standard deviation.

Table IV-2-6. Age and number of whitespotted conger recaptured in the eastern Seto Inland Sea from 1997 to 2008

Age	1		2	3
Sex	Male	Female	Female	Female
Harima Nada Sea	1	5	2	
Akashi Strait		34	11	2
Osaka Bay	1		7	2

Table IV-2-7. Number of male and female whitespotted conger recaptured in Osaka Bay and the Kii Channel from 1997 to 2008

Month	Male	Female	
	Osaka Bay	Osaka Bay	Kii Channel
Jan.		6	
Feb.		1	1
Mar.		5	1
Apr.		3	
May			
June			
July		1	
Aug.	3	1	
Sep.			
Oct.	1		
Nov.			
Dec.			

V. Fishery status of whitespotted conger and stock management approach

A fishery resource management project started in the eastern Seto Inland Sea in 1988. The six prefectures (Okayama, Hyogo, Osaka, Wakayama, Kagawa, and Tokushima) facing the eastern Seto Inland Sea formed the eastern Seto Inland Sea block for the purpose of the fishery resource management (Anon. 1991). In this project (phase I), four species were targeted: marbled flounder *Pseudopleuronectes yokohamae* (Günther, 1877), ridged-eye flounder *Pleuronichthys cornutus* (Temminck & Schlegel, 1846), bastard halibut *Paralichthys olivaceus* (Temminck & Schlegel, 1846), and red seabream *Pagrus major* (Temminck & Schlegel, 1843). The project addressed avoiding and reducing the discards of these fishes in various fisheries. Following the phase-I project, since 1993, a survey of fishery management for the fish species caught by the small trawl fishery has been conducted as a phase-II project (Anon. 1996). This phase-II project has focused on whitespotted conger because this species is one of the most commercially important fishes caught by the small trawl fishery in the eastern Seto Inland Sea.

In this chapter, the catch and fishing status of whitespotted conger in the eastern Seto Inland Sea are reported. The possible use of enlarged mesh size in the small trawl fishery for the stock management of the fish is discussed based on mesh and artificial selectivity experiments in the northeastern Harima Nada Sea. Knowledge of the mesh selectivity of whitespotted conger will provide fishermen with useful information on how to take appropriate stock management options, such as the feasibility of enlarging the mesh size in the codend.

1. Whitespotted conger fishery in the eastern Seto Inland Sea off Hyogo Prefecture

Whitespotted conger are usually caught by three fisheries (small trawl, longline, and others) in the eastern Seto Inland Sea off Hyogo Prefecture. Of these fisheries, the small trawl fishery is the main one in this region and includes some variations, such as beam trawl, dredge trawl, otter trawl, etc. C*hin-kogi*, a variant of the dredge trawl equipped with chains or net-sinkers on a ground rope, is usually operated in the northeastern Seto Inland Sea, while *ita-biki*, a small otter trawl, and/or other trawl fisheries are commonly operated both in the western Harima Nada Sea and Osaka Bay off Hyogo Prefecture. On the other hand, in

Osaka Bay off Osaka Prefecture, the species is commercially caught by "other fishery", which is considered to be the pot fishery (Nabeshima et al. 1995).

In this section, annual and monthly changes in the catch as well as monthly changes in length frequency distribution of whitespotted conger caught in the Harima Nada Sea and Osaka Bay off Hyogo Prefecture are described.

Materials and Methods

Fishery statistics

Information on the catch of whitespotted conger and cumulative fishing effort of the small trawl fishery was collected from *Annual Statistical Reports on Agriculture, Forestry, and Fisheries of Hyogo Prefecture* published from 1986 to 2010 (Anon. 1986-2010). The catch data of "congrid fishes" found in these annual reports are herein regarded as those of whitespotted conger because congrids commercially caught in the eastern Seto Inland Sea are a single species (i.e., whitespotted conger *Conger myriaster*).

Annual catch survey at fisheries cooperative associations

Monthly catch data of whitespotted conger were collected from 1994 to 1997 at the three fisheries cooperative associations in Tasakago, Kariya, and Nushima, Hyogo Prefecture. Most of the fishermen belonging to these three associations are engaged in the small trawl fishery and catch the species in the northeastern Harima Nada Sea, Osaka Bay, and the northern Kii Channel, respectively (Fig. V-1-1).

Fishing status in Osaka Bay

A monthly sampling was carried out for a year from January to December in 1994 at Fisheries Cooperative Association in Kamaguchi (Fig. V-1-1). Whitespotted conger caught by the small trawl fishery (an otter trawl, called *ita-biki*) were collected there from fishing boats and brought to the laboratory, where they were measured for total length (TL, mm) and body weight (BW, g).

Fishing status in the northeastern Harima Nada Sea

A monthly fishing survey was conducted in the northeastern Harima Nada Sea for one year from October 1994 to October 1995, using a chartered small trawl fishing boat (a dredge trawl, called *chin-kogi*) belonging to Fisheries Cooperative Association in Takasago (Fig. V-1-1). The fish caught through this survey were divided by a fisherman into two groups, fish to be landed or fish to be discarded. All the fish of these groups were separately transferred to the laboratory, where they were measured for TL (mm) and BW (g). Artificial selectivity was calculated by 10-mm TL class as follows (Nishikawa et al. 1994): Artificial selectivity (%) = (Number of fish for landing)·(Number of fish caught in the codend)$^{-1}$·100. In addition, following Chen et al. (1992), an artificial selectivity master curve (logistic model) was also calculated by a least square method: $S_a = 1\cdot[1+\exp{-k(L-m)}]^{-1}$, where S_a is artificial selectivity, L is TL class (mm), k and m are constant numbers of logistic curve. The 25, 50, and 75% artificially selected TLs were deduced from the following formulae: $L_{25} = (km-\ln 3)k^{-1}$, $L_{50} = m$, and $L_{75} = (km+\ln 3)k^{-1}$, respectively.

Results

Fishery statistics

Whitespotted conger are one of the commercially important fishes in the small trawl fishery as well as in the fisheries in the eastern Seto Inland Sea off Hyogo Prefecture (Tables V-1-1, V-1-2). The average annual catch of the fish in this region was 1,700 metric tons (mt) from 1984 to 1997, but the catch decreased to 562 mt in 1999. After the catch slightly recovered, it was rather stable from 2000 to 2008 and was 582 mt in 2008 (Fig. V-1-2, top). In this region, whitespotted conger were mostly caught by the small trawl fishery. The annual percentage of the species catch from the small trawl fishery in the total catch was stable as high as 70% during the whole survey period from 1984 to 2008 (Fig. V-1-2, bottom). The catch in the longline fishery decreased gradually and that in other fisheries showed a very little increase trend.

The cumulative fishing effort of the small trawl fishery decreased gradually from 1984 to 2006 (Fig. V-1-3). This trend, however, did not coincide with annual changes in catch of the fish.

The catch of whitespotted conger at the three fisheries cooperative associations in Takasago, Kariya, and Nushima exhibited a clear seasonal fluctuation every year (Fig. V-1-4). It was constantly high both in May-August and November-January, while it always remained low both in September-October and February-April.

Length frequency distribution of whitespotted conger from the small trawl fishery

A. Osaka Bay

Whitespotted conger caught in Osaka Bay by the small trawl fishery ranged from 198-891 (mean: 319, *N*=3,702) mm TL and from 14-1,356 (50, *N*=2,934) g BW (Fig. V-1-5). Almost all the fish measured 250 to 450 mm TL, but only some fish were over 500 mm TL.

In January 1994, there were two (small and large) modes of the fish size (Fig. V-1-5). The large-sized fish were not recognized in other months, but the small-sized fish predominated in the catch from February to September 1994 with growth. In October 1994, however, length frequency distribution of the fish suddenly changed (Fig. V-1-5): the mode shifted smaller from 360 mm TL in September to 270 mm TL in October. These, newly recruited small-sized fish accounted for almost all catches from October to December 1994.

The mean percentage of whitespotted conger less than 300 mm TL was 47% from January to April and November to December in 1994 (Fig. V-1-6). It declined from April to June and remained at a low level until September but, in October, jumped up dramatically to more than 60%. Those fish were composed of 40% in the overall samples (*N*=4,036).

B. The northeastern Harima Nada Sea

Whitespotted conger caught in the northeastern Harima Nada Sea ranged from 224-473 (mean: 313, *N*=917) mm TL and from 15-176 (46, *N*=917) g BW (Fig. V-1-7). There was no catch of the fish larger than 500 mm TL. Although the shift of length frequency distribution of the fish was not as clear as in Osaka Bay, there was a shift in September 1995, when catch of the small-sized fish increased (Fig. V-1-7). The 25, 50, and 75% artificially selected TLs were calculated to be 250, 262, and 274 mm TL, respectively, using the estimated parameters (m=261.7, k=0.092), and almost all the fish examined were larger than 250 mm TL because the small-sized fish were discarded at sea (Fig. V-1-8).

Discussion

Annual changes in total catch of whitespotted conger in the eastern Seto Inland Sea off Hyogo Prefecture are well consistent with those in catch from the small trawl fishery because the most of the fish are caught by this fishery (Fig. V-1-2). One of the reasons why the catch is mostly by the small trawl fishery in this region is because the pot fishery to catch whitespotted conger is strictly prohibited from December to May under *Hyogo Prefectural Fishery Adjustment Rules* outside the common fishery right areas, and only a few fisheries cooperative associations are permitted to operate the fishery. There was a clear seasonal variation in monthly catch: high in May-August and November-January but low in September-October and February-April (Fig. V-1-4). Although it is not easy to explain its causes, one of the possible explanations is that water temperature is related to such fluctuation because the feeding activity of the species declines over 23°C and under 14°C (see Chapter IV-1).

This study has shown that only one or two modes were usually recognized in length frequency distribution of whitespotted conger commercially caught in the eastern Seto Inland Sea (Figs. V-1-5, V-1-7). Most of those fish measured 250 to 450 mm TL. In Osaka Bay, the small-sized fish (<300 mm TL) newly appeared in October (Fig. V-1-5), and their percentage showed a sharp rise in October (Fig. V-1-6). Similarly in the Harima Nada Sea, the mode of the fish size shifted smaller in September (Fig. V-1-7). As described in Chapters II and IV, this study has shown that whitespotted conger occur as leptocephali from February to May in the Harima Nada Sea, and then they settle down to the ground and can grow to about 300 mm TL in October. These results strongly suggest that the fish being recognizable in spring as leptocephali begin recruiting to the fishery at 250 mm TL in September-October and become a target for the catch of the small trawl fishery. Those fish are also considered to be caught continuously all year round and to account for most of the catch. Since annual changes in fishing effort of the small trawl fishery did not coincide with those in the total catch (Figs. V-1-2, V-1-3), it is most likely that fluctuations in the catch largely depends on the amount of the newly recruited fish (i.e., that of the leptocephali migrating to the eastern Seto Inland Sea).

In Osaka Bay, the large-sized fish were recognized in January but soon disappeared. Further, a few and no fish over 500 mm TL were caught in Osaka Bay and in the Harima Nada Sea, respectively, which suggests that the those fish inhabit the area that is not fished by the small trawl fishery. As reported in Chapter IV-2-3, the large-sized fish (>500 mm TL) seem to leave Osaka Bay for other regions in January and afterwards

To summarize, in the eastern Seto Inland Sea off Hyogo Prefecture, the average catch of whitespotted conger was 1,700 mt from 1984 to 1997, but the annual catch decreased to 562 mt in 1999. Subsequently, it slightly recovered and was rather stable from 2000 to 2008. The monthly catch showed a seasonal fluctuation every year, being high both in May-August and November-January but low both in September-October and February-April. Whitespotted conger were mostly caught by the small trawl fishery and measured 250 to 450 mm TL. Only a few large-sized fish (>500 mm TL) were caught. Both in Osaka Bay and the Harima Nada Sea, a size of 250 mm TL was obviously the lower limit for catch and landing. The fish arrived in this region as leptocephali in spring and became a target of the small trawl fishery at 250 mm TL in fall. After recruitment, they were caught continuously throughout the year and accounted largely for the annual catch. The fluctuation of the annual catch might be related to the amount of the leptocephali migrating to the region.

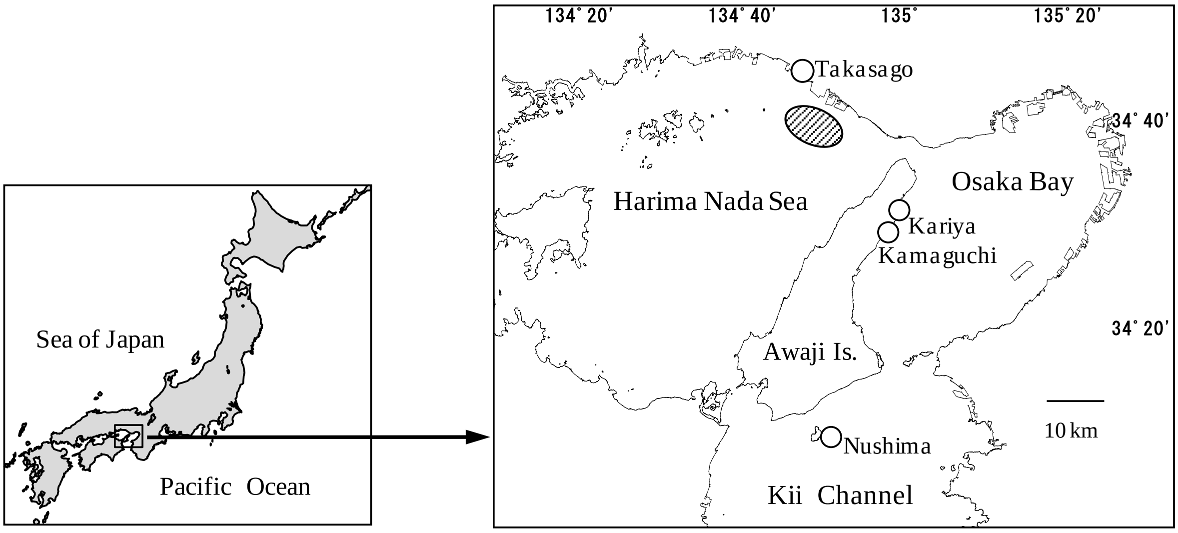

Fig. V-1-1. A study area (hatched) in the eastern Seto Inland Sea. The locations of the four fisheries cooperative associations in Takasago, Kariya, Kamaguchi, and Nushima, where the catch data of whitespotted conger were collected, are indicated by open circles. The fishing survey was carried out in the hatched area.

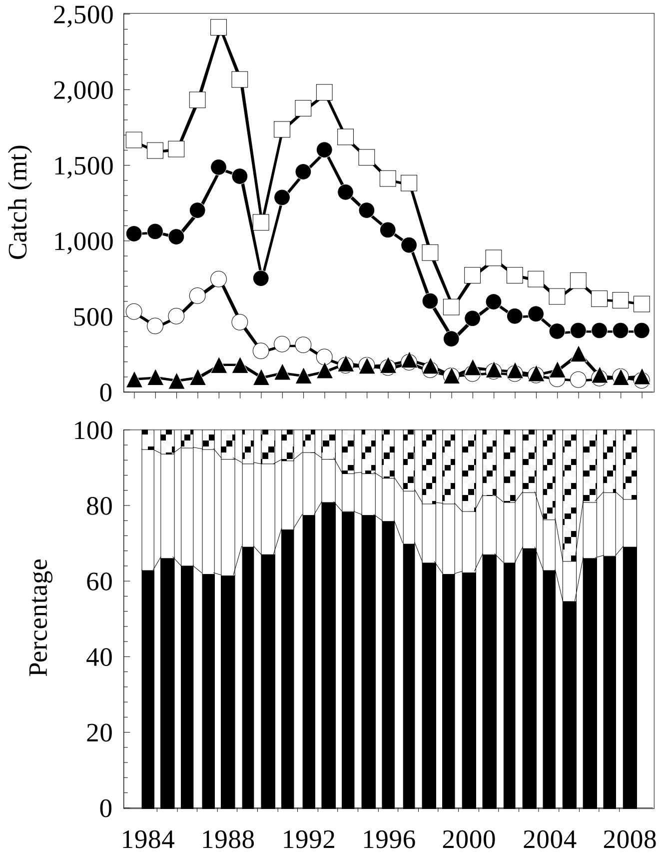

Fig. V-1-2. Annual changes in catch [top: metric tons (mt); bottom: percentage] of whitespotted conger from various fisheries in the Seto Inland Sea off Hyogo Prefecture from 1984 to 2008. Closed circles and bars, small trawl fishery; open circles and bars, longline fishery; closed triangles and hatched bars, other fisheries; open squares, total catch.

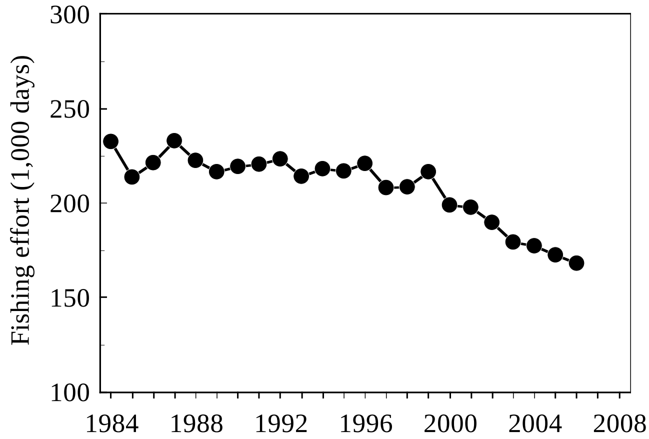

Fig. V-1-3. Annual changes in cumulative fishing effort of the small trawl fishery in the Seto Inland Sea off Hyogo Prefecture from 1984 to 2006.

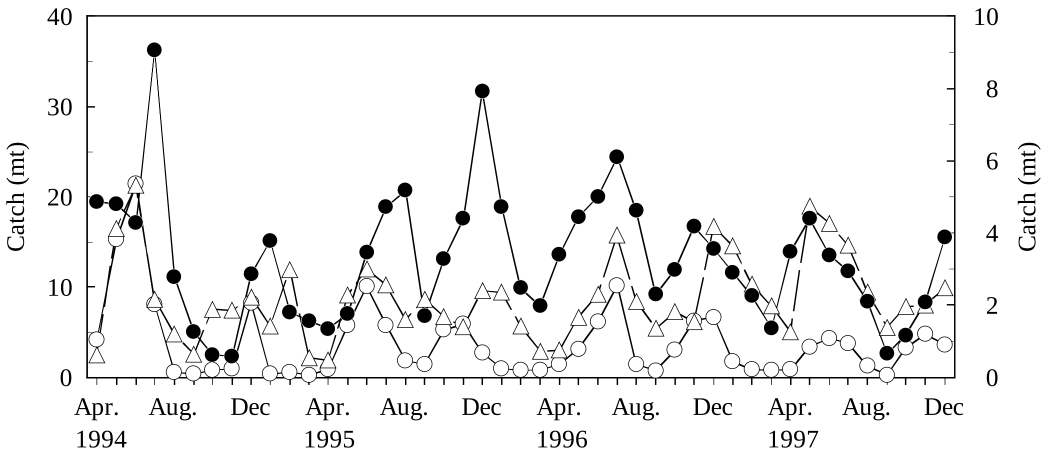

Fig. V-1-4. Monthly changes in catch of whitespotted conger at fisheries cooperative associations in Takasago, Kariya, and Nushima. Open circles, catch in Takasago; closed circles, catch in Kariya; open triangles, catch in Nushima; left axis for catch in Kariya; right axis for catches in Takasago and Nushima.

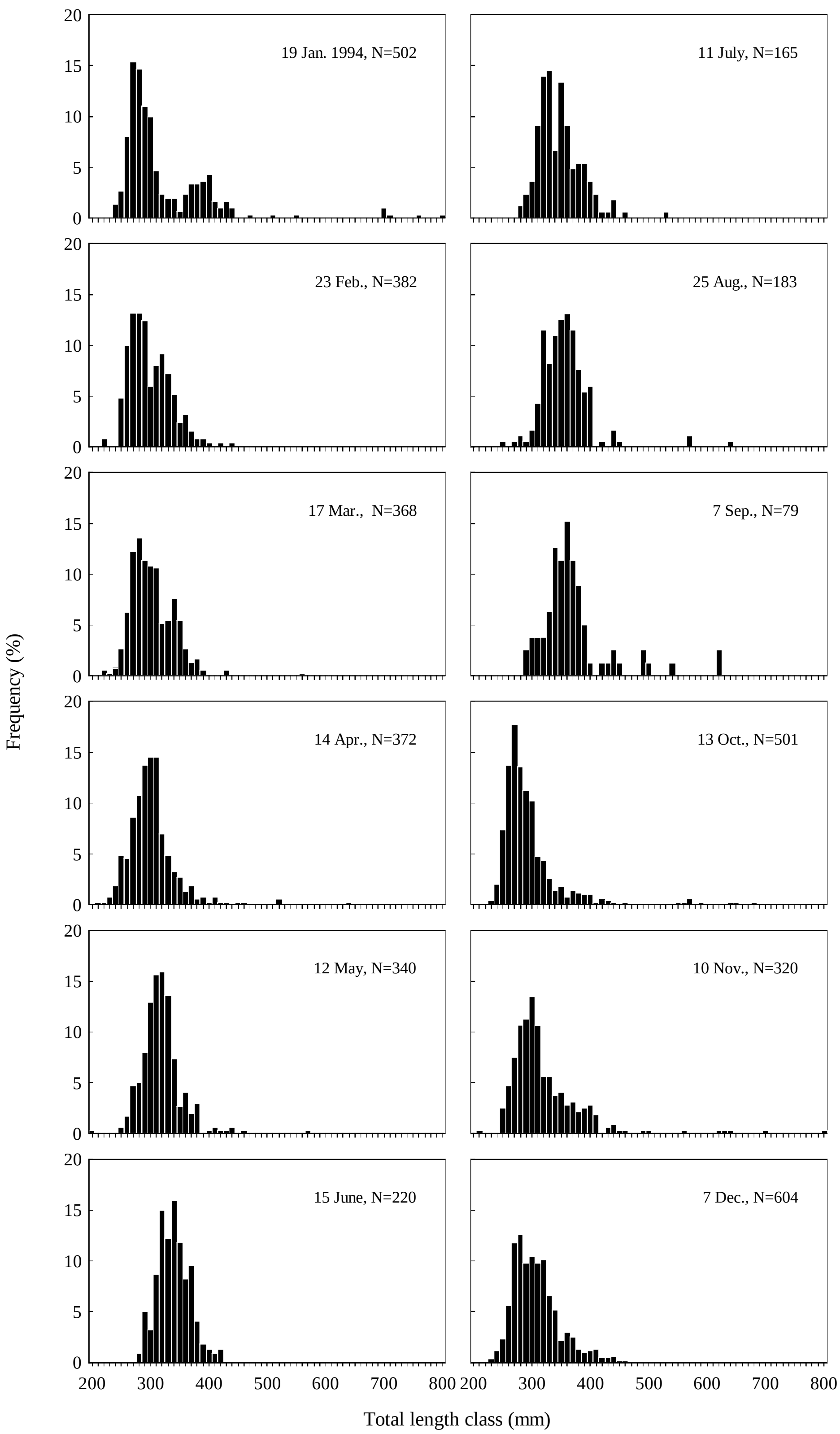

Fig. V-1-5. Monthly changes in length frequency distribution of whitespotted conger caught in Osaka Bay by the small trawl fishery from January to December 1994. N, sample size.

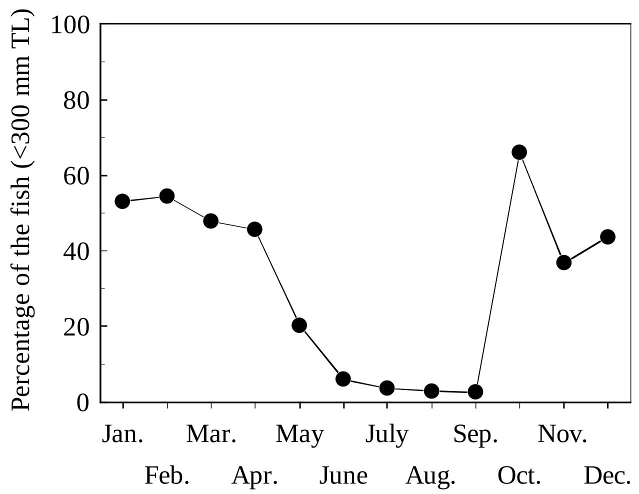

Fig. V-1-6. Monthly changes in percentage of whitespotted conger less than 300 mm TL caught in Osaka Bay by the small trawl fishery from January to December 1994.

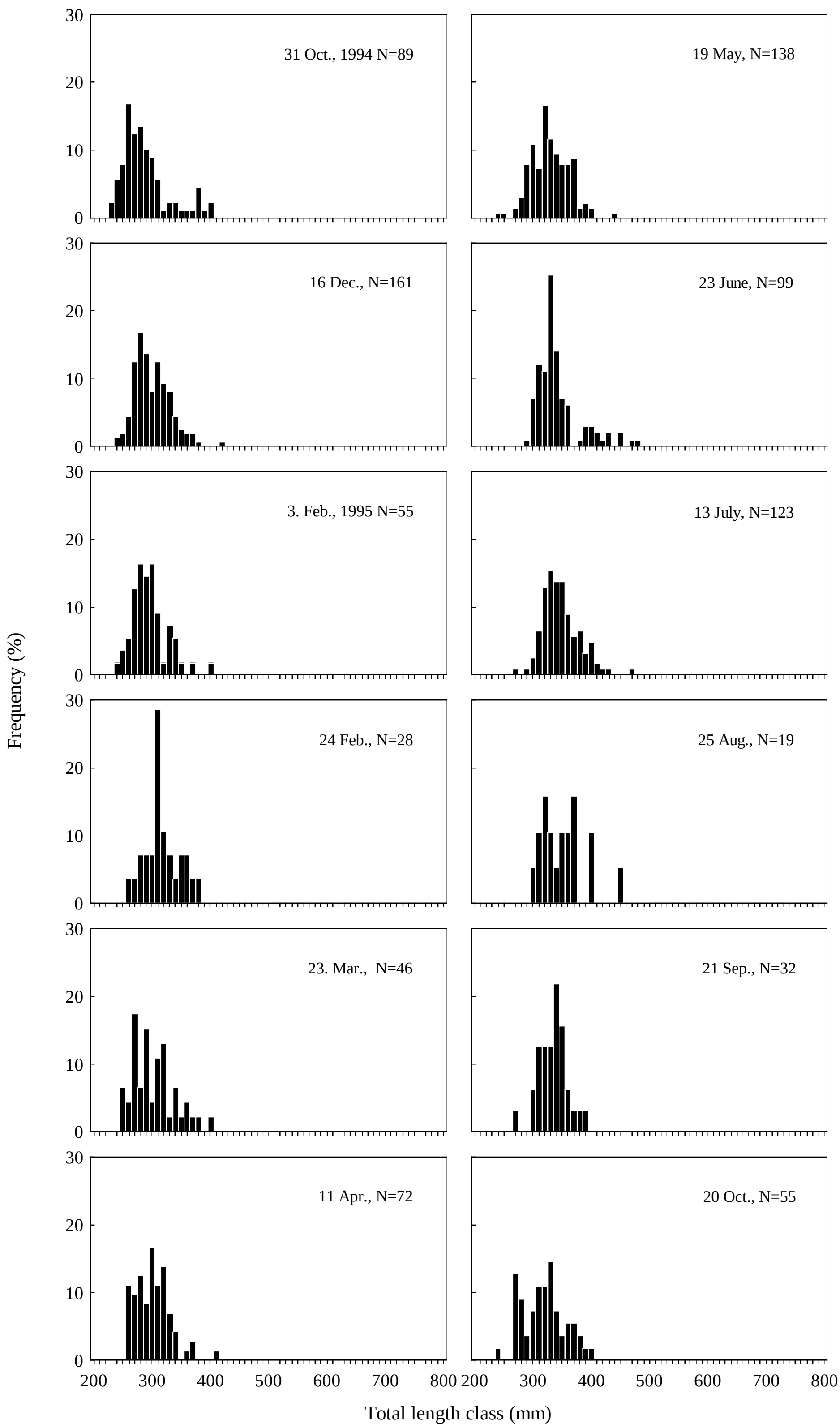

Fig. V-1-7. Monthly changes in length frequency distribution of whitespotted conger caught in the northeastern Harima Nada Sea by a small trawl fishing boat from October 1994 to October 1995. N, sample size.

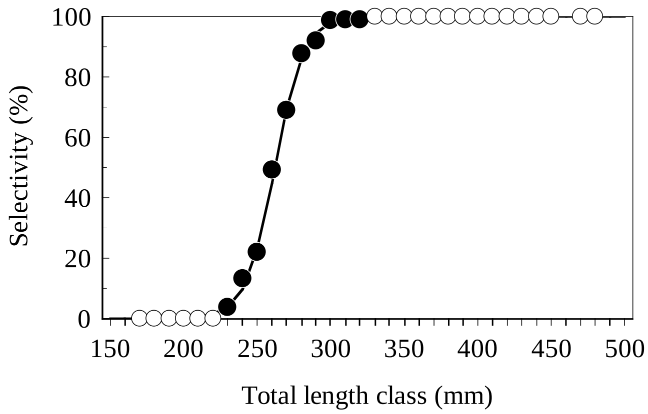

Fig. V-1-8. Artificial selectivity master curve of whitespotted conger caught in the northeastern Harima Nada Sea. Open circles, eliminated data for the parameter estimation of the logistic model.

Table V-1-1. Overall catch of the main species caught in the Seto Inland Sea off Hyogo Prefecture in 2008

Common name (main species)	Catch (mt)
Pacific sandlance	13,814
Japanese anchovy juveniles	8,807
Octopods	3,234
Japanese jack mackerel and Decapterid fishes	1,637
Asian seaperches	1,233
Prawns and shrimps	1,170
Righteye flounders and Tonguefishes	1,131
Largehead hairtail	959
Red seabream	868
Congrid fishes	**582**
Others	9,887
Total	41,872

Table V-1-2. Catch of main species caught by the small trawl fishery in the Seto Inland Sea off Hyogo Prefecture in 2008

Common name (main species)	Catch (mt)
Octopods	2,159
Prawns and shrimps	1,154
Righteye flounders and Tonguefishes	915
Asian seaperches	821
Squids and cuttlefishes	755
Japanese jack mackerel and Decapterid fishes	492
Red seabream	455
Congrid fishes	**403**
Others	3,995
Total	11,149

2. Mesh selectivity of whitespotted conger in the small trawl fishery

In the eastern Seto Inland Sea, a codend with a small mesh size is usually used in the small trawl fishery to catch whitespotted conger, and it has been considered that this species is a mesh-defining species of the fishery in the waters (Tanda 2008). Enlargement of the mesh size of the codend is one of the important management options to protect the commercially unutilized juvenile fish. Nishikawa et al. (1994) reported a mesh selectivity of whitespotted conger in the small otter trawl fishery (called *ita-biki*) which commonly operates in Osaka Bay off Hyogo Prefecture. However, information on the relationship between the mesh size and total length of whitespotted conger escaping from the codend is still limited.

In this section, a mesh selectivity of whitespotted conger caught in the Harima Nada Sea is described, based on a fishing experiment using a small trawl fishing boat (a dredge trawl, called *chin-kogi*) from 1994 to 1995. Possible use of the enlarged mesh size in the codend as an option for future stock management of the species is also discussed.

Materials and Methods

Mesh selectivity survey at sea

A mesh selectivity survey was conducted during the fishing survey described in Chapter V-1 at almost monthly intervals from October 1994 to October 1995 in the northeastern Harima Nada Sea. The codend was covered by a cover net, whose mesh size was smaller than that of the codend to sample the fish escaping through the codend. The codend consisted of a knotless net with a 23 mm mesh aperture (nominal mesh size: 12 *setsu*) which is usually used in commercial fishing. The cover net was of a 17 mm mesh aperture (nominal mesh size: 22 *setsu*) with threefold long of the codend to avoid a masking effect (Tokai et al. 1990; Nishikawa et al. 1994). In this study, the net was hauled 6-9 times a night and usually towed for 20-30 min at a speed of 2-3 knots. The fish caught in the codend were divided into fish for landing and fish for discarding. In addition to these 2 groups, the fish sampled in the cover net were transferred separately to the laboratory, where the 3 groups were measured for total length (TL, mm) and body weight (BW, g).

Mesh and artificial selectivities

Mesh selectivity was defined by the 10-mm TL size class following Tokai (1993) and Nishikawa et al. (1994): Mesh selectivity (%) = (Number of fish caught in the codend)·(Number of fish caught in the codend and cover net)$^{-1}$·100. Artificial selectivity was also calculated in the same way as in Chapter V-1.

A mesh selectivity master curve (logistic model) was calculated by a least square method following Chen et al. (1992): $S_m = 1\cdot[1+\exp\text{-}k(L/p\text{-}m)]^{-1}$, where S_m is mesh selectivity, L is TL class (mm), p is mesh size, k and m are constant numbers of logistic curve. The 25, 50, and 75% mesh selected TLs were deduced from the formulae as follows: $L_{25} = p(km\text{-}\ln3)k^{-1}$, $L_{50} = pm$, and $L_{75} = p(km+\ln3)k^{-1}$, respectively.

Survivability of the fish passing through the codend

Ten rearing experiments were conducted from October 1994 to October 1995 using whitespotted conger caught in the cover net to determine their survivability after passing through the codend. The fish were transported alive to the laboratory, where they were reared for seven days by feeding frozen-stored sardine in a 0.5 *kl* round-shaped, black-colored FRP tank. Three PVC pipes (75 mm in nominal diameter, 30-50 cm long) were disposed in the water. A total of 10 *kl* sand-filtered seawater was supplied into the tank a day. All surviving fish were measured for TL (mm) and BW (g) after each rearing experiment.

Results

Mesh and artificial selectivities

The small-sized fish (<250 mm TL) were caught in the codend with a 23 mm mesh aperture from August to December, but these fish were mostly discarded. The landed fish measured more than 300 and 250 mm TL from May to September and October to next April, respectively (Fig. V-2-1).

The mesh selectivity increased from April to July but dropped in August (Fig. V-2-2). While the fish caught in the codend were mostly over 250 mm TL from February to July (Fig. V-2-1), the artificial selectivity was nearly 100% (Fig. V-2-2), and almost all the fish caught were not discarded. In association with the appearance of the small-sized fish (<250 mm TL) from August to December, the artificial selectivity abruptly decreased in August and ranged from 79 to 29% (Figs. V-2-1, V-2-2).

The parameters of the logistic curve were estimated as m=12.1 and k=0.99. The calculated 25, 50, and 75% mesh selected TLs are shown in Table V-2-1. In the codend with a mesh aperture of 23 mm (12 *setsu*), 25% of whitespotted conger of 256 mm TL can be captured. Also, 50 and 75% of the fish can remain at 282 and 308 mm TL, respectively, in the cod end. Most of the fish over 300 mm TL can escape from the codend with a 29 mm mesh aperture (10 *setsu*).

Survivability of the fish passing through the codend

Whitespotted conger used for the rearing experiments were those that escaped from 23 mm apertures of the codend. They measured 178-377 (mean: 257, N=276) mm TL and 7-79 (22, N=276) g BW (Table V-2-2). Mean water temperature ranged from 8.5-27.8°C (Table V-2-2), which was the same as the sea surface temperature of the fishing ground. No mortality was observed during the experiments.

Discussion

If the mesh size of the usual codend can be enlarged as one of the options for the stock management to protect small whitespotted conger, their length frequency distribution as well as the mesh and artificial selectivities should be considered. Although the landed fish from the northeastern Harima Nada Sea are usually more than 250 mm TL (see Chapter V-1), the fish smaller than this size are caught in the codend from August to December (Fig. V-2-1), when the artificial selectivity is low (Fig. V-2-2), and thus on-board fish selection for discarding bothers the fishermen. In this study, the codend was made of a net with a 23 mm mesh aperture (12 *setsu*), and its 50% mesh selected TL was estimated 282 mm (Table V-2-1). Based on the mesh selected TLs calculated, observed monthly changes in length frequency distribution of the fish caught in the codend, and mesh and artificial selectivities (Figs. V-2-1, V-2-2, Table V-2-1), it may be possible to enlarge the codend mesh size from 23 mm (12 *setsu*) to 26 mm (11 *setsu*) during May to September because the smallest size for landing is more than 300 mm TL. Another issue is while the fish less than 300 mm TL are landed from October to next April. In this case, we need discuss the use of a larger mesh size for the codend to protect such smaller fish (i.e., “Which is more profitable to protect the smaller fish or to catch them now?"). It seems also possible to enlarge the codend mesh size from 23 mm (12 *setsu*) to 26 mm (11 *setsu*) because of the following reasons: 1) no mortality was observed in the fish collected from the cover net during the rearing experiments (this study; Tanda and Nishikawa 2001), which suggests that the escaped fish can survive; 2) the fish grow from 250 to at least 300 mm TL within the year (see Chapters IV-1, IV-2-1); 3) among the three market sizes [small (<30 cm TL), medium (30-35 cm TL), and large (>35 cm TL)], the wholesale price of the medium-sized fish is two times higher than that of the small-sized fish in the northeastern Harima Nada Sea (Anon. 1996); and 4) if the fishermen release the small-sized fish (<300 mm TL), their catch sales are estimated to fall down to 93% of the same year's catch sales but expected to increase to 111% in 3 years (Anon. 1996). Therefore, it is considered that enlarging the codend mesh size will reduce sorting operation and discards but increase catch sales. Also, 300 mm TL is generally recommended as the minimum size limit for commercial whitespotted conger. Nonetheless, the fishermen never agree to use a 29 mm (10 *setsu*) mesh size for the codend because such codend can allow 50% of individuals of 353 mm TL to escape (i.e., most of the commercial-sized fish will be lost).

Even if the same mesh size is used for the codend, a square-shaped aperture can allow larger fish to escape than a diamond-shaped aperture (Chen et al. 1992). In Osaka Bay, a fishing experiment was conducted for the mesh selectivity of whitespotted conger by using a diamond-shaped mesh for the codend (Nishikawa et al. 1994). In contrast, in this study conducted in the northeastern Harima Nada Sea, I used a square-shaped mesh and its mesh size was 23.3 mm. A 50% mesh selected TL of this mesh size was estimated 310 mm from the mesh selectivity master curve presented by Nishikawa et al. (1994). This value is larger than that (282 mm) in this study. It is thus likely that the mesh selectivity is affected by the difference in fishing method and the amount and content of catch in the codend. Since it may also fluctuate by the fishing location, the estimated parameters are probably not valid for other regions.

In conclusion, I conducted a fishing survey in the northeastern Harima Nada Sea to examine the mesh and artificial selectivities using a usual codend with a 23 mm mesh aperture. A 50% mesh selected TL was estimated as 282 mm. Based on the monthly changes in length frequency distribution and the mesh and artificial selectivities, it appeared possible to enlarge the codend mesh size from 23 mm (12 *setsu*) to 26 mm (11 *setsu*). Since the mesh selectivity was considered to be closely related to various fishing conditions (e.g., the fishing method and area), the parameters of the mesh selectivity obtained in this study might not be valid for other regions. Therefore, the mesh selectivity of whitespotted conger needs to be examined by using the fishing method in the commercial fishing ground.

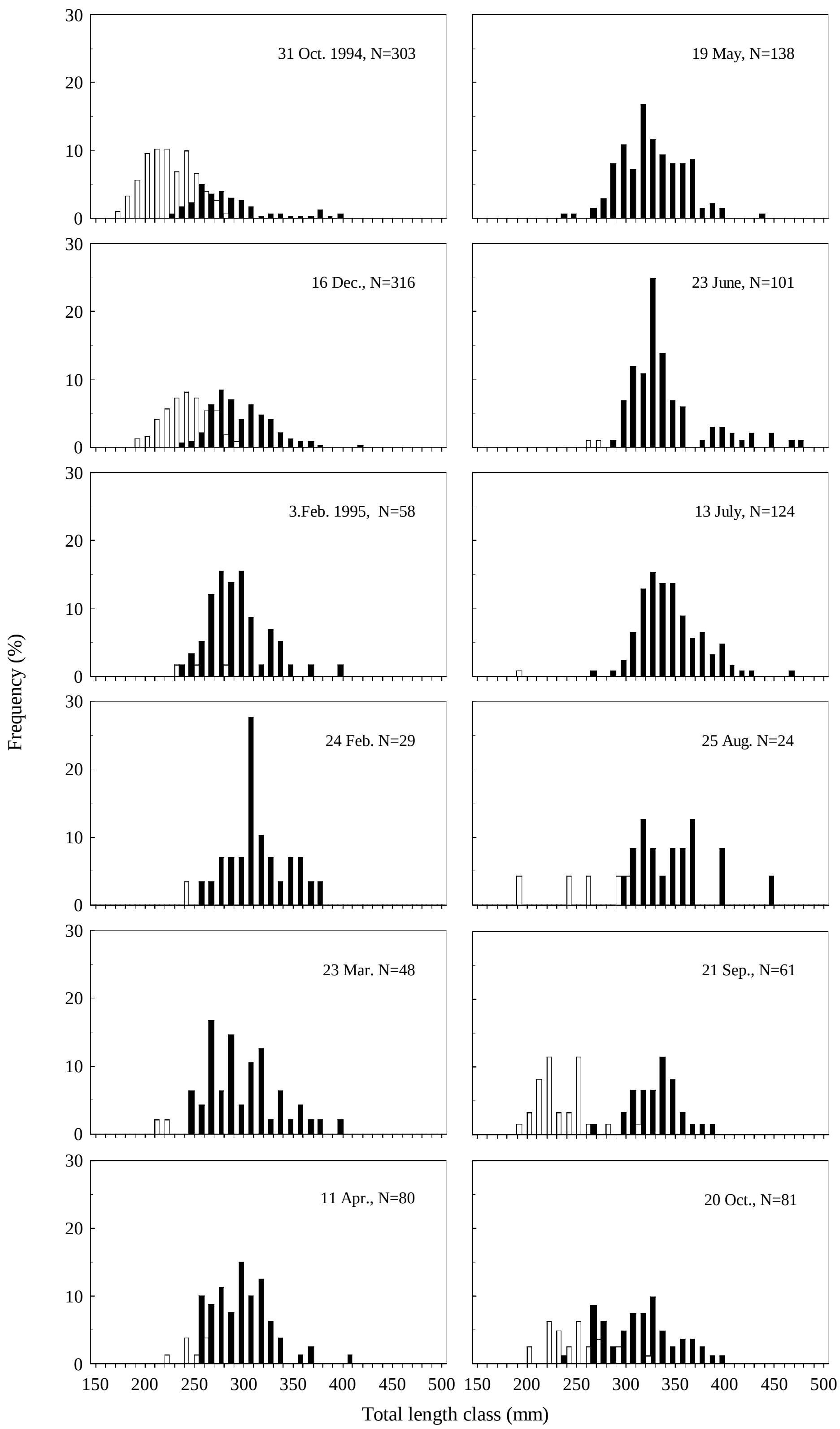

Fig. V-2-1. Monthly changes in length frequency distribution of whitespotted conger caught in the codend of a small trawl fishing boat in the northeastern Harima Nada Sea from October 1994 to October 1995. Open bars, fish to be discarded; closed bars, fish to be landed. N, sample size.

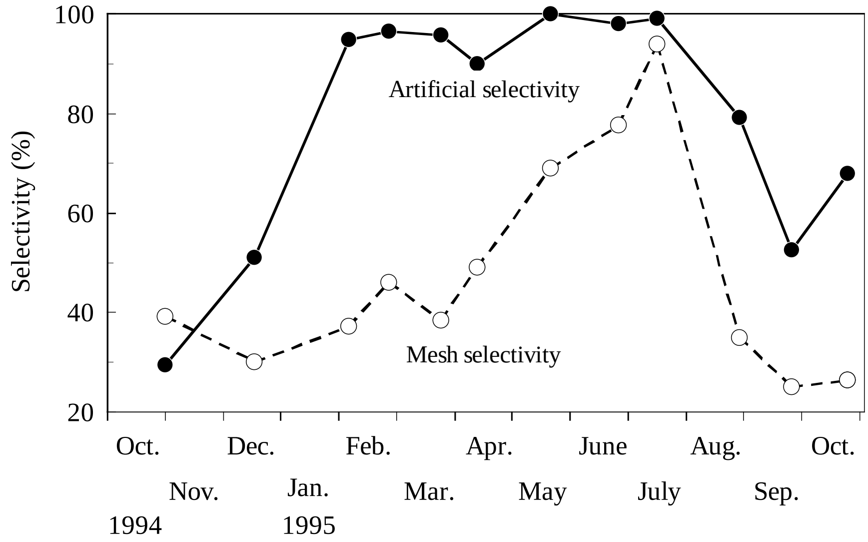

Fig. V-2-2. Seasonal changes in mesh selectivity (open circles with dashed line) and artificial selectivity (closed circles with solid line) of whitespotted conger caught in the northeastern Harima Nada Sea from October 1994 to October 1995.

Table V-2-1. Calculated mesh selected size of whitespotted conger at various mesh sizes of the codends

Mesh size (mm)	23 ± 0.6 [1]	26 ± 0.3	29 ± 0.4
	12 [2]	11	10
25 % selective TL	256	282	321
50 % selective TL	282	311	353
75 % selective TL	308	339	386

[1] Mean ± SD, *N* =100; [2] nominal mesh size, "*setsu* " or "*fushi* "; TL, total length (mm).

Table V-2-2. Results of 7-day rearing experiment of whitespotted conger caught in the cover net

Date of catch	1994		1995							
	31 Oct.	16 Dec.	24 Feb.	23 Mar.	11 Apr.	23 June	13 July	25 Aug.	21 Sep.	20 Oct.
Total length (mm)	215 ± 20.7 [1]	256 ± 28.1	264 ± 27.7	256 ± 25.8	267 ± 27.6	294 ± 24.1	312 ± 32.7	245 ± 19.5	248 ± 24.2	257 ± 32.1
Body weight (g)	12 ± 3.3	22 ± 7.7	24 ± 7.3	23 ± 6.6	27 ± 7.7	32 ± 8.9	42 ± 18.2	17 ± 5.8	18 ± 5.8	20 ± 9.4
N	30	30	28	30	30	29	8	29	30	32
Mean WT (ºC)	20.4	12.3	8.5	10.5	12.1	21.0	23.6	27.8	24.3	22.0

All the fish were survived throughout the experimental period. [1] Mean ± SD; *N*, number of fish examined.

VI. Biological aspects of whitespotted conger in the Akashi Strait

The Akashi Strait is located between Honshu (the main island of Japan) and Awaji Island in the eastern Seto Inland Sea (Fig. VI-1). The distance between both islands is only 4 km, and the maximum water depth of the strait is about 120 m; the strait also has a strong tidal current (Kaseno 1976). There are various fisheries using different types of fishing gear, such as small trawls, longlines, boat seines, gillnets, angling, etc., whereas the fishery using pots is not commonly operated because of the strong current (Uchihashi 1976).

Although large-sized whitespotted conger are generally known to be commercially caught in the Akashi Strait, little information is available on the biology of the species there. Because those large-sized fish are considered to be a spawning stock (see Chapter IV-2-3), it is very important to study the ecology of whitespotted conger in the Akashi Strait in terms of stock management and spawning stock conservation.

Since 1982, a monitoring survey using pots has been conducted in the Akashi Strait in order to clarify annual changes in length frequency distribution and catch per unit effort (CPUE) of whitespotted conger. Although this survey must be operated during the neap tide, it has the advantage of stable catchability, regardless of fishing grounds, and is considered to be appropriate to conduct the stock assessment in the Akashi Strait.

In this chapter, biological aspects of whitespotted conger in the Akashi Strait are presented. Seasonal changes in gonadosomatic index, relative condition factor, and age composition are also discussed on the assumption that the large-sized females conduct a spawning migration in the eastern Seto Inland Sea including this strait.

Materials and Methods

Fish collection

The study area is located in the western Akashi Strait (Fig. VI-1). Water depth of the survey area ranges from 20-50 m. The bottom consisted of gravel and cobbles. In 1982 to 2009, a fishing survey has been conducted monthly from 1982 to 1999 and 2-5 times a year from 2000 to 2009, using commercially available pots (see Fig. III-3). Sampling was done from evening to night. Deeply frozen sardines were thawed, cut in pieces, and put as bait in the pots. Pots were usually put down to the sea before 1 hour of sunset and allowed the fish to trap for 4 hours. The effective number of pots in each fishing survey ranged from 60-110. The CPUE was expressed as mean number of the fish caught for 4 dipping hours per pot.

Oceanographic data, such as water temperature (WT), salinity, and depth, were obtained with STD (JFE Advantech Co., Ltd., Nishinomiya, Japan) before fishing.

Fish examination

The fish caught were transferred to the laboratory, where they were measured for total length (TL, mm) and body weight (BW, g). In 1996 to 2009, they were sexed by the observation of the gonad (see Table IV-2-2), and the gonad was weighed (GW, g). For age determination, otoliths were removed and stored in small sealable plastic bags until analysis. Burnt otoliths were observed by UV light technique (Katayama et al. 2002) and, before observation, their serially-transverse sections were etched with 0.2N HCl for several tens of seconds. As the spawning season is estimated to be from August through February (Tanaka et al. 1987; Lee and Byun 1996; Mochioka 2001; Kurogi et al. 2002), age is expressed chronologically, assuming that the fish hatch every January. Gonadosomatic index (GSI) and relative condition factor (CF) were calculated as follows: GSI (%) = $GW \cdot BW^{-1} \cdot 100$, $CF = BW \cdot TL^{-3} \cdot 10^{6}$, respectively.

Statistical analysis

Results were presented as mean and standard deviation (SD). Significant differences were determined by one-way analysis of variance (ANOVA), Tukey-Kramer method, Pearson's correlation coefficient test, or Mann-Whitney's *U* test.

Results

Total length distribution

A total of 14,370 whitespotted conger were collected in this survey, and 7,829 fish (54%) were larger than 500 mm TL. The overall TL and BW ranged from 217-953 (mean: 519, *N*=14,370) mm and from 12-2,028 (283, *N*=14,354) g. The males and females measured 390-506 (446, *N*=17) and 314-950 (575, *N*=773) mm TL, respectively. Of the 829 fish examined for the sex, the vast majority (*N*=773, 93%) were females, but the remaining 17 and 39 fish were males and unsexed, respectively.

There were one or two major modes in length frequency distribution (Fig. VI-2). In October, the fish less than 400 mm TL newly appeared. The proportion of these fish gradually increased in the following months. Further, the percentage of the large-sized fish (>500 mm TL) was about 40% in January then increased gradually and reached 76% in December (Fig. VI-3). The overall monthly mean TL (MTL) gradually increased during a period from February to December (Fig. VI-4). There was a significant difference in MTL between four seasons (P<0.001, ANOVA): The MTL in the fall (October-December) was the highest (P<0.001, Tukey-Kramer test) (Fig. VI-5).

CPUE

While the CPUE showed a considerably large annual and seasonal fluctuations, it showed a decreasing trend from 1982 to 1999 but a gradual recovery after 2000 (Fig. VI-6). It was high from May to August and November to January (the highest in June) but low from September to October and February to April (the lowest in March) (Fig. VI-7). This monthly change in mean CPUE well coincided with that of WT. It was also usually high when WT ranged from 10-25°C but low when WT was very high (over 25°C) or very low (under 10°C) (Figs. VI-7, VI-8).

The annual CPUE of whitespotted conger caught by the pot survey was correlated with the annual commercial catch of the species in the eastern Seto Inland Sea off Hyogo Prefecture (Fig. VI-9). There was a positive, significant correlation between the annual CPUE and catch from 1984 to 1999 (P=0.002, r=0.7), but no significant correlative relationship was detected from 2000 to 2008 (P=0.27) (Fig. VI-10).

Gonadosomatic index

As stated above, the majority of the fish examined for sex were females. The overall GSI ranged from 0.02-5.06 (mean: 1.59, N=245) in females and from 0.14-0.44 (0.25, N=6) in males. Further, GSI ranged from 0.18-5.06 (mean: 1.65, N=233) in the large-sized females (>500 mm TL), while it ranged from 0.02-0.86 (0.46, N=12) in the small-sized ones. Most of the GSI of the large-sized females were less than 4, and the mean monthly GSI were 1.5 in April-December and 2.7 in January-February, respectively (Fig. VI-11). Despite the small number (N=4) of the large-sized females examined in February, the GSI of this month were clearly separated into two groups (high and low).

There was a significant difference in GSI of the large-sized females (>500 mm TL) between four seasons (P<0.001, ANOVA). The GSI was the highest in January-February (P<0.001, Tukey-Kramer test), decreased markedly in April-June but increased gradually in July-December (Fig. VI-12).

Condition factor

The overall CF ranged from 1.3-2.8 (mean: 1.8, N=772) in females and from 1.5-2.2 (mean: 1.8, N=17) in males. In the large- and small-sized females, CF ranged from 1.3-2.8 (1.9, N=599) and from 1.3-2.2 (1.7, N=173), respectively. The male CF ranged from 1.5-2.2 (1.8, N=16) in the small-sized fish and was 1.6 in one large-sized specimen (506 mm TL).

Like GSI, there was a significant difference in CF of the large-sized females between four seasons (P<0.001, ANOVA): it was the highest in January-February (P<0.001, Tukey-Kramer test) but decreased in April-June. There was no significant difference in CF of the small-sized females between four seasons (Fig. VI-13).

Age composition

Of the 291 fish examined for age, 276 (95%) were females, but the remaining one and 14 fish were a male and unsexed, respectively. The male was age-2 (395 mm TL). The females were age-1 to 4 but did not contain any fish of age-5 and more (Fig. VI-14). Since there was a wide variation in TL for each age, the TL of the fish overlapped from age-1 to 4.

Discussion

Based on a long term fishing survey conducted from 1982 to 2009, this study has shown for the first time biological information on whitespotted conger, especially large-sized fish, caught in the Akashi Strait. Unlike the fish in Osaka Bay and the northeastern Harima Nada Sea (see Chapter V-1), the fish caught in this study were usually over 450 mm TL, and many of them measured more than 500 mm MTL between July and December (Figs. VI-2, VI-4, VI-5). In addition, almost all the fish examined were females. These results clearly indicate that whitespotted conger inhabiting the Akashi Strait are large-sized females. No evidence of their spawning, however, was obtained during this survey.

After recruitment of the fish less than 400 mm TL in October, they grew and were replaced by the newly appearing small-sized fish in next October (Fig. VI-2). The large-sized fish (>500 mm TL), on the other hand, were more abundant than small-sized fish from July to December. The percentage of the fish more than 500 mm TL dropped in January and thereafter increased gradually (Fig. VI-3). In addition, both the monthly GSI and CF of the large-sized females peaked in January-February, dropped in April-June, but then gradually increased (Figs. VI-11, VI-12, VI-13). In January-February, most of the GSI in the large-sized females caught in the Akashi Strait remained less than 4 (Fig. VI-11), which was significantly lower (P=0.001, U test) than those of tag-released and recaptured females in Osaka Bay and the Kii Channel (see Chapter IV-2-3). Moreover, the females caught in the Akashi Strait were found to be less than age-5 (Fig. VI-14). These results can support the new hypothesis proposed in Chapter IV-2-3 that large-sized female whitespotted conger (>500mm TL) move from the Akashi Strait to other regions for spawning during January to August, and other fish remaining in the strait continue to grow. Especially, the females with high GSI (>4) caught in January-February may be just about to begin their spawning migration. Thus, the females more than 500 mm TL which acquired high GSI and CF by age-5 might launch spawning migration. Consequently, this strait is considered to be an important region for the growth and maturation of the species. The migration of males, however, is still yet unknown because of the small sample size in this study.

The monthly change in mean CPUE of whitespotted conger was closely related to that in WT, and high CPUEs were observed when WT ranged from 10-25°C (Figs. VI-7, VI-8). This is probably because the feeding of the species is dependent on water temperature (see Chapter IV-1).

In 1984 to 1999, the annual change in CPUE was significantly correlated with the annual commercial catch of the species in the eastern Seto Inland Sea off Hyogo Prefecture, but the correlative relationship disappeared from 2000 to 2008 (Figs. VI-9, VI-10). This non-correlative relationship during the latter period may be due to the reduction of the frequency of the survey because it was conducted almost monthly intervals from 1984 to 1999, but it was done only 2-5 times a year from 2000 to 2008. Thus, it is desirable to conduct the monthly pot survey in order to get knowledge for the stock assessment of whitespotted conger in the eastern Seto Inland Sea off Hyogo Prefecture. It should be also noted that we need to analyze the relationship between catch data from the survey and commercial fisheries. More information on the age composition and other biological aspects of the species in the Akashi Strait is necessary to clarify the trigger to launch its spawning migration.

To summarize, length frequency distribution of whitespotted conger caught in the Akashi Strait by the pot survey showed the presence of two size groups. The large-sized females were dominant in this strait. The Akashi Strait is likely to be an important region for the growth and maturation of whitespotted conger before they conduct the spawning migration. The species may stay there up to four years. If monthly pot surveys could be conducted, it may be possible to provide more reliable information on the abundance of whitespotted conger in the Akashi Strait.

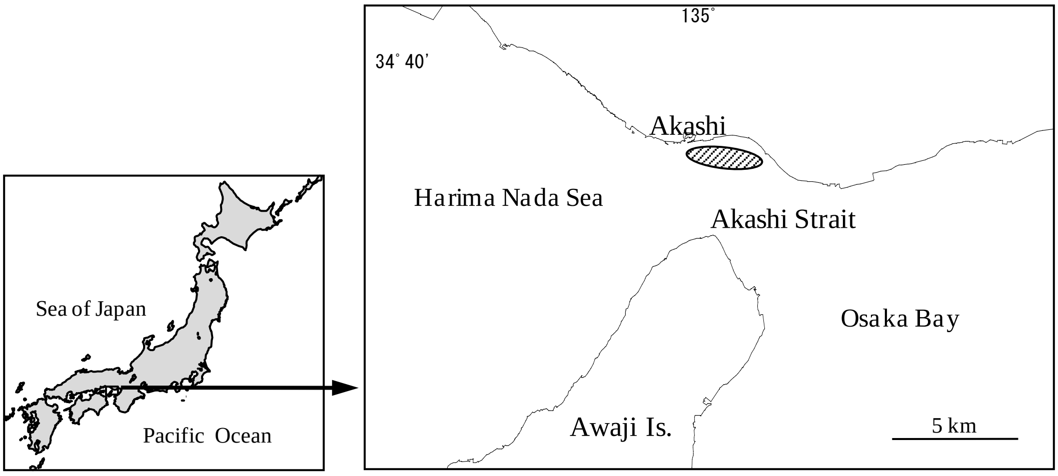

Fig. VI-1. The study area (hatched) for the pot survey in the Akashi Strait, the eastern Seto Inland Sea.

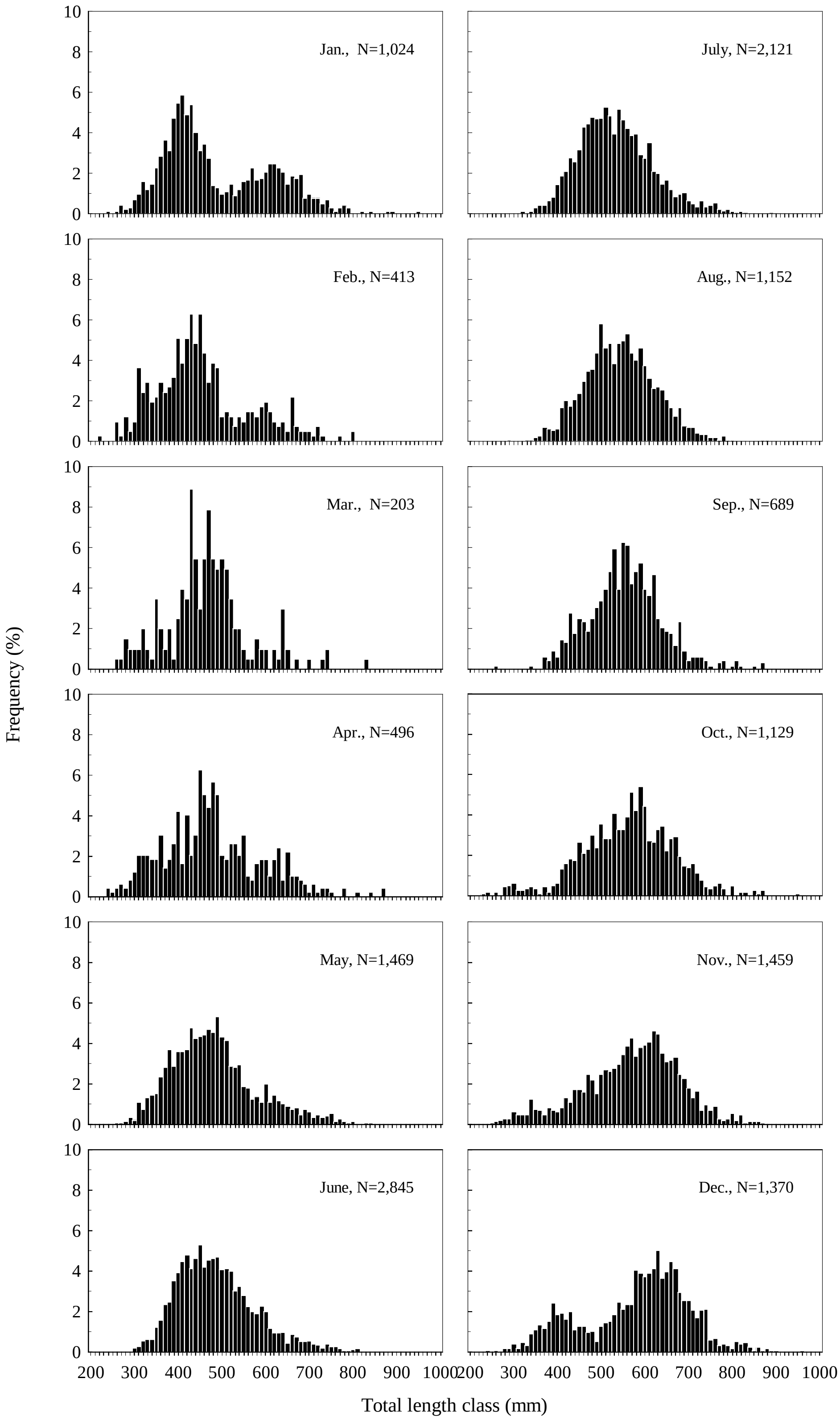

Fig. VI-2. Monthly changes in length frequency distribution of whitespotted conger caught in the Akashi Strait through the pot survey. Monthly data taken from 1982 to 2009 are combined. N, sample size.

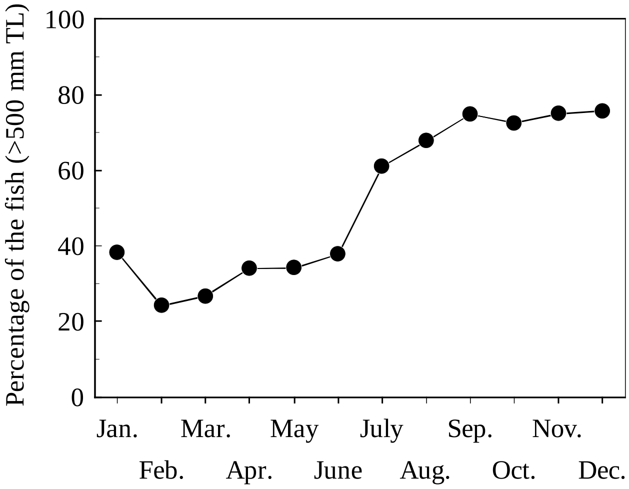

Fig. VI-3. Monthly changes in proportion of large-sized whitespotted conger (>500 mm TL) caught in the Akashi Strait through the pot survey. Monthly data taken from 1982 to 2009 are combined.

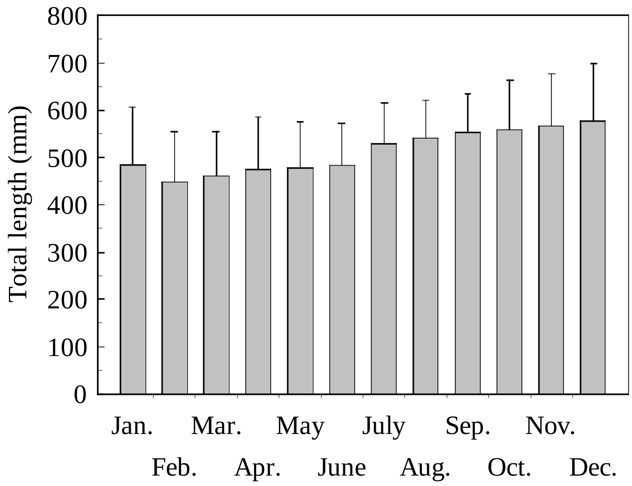

Fig. VI-4. Monthly changes in mean total length of whitespotted conger caught in the Akashi Strait through the pot survey. Monthly data taken from 1982 to 2009 are combined. Vertical bars represent standard deviation.

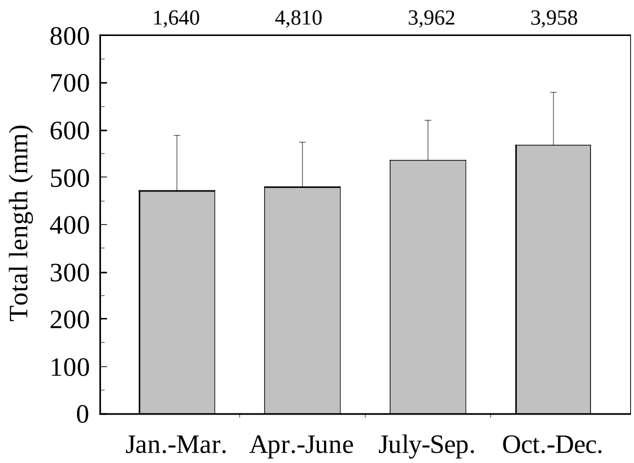

Fig. VI-5. Seasonal changes in mean total length of whitespotted conger caught in the Akashi Strait through the pot survey. Seasonal data taken from 1982 to 2009 are combined. Vertical bars represent standard deviation. Sample size is given for each sampling season.

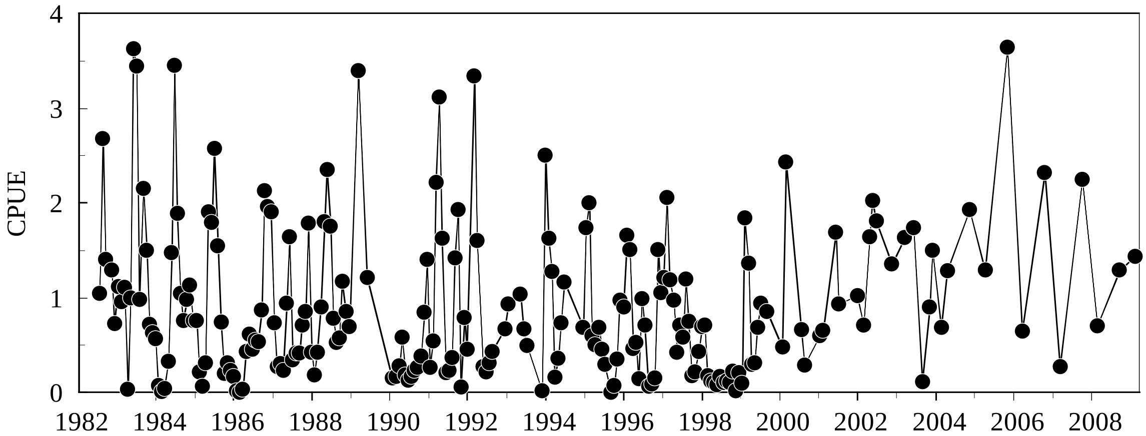

Fig. VI-6. Seasonal changes in CPUE (mean number of the fish caught in a pot per 4 dipping hours) through the pot survey in the Akashi Strait from June 1982 to November 2009.

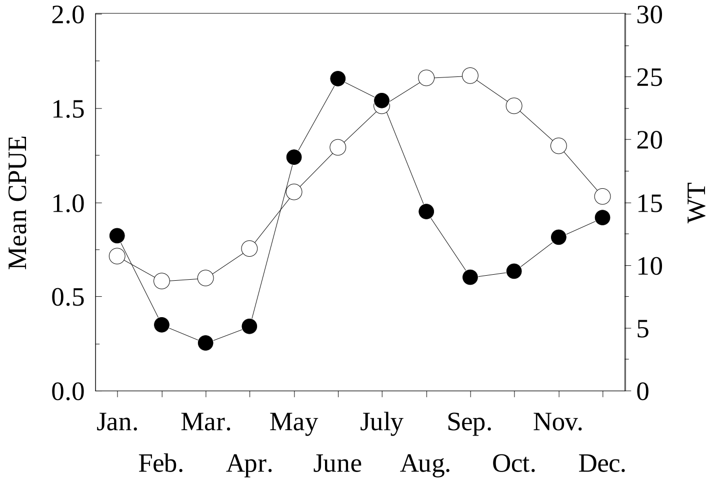

Fig. VI-7. Monthly changes in mean CPUE and bottom water temperature during the pot survey in the Akashi Strait. Monthly data taken from 1982 to 2009 are combined. Closed circles, CPUE; open circles, bottom water temperature (WT, °C).

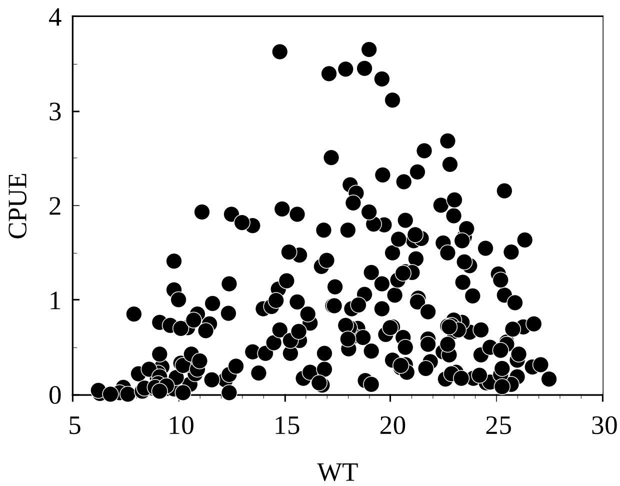

Fig. VI-8. Relationship between bottom water temperature (WT, °C) and CPUE during the pot survey in the Akashi Strait from 1982 to 2009.

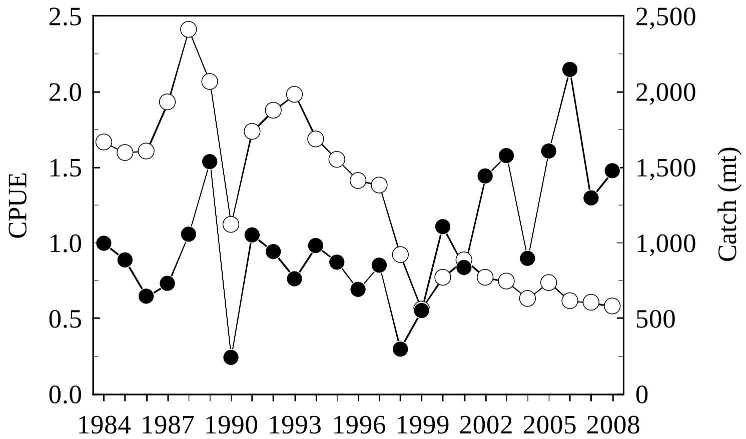

Fig. VI-9. Annual changes in CPUE and commercial catch of whitespotted conger in the Akashi Strait and the eastern Seto Inland Sea off Hyogo Prefecture, respectively, from 1984 to 2008. CPUE data were collected through the pot survey in the Akashi Strait. Closed circles, CPUE; open circles, catch (metric tons, mt).

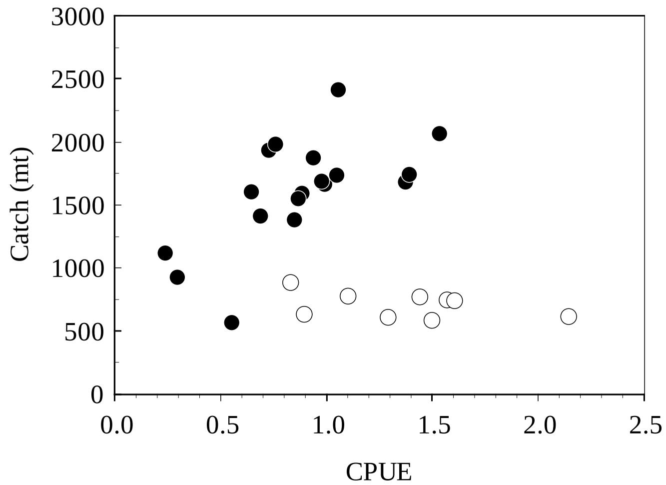

Fig. VI-10. Relationship between annual CPUE and catch of whitespotted conger in the Akashi Strait and the eastern Seto Inland Sea off Hyogo Prefecture, respectively, from 1984 to 2008. CPUE data were collected through the pot survey in the Akashi Strait. Closed circles, data from 1984 to 1999; open circles, data from 2000 to 2008.

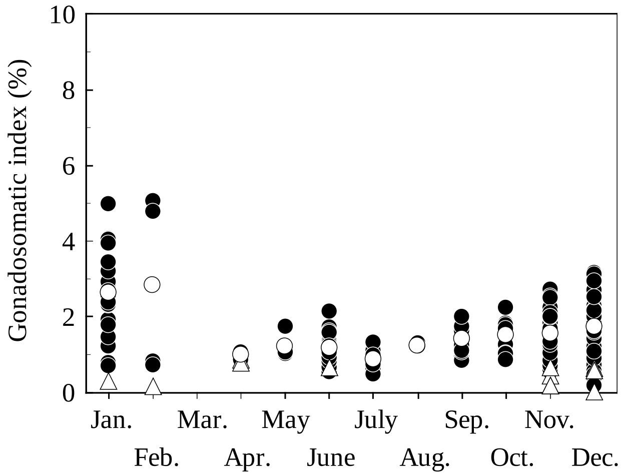

Fig. VI-11. Monthly changes in gonadosomatic index of female whitespotted conger caught in the Akashi Strait through the pot survey. Monthly data taken from 1996 to 2009 are combined. Closed circles, actual values from large-sized fish (>500 mm TL, *N*=233); open circles, mean values from large-sized fish; open triangles, actual values from small-sized fish (*N*=12).

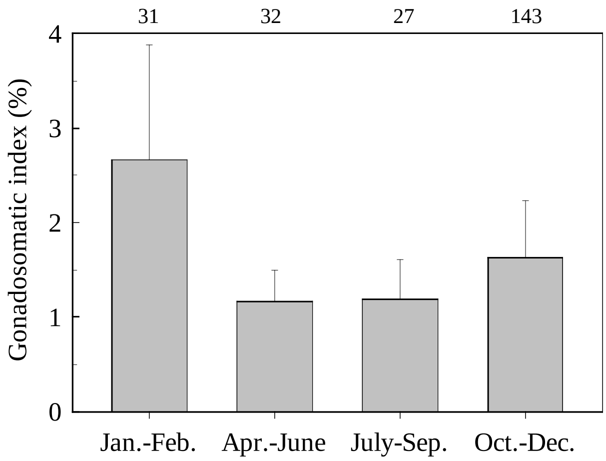

Fig. VI-12. Seasonal changes in mean gonadosomatic index of large-sized female whitespotted conger (>500 mm TL) caught in the Akashi Strait through the pot survey. Seasonal data taken from 1996 to 2009 are combined. Vertical bars indicate standard deviation. Sample size is given for each sampling season. No data in March are available.

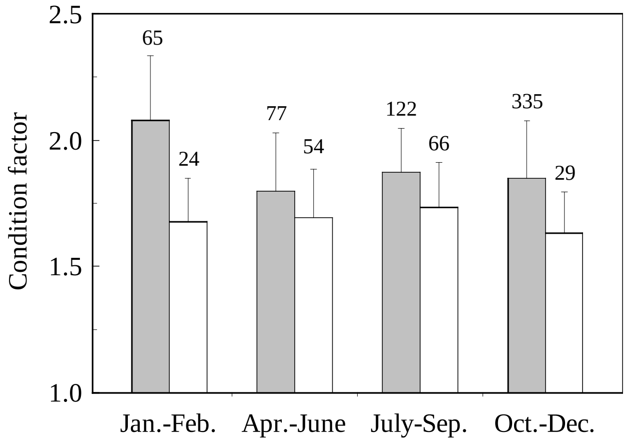

Fig.VI-13. Seasonal changes in mean condition factor of female whitespotted conger caught in the Akashi Strait through the pot survey. Shaded bars, large-sized fish (>500 mm TL); open bars, small-sized fish. Seasonal data taken from 1996 to 2009 are combined. Vertical bars indicate standard deviation. Sample size is given for each sampling season. No data in March are available.

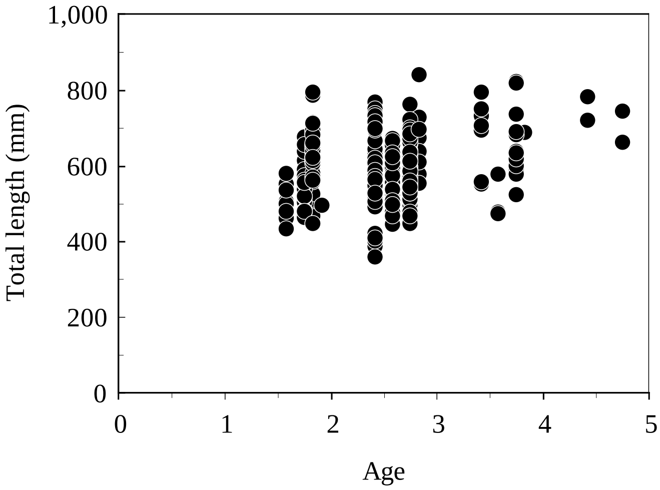

Fig. VI-14. Total length of female whitespotted conger of various ages caught in the Akashi Strait through the pot survey from 1996 to 2009.

VII. General discussion

This study provides various aspects of the biology of whitespotted conger during part of their life history (from migration to the Harima Nada Sea to probable spawning migration to a yet unknown spawning ground). The species is one of the commercially important marine fishes in the eastern Seto Inland Sea and caught mainly by the small trawl fishery. Nonetheless, when the research on the species started in 1993, the recognition of its early stage (leptocephali and newly settled juveniles) by fishermen was very poor: some believed that the morid *Laemonema nana* is a juvenile of whitespotted conger. The continuous research, however, has led the fishermen to a better understanding for the biology of the species. Currently, they know that the leptocephali migrating to the eastern Seto Inland Sea in every early spring are whitespotted conger. This study also provides the fundamental knowledge on the fishery stock management of whitespotted conger in the eastern Seto Inland Sea.

In this final chapter, I briefly review the life history of the species in the eastern Seto Inland Sea and, based on the information I obtained in this study, suggest the way we should take for its fishery stock management.

Overview of the life history of whitespotted conger in the eastern Seto Inland Sea

Whitespotted conger leptocephali commonly emerge in the eastern Kii Channel in November (Utsumi 2009) and, with metamorphosing, occur in the northeastern Harima Nada Sea from February to May when sea surface temperature ranges from 8-18°C. After finishing metamorphosis, they begin the demersal life at 10-20 m in depth on the sand-mud and gravel bottoms. They initially feed on crustaceans and then shift their prey items to polychaetes and teleosts. Whitespotted conger grow and begin recruiting to the small trawl fishery at 250 mm in total length (TL) in every fall, some fish reach 400 mm TL by December. After recruitment, they are continuously caught by the fishery until next fall and account largely for the annual catch. The species exhibits various growth rates: some fish may reach over 60 cm TL within one and a half year. With growth, they tend to move deeper areas and assemble in such waters as the Akashi Strait. The fish show high diversity in growth not only between individuals but also sexes. Age-0 to age-5 fish are found, and age-0 and age-1 fish are mainly caught in commercial fisheries in the eastern Seto Inland Sea.

Female whitespotted conger spend up to five years in the eastern Seto Inland Sea and begin the spawning migration by age-5 from January through August to a yet unknown spawning ground although the migration of males has not been clarified. The species is likely to have different migratory behavior between sexes.

Fishery stock management approach

Whitespotted conger leptocephali are found as bycatch of the boat seine fishery targeting Pacific sandlance juveniles in the eastern Seto Inland Sea. Because of the filter system attached to the fishing net, a large number of the leptocephali are caught as bycatch. Although the impact of bycatch on the stock abundance of whitespotted conger is not clear in the region, we should try to minimize such bycatch because Ishida et al. (2003) reported on a negative impact of bycatch on the stock of the species in the Tohoku region. Minimizing the bycatch in the boat seine fishery may also reduce unintentional bycatches of other valuable marine animals as well.

After metamorphosis, whitespotted conger juveniles settle down to the ground and begin their demersal life. The juveniles show a strong preference for crustaceans as food items. Although crustaceans are more abundant on the gravel bottom than sand-mud bottom, they prefer the sand-mud bottom at depths of 10-20 m. Thus, it is important to conserve the sand-mud bottom as a nursery ground for the juveniles. The gravel bottom where crustaceans predominate may be significant as a food supplying ground.

Based on my analysis of the age, growth, and fishing status of whitespotted conger in the eastern Seto Inland Sea, the species begins recruiting to the small trawl fishery at 250 mm TL from September to October. These fish are continuously caught for a year, which indicates that age-0 and age-1 fish account largely for the annual catch of the species. The recruited fish are those that migrate to the region as leptocephali from February to May. These results suggest that the annual catch of the species there depends on the annual abundance of the migrating leptocephali. It is, however, impossible to control the abundance of migrating leptocephali. In addition, although the spawning migration from the region to other areas is suggested in this study, there has been so far no evidence that the large-sized fish occurring in the eastern Seto Inland Sea contain fully mature fish. Therefore, it is quite difficult at present to get agreement of the fishermen for the reduction of the catch of those large-sized fish as a stock management option. Thus, for the possible stock management of the species, it is the best to conserve the small-sized fish until a certain size and to prevent and/or reduce non-commercial catches because the wholesale price of the medium-sized fish is two times higher than that of the small-sized fish (Anon. 1996). For the latter purpose, my study on the mesh selectivity (Chapter V-2) can provide useful information. As discussed above, minimizing unintentional bycatches may be also effective.

For future stock management of whitespotted conger in the eastern Seto Inland Sea, more information is necessary based on the following research: 1) a monitoring survey to determine the annual abundance of the migrating leptocephali should be addressed. If such data are available, it will be quite useful to forecast the annual catch and stock of the species and also to discuss the factors on the catch decline from the view point of growth overfishing or recruitment overfishing. If the annual abundance of the migrating leptocephali has been stable, the causes of the catch decline of whitespotted conger may exist after their migration into the eastern Seto Inland Sea. Alternatively, if the annual abundance of the migrating leptocephali has been fluctuated, a spawning stock may decrease in a yet unknown spawning ground, and/or there may be difficulty during their migration to Japanese coastal waters. It is also helpful to assess the negative impact of bycatches on the stock; 2) an investigation should be conducted for the sex ratio of the species by age (fish size) and region. In this study, the male- and female-biased sex ratios were observed in the small- and large-sized fish, respectively. No adequate explanation is possible, but the biased sex ratio may be caused by differences in growth, habitat, and movement between sexes. The females may leave for somewhere out of the survey area (e.g., deeper area) before recruitment to fisheries, and the males may conduct migration to a yet unknown spawning ground earlier than females; 3) a study on the reproductive biology and farming of the species is needed. Although the ovulation can be induced by a hormonal treatment (Horie et al. 2001), and the spermiation was observed in captivity (Utoh et al. 2004), our knowledge of the reproductive biology is quite limited in terms of fish culture. If we can artificially produce numerous whitespotted conger juveniles and release them to the natural waters, stock enhancement techniques would be a great tool for the fishery stock management of the species in Japan; and 4) a survey on the spawning ground of whitespotted conger should be conducted. This may be the most important research issue for the species in Japanese waters. In this study, I have suggested that whitespotted conger conduct the spawning migration by age-5 from the northeastern Harima Nada Sea to the Kii Channel during a period from January to August.

Also, based on various surveys by other Japanese scientists, much information has been currently accumulated on the biology of the species, but nothing is known about the spawning ground and factors to trigger the launch of spawning migration. Such information is essential to fully understand the biology of the species and to conduct an efficient fishery stock management in the future.

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