Seasonal distribution of *Abyssicola macrochir* (Günter) on the upper continental slope off the southern Tohoku coast, northeastern Japan, in relation to their life history

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The longarm grenadier, *Abyssicola macrochir* (Günter), which dominates in a demersal fish assemblage on the upper continental slope from 200 to 500 m off the Pacific coast of northeastern Japan (Tohoku coast), was examined with respect to distribution, age composition, life cycle and feeding habits, in 1999 and 2000. A dense population of *A. macrochir* was observed off the southern Tohoku coast during autumn, but the population was sparse during other seasons. The population was mainly composed of 0+, 1+ and 2+ fish. GSIs lower than 1.0 were observed throughout the year, suggesting that they were at an immature stage. Major prey organisms were micronekton such as *Euphausia pacifica*, *Sergestes similis* and *Diaphus theta*. These observations suggest that young immature *A. macrochir*, subtropical demersal fish, use the upper continental slope off the southern Tohoku coast seasonally to feed on highly productive subarctic micronektons in autumn when warm water expands northward from the Kuroshio Extension to the area.

Key words: *Abyssicola macrochir*, immature, feeding habits, continental slope, age, otolith

Introduction

The necessity to evaluate the impacts of fishing on deep sea fish resources has recently been debated by international fishery councils such as ICES. However, the ecological aspects of deep sea fishes have not been sufficiently revealed to date because of the difficulty involved in covering the wide distribution ranges of these fishes by bottom trawlings.

The longarm grenadier, *Abyssicola macrochir* (Günter), tenagadara in Japanese, a gadid fish belonging to the family Macrouridae, inhabits the upper to middle continental slope at a depth of 300 to 830 m off the Pacific coast of Japan from southeastern Hokkaido to the Okinawa (Okamura, 1970; Cohen *et al.*, 1990). *A. macrochir* is the predominant species in a demersal fish assemblage on the upper continental slope off the Joban area off southern Tohoku coast in autumn, thus constituting a key species of the assemblage (Fujiwara *et al.*, 2001). On the other hand, with the recent decline in the population size of commercially important bottom fishes such as *Gadus macrocephalus* and *Thragra chalcogramma*, the catch of *A. macrochir* by commercial bottom trawlers in the Japanese waters has increased as a material for fish paste products. However, there are few reports on the life history of *A. microchir* that include information on their spawning grounds.

The purpose of the present study is to determine the seasonal distribution of *A. macrochir* on the upper continental slope off the southern Tohoku coast in relation to the characteristics of age composition, maturation condition and feeding habits.

Materials and Methods

The distribution of *A. microchir* was analyzed using the catch record of bottom trawl surveys conducted in October 1999 (RV Wakataka-maru) and April 2000 (RV Tanshu-maru) by the Tohoku National Fisheries Research Institute (TNFRI). Fourteen transects were set to cover the waters off Aomori to Ibaraki prefectures, and sampling stations were arrayed along the lines from depths of 150 to 900 m at regular intervals (Fig. 1). The dimensions of the trawl net were as follows: 13 m in wing net length, 26.1 m in main net length, 5.4 m in net mouth width, and 5.0 m in cod-end length. The cod-end with a mesh size of 50 mm was covered with a cover net of mesh size 8 mm to catch smaller individuals. As a rule, the net was towed for 30 min at that fishing depth. Catch-in-number records were converted into density using the tow area calculated by the method described by Kitagawa and Hattori (1998). The distribution density of the fish obtained between October 1999 and April 2000 was compared.

We also used catch-in-weight records obtained from

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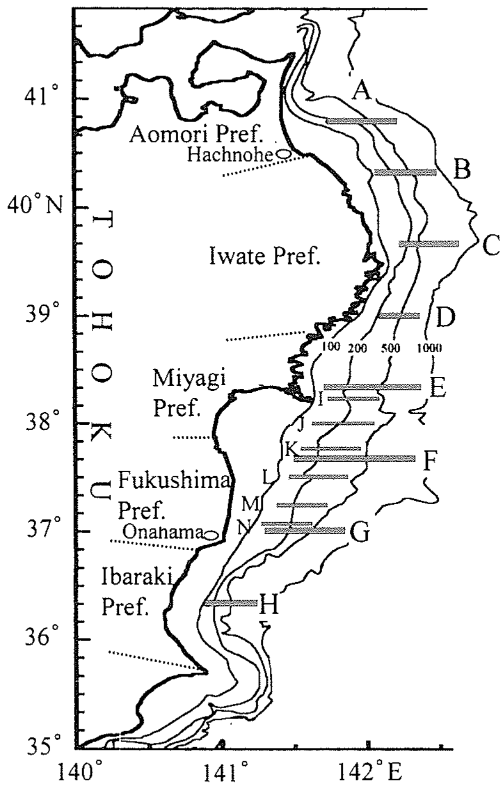


Figure 1. Locations of the transects A–N on the continental slope along the Pacific coast of Aomori to Ibaraki prefectures. Sampling stations of bottom trawl surveys were arrayed along each transect from depths of 150 to 900 m at regular intervals. Surveys in October 1999 and April 2000 were carried out for line A to H and line I to N, respectively.

fishing log books of two commercial bottom trawlers, i.e. Ryujin-maru No. 77 and Ryujin-maru No. 81. The main fishing ground of these two trawlers was located on the continental slope at a depth of 150 to 1000 m off the Miyagi to Ibaraki prefectures. Total catch in kg and total effort in operation days were summed up each month for five latitudinally divided areas: northern Miyagi waters between 38°30′N and 39°00′N, southern Miyagi waters between 38°00′N and 38°30′N, northern Fukushima waters between 37°30′N and 38°00′N, southern Fukushima waters between 37°00′N and 37°30′N, and Ibaraki waters between 36°00′N and 37°00′N. Monthly CPUEs in kg per day were calculated for these areas.

Specimens for age determination were collected from catches of three bottom trawl surveys conducted by TNFRI in October 1999 and June 2000 using Wakataka-maru and in April 2000 using Tanshu-maru. Other specimens were from bottom trawl survey carried out by Iwate Prefectural Fisheries Research Laboratory in Nov. 1999 using Iwate-maru, and also from catches of commercial bottom trawlings from Sep. 1999 through June 2000 by Ryujin-maru No. 81. Approximately one hundred individuals were randomly collected from each catch of the bottom trawl surveys on board and additionally from the landings of commercial trawlers at fish markets. Yearly formation of a transparent zone in the otolith was confirmed by observing the otolith margins of these specimens. Pre-anal length (PAL) of all these individuals was measured to the nearest 0.1 cm.

Sagittal otoliths were removed from approximately fifty individuals that were re-sampled from the samples mentioned above. These otoliths were burned at 200°C for 5 min, embedded in clear polyethylene resin and serially sectioned along the dorso-ventral axis across the core at approximately 0.3 mm intervals with a diamond circular saw. The sections were mounted on glass slides, and the annuli were counted and measured using a binocular microscope.

For a part of the specimens that were examined for age and growth, body and gonad weights were measured to calculate gonadosomatic index (GSI: gonad weight* 100/body weight). The stomach contents of the individuals that were caught during the October survey in 2002 by TNFRI were identified and classified to certain taxonomical categories as low as possible.

Results

Abyssicola macrochir population was densely distributed in the waters south of 39°N and at a depth ranging from 250 m to 550 m in October, clearly indicating a southward positive cline of the biomass. However, the biomass considerably decreased in April, and the northern boundary of the distribution retreated to 38°N (Fig. 2).

Monthly CPUEs in kg per day, based on catch-in-weight records of commercial bottom trawlers, were calculated for the five latitudinally divided areas (Fig. 3). High CPUEs were found between the waters off northern Miyagi and southern Fukushima from September to November, while it could not be judged whether the CPUEs in the waters off Ibaraki were high during these months because of the absence of any commercial trawl operations in the waters. Thereafter, CPUEs became extremely low or nearly zero in most areas, including the waters off Ibaraki, after December. This reduction in CPUE seems to be a reflection of the southward retreat of the distribution range. This situation lasted until June of the following year. Notably, these changes occurred within a short period; at least within a month in the case of the reduction and within three months in the case of the increase.

Intact sagittal otoliths of *A. macrochir* were completely opaque before burning and sectioning. Fine and narrow transparent zones became observable in a burned otolith section (Fig. 4). Seasonal changes in the occurrence of otoliths with a marginal transparent zone are presented in

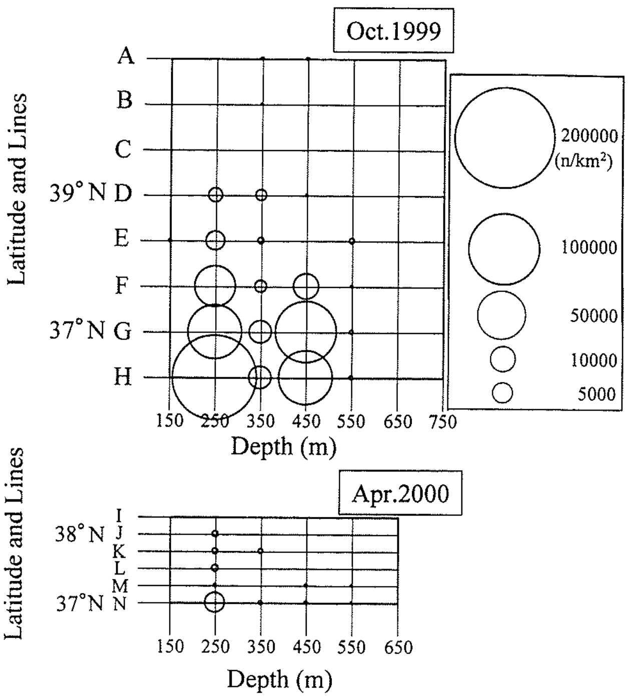


Figure 2. Distribution of density in individuals per km^2 of *A. macrochir* in October 1999 (top) and April 2000 (bottom).

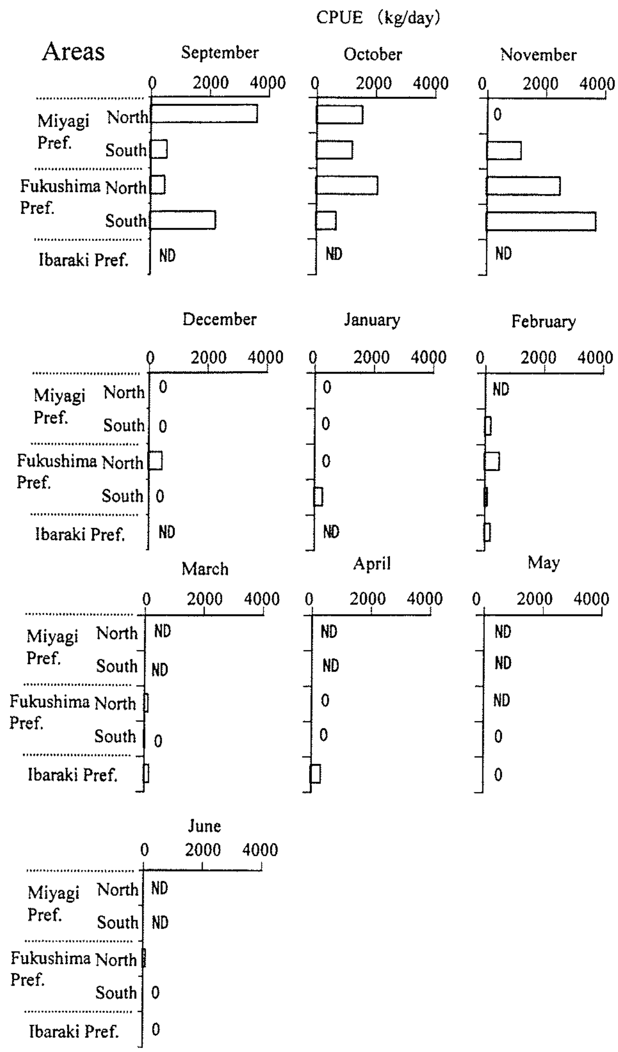
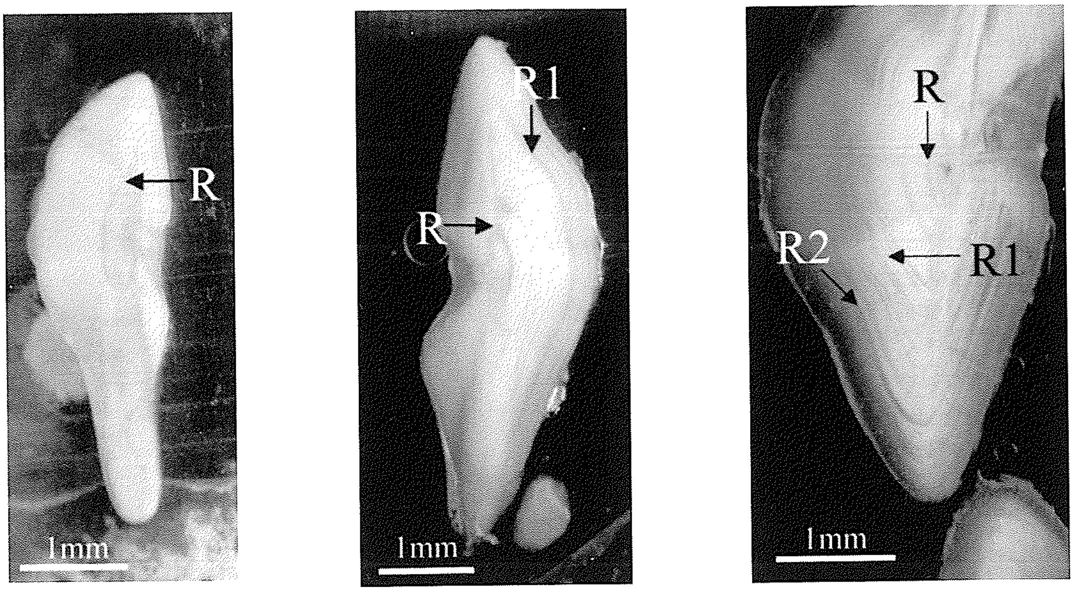


Figure 3. Distribution of monthly CPUEs (kg/day) of commercial bottom trawlers based on catch-in-weight records obtained from fishing log books of Ryujin-maru No. 77 and Ryujin-maru No. 81. July and August are the closed seasons for fishing.

Fig. 5. Marginal transparent zones were formed at a high proportion of approximately 70 to 90% from November to February but rarely occurred in other months. This suggests that the transparent zone were formed annually from November to March.

Since PALs in October 1999 were not significantly different between the sexes for each age (Kolmogorov-Smilnov test, $p<0.05$) (Table 1), the data on age and growth of both sexes were pooled. Assuming the birthdate of January 1 (The Technical Subcommittee of the Canada/U.S. Groundfish Committee, 2000), the growth was expressed by Bertalanffy's growth equation, $PAL=165(1-\exp(-0.52)(t-0.31))$; the parameters of this equation were estimated by the non-linear least squares method (Fig. 6). Estimated PALs in October were 39 mm in age 0+ fish, 88 mm in age 1+ fish and 119 mm in age 2+ fish. The asymptotic PAL was estimated at 165 mm. However, this would be an underestimation caused by the extrapolation of the growth curve over the age range of the specimens used for age determination. To convert PAL composition to age composition, an age-length key was prepared (Table 2). In this key, fish aged 3+ and older were pooled. This was because of the negligible density of these older fish in the survey area and the difficulty in age determination due to very narrow distances between transparent zones. PAL composition in fish density per square km of each age class in October 1999 was obtained by converting the mean density of each size class estimated for the entire survey area into age composition in density using the age-length key. Age-specific size compositions in density were apparently unimodal without densely overlapping one another, having a mode at 40 to 50 mm for age 0+, at 70 to 80 mm for age 1+ and at 120 to 130 mm for age 2+ (Fig. 7).

Comparing the distribution in density of fish per square km in October 1999 among age classes, a distinct shift of the habitat toward deeper waters with an increase in age was observed; 0+ fish, at a depth of around 250 m: 1+ fish, from 250 to 450 m: fish aged 2+, from 350 to 450 m: and fish aged 3+ and older, water at a depth greater than 450 m (Fig. 8). This seems to be a bigger-deeper phenomenon (Heincke's law) (Merrett *et al.*, 1991).



Age 0+ fish (TL=172mm, PAL=39mm) caught at 250m depth.

Age 1+ fish (TL=314mm, PAL=80mm) caught at 350m depth.

Age 2+ fish (TL=472mm, PAL=120mm) caught at 450m depth.

Figure 4. Transparent zones found on sagittal otoliths of *A. macrochir* collected at a station on the transect G off Onahama in October 1999. R, R1 and R2 denote a pseudoannulus and first annulus and second annulus respectively.

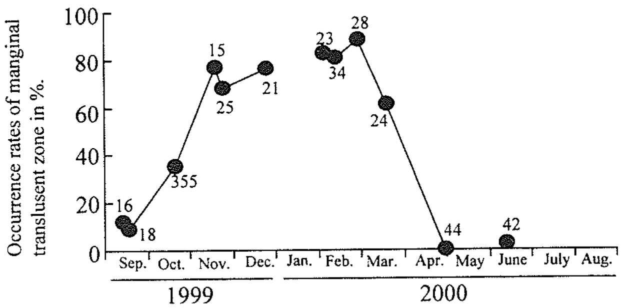


Figure 5. Temporal changes in occurrence of otoliths with a marginal transparent zone in the waters off southern Tohoku. Numerals near closed circles denote the number of otoliths observed.

Table 1. Pre-anal length at each age in October 1999 and its comparison between female and male. *Results of Kolmogorov-Smirnov test (p<0.05).

age	PAL(mm)				P*
	female		male		
	data	mean (SE)	data	mean (SE)	
1+	35	94.7 (2.23)	47	93.4 (1.68)	0.998
2+	74	120.6 (1.30)	94	115.7 (0.92)	0.060
3+	15	145.3 (2.08)	5	134.2 (6.06)	0.388
0+	223	38.5 (0.44)			

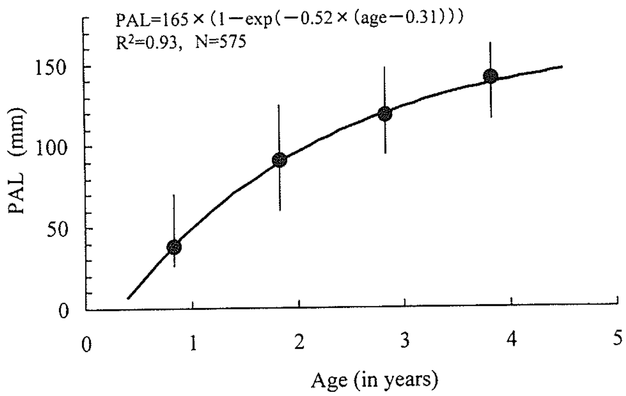


Figure 6. Calculated von Bertalanffy growth curve. Open circles and vertical lines show the mean and range of pre-anal length at ages in October 1999.

GSIs were all less than 1.0 through the year in both sexes, except for two females with a GSI of 34.1 and 3.34 in June (Fig. 9). These females, which were caught in the water at a depth of 481 m off Onahama in June 2000, were considerably larger in body size, with a PAL of 204 mm and 174 mm, respectively, compared with other individuals abundant in the catch from the waters off southern Tohoku.

The occurrence rates in percentage of respective food items in the stomachs of the fish in October 2002 presented for respective body size ranges and/or depths of habitats (Fig. 10). *Euphausia pacifica* occurred at a high rate of 87% in fish with a PAL of 29 to 50 mm in the waters at a depth of 250 m. However, with an increase in depth and/or

Table 2. Age-length key for *A. macrochir* from the Pacific coast off northeast Japan, in October 1999.

Range of PAL (mm)	age				Sample Size
	0+	1+	2+	3+ & older	
<30	1.00	0.00	0.00	0.00	15
30–40	1.00	0.00	0.00	0.00	119
40–50	1.00	0.00	0.00	0.00	81
50–60	1.00	0.00	0.00	0.00	6
60–70	0.25	0.75	0.00	0.00	8
70–80	0.03	0.97	0.00	0.00	29
80–90	0.00	1.00	0.00	0.00	28
90–100	0.00	0.92	0.08	0.00	38
100–110	0.00	0.46	0.54	0.00	59
110–120	0.00	0.10	0.88	0.02	81
120–130	0.00	0.03	0.93	0.03	59
130–140	0.00	0.00	0.84	0.16	25
140–150	0.00	0.00	0.36	0.64	25
150–160	0.00	0.00	0.00	1.00	2
>160	0.00	0.00	0.00	1.00	2

with an increase in body size, the occurrence rate of *Euphausia pacifica* decreased, and was mainly replaced by sergestid shrimps including *Sergestes similis*. *Sergestes similis* increased its rate of occurrence from 0% in fish with a PAL of 79 to 108 mm in the waters at a depth of 250 m to approximately 80% in fish with a PAL of 133 to 177 mm at a depth of 450 m and 550 m through an intermediate rate of 50% in fish with a PAL of 121 to 147 mm at a depth of 350 m. With such changes, the fish preyed on fishes such as *Diaphus theta*, *Ceratoscopelus warmingi*, *Leuroglossus*

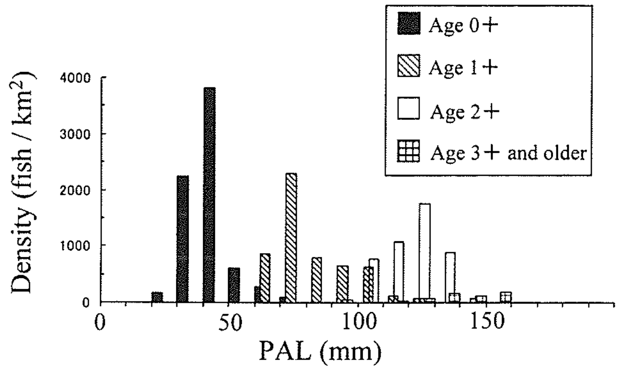


Figure 7. Age specific pre-anal length (PAL) composition in density of fish per km^2.

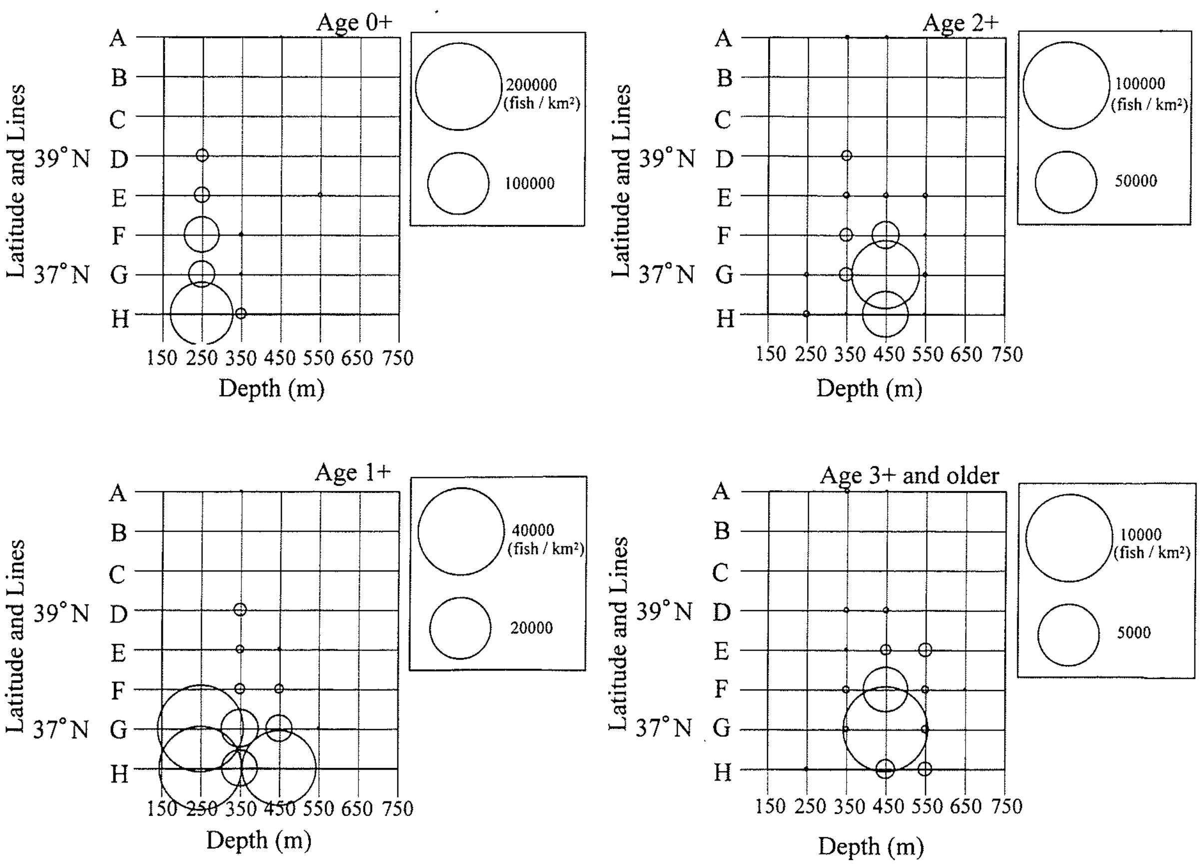


Figure 8. Geographical distribution of density of fish per km^2 for each age class of *A. macrochir* in October 1999.

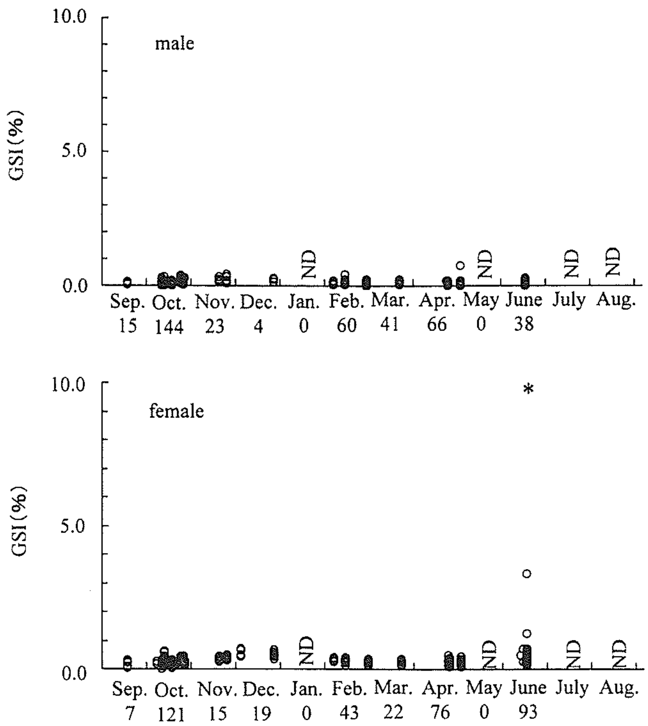


Figure 9. Seasonal changes in gonado-somatic index (GSI) in *A. macrochir* in the waters off southern Tohoku. An asterisk shows a fish with exceptionally high GSI (PAL is 174 mm and GSI is 34.05) collected from the waters at a depth of 481 m off Onahama in June 2000. Numerals indicated below months indicate the number of fish examined in each month.

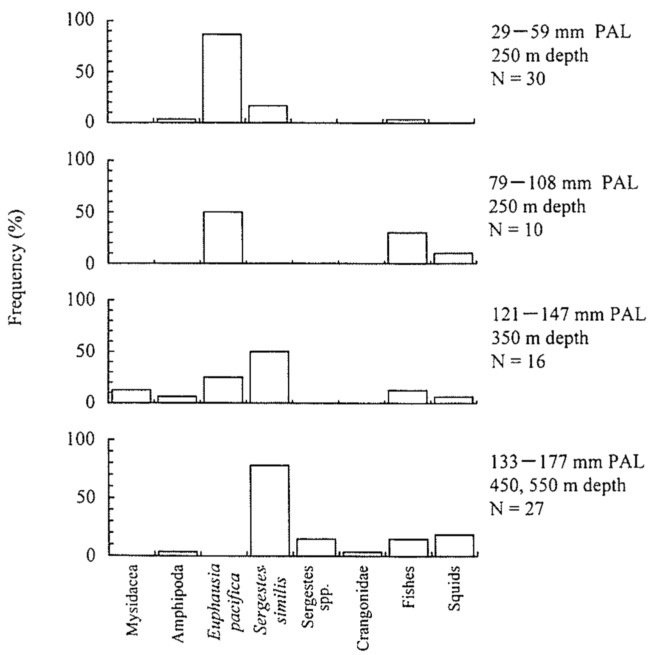


Figure 10. Frequencies of each occurrence of food organism in stomachs of *A. macrochir* in the waters off southern Tohoku in October 2002.

schmidti, *Gonostoma gracile* and a squid, *Watasenia scintillans*.

Discussion

The dense population distribution of *A. macrochir* with a clear positive southward cline in October 1999 shifted to a sparse distribution in April 2000. The same phenomenon was also observed with regard to seasonal changes in the CPUE of commercial bottom trawlers. Additionally, the northern border of the distribution retreated southward with a decline in the density. These facts suggest that the fish migrated south to north, i.e. into the upper continental slope of the waters off northern Miyagi to Ibaraki, from late summer to autumn. Although the waters from which they migrated were not clearly shown in this study, it was at least ascertained that their main habitats, where they spend their life during other months, are in the warm water areas south of Ibaraki.

Most individuals of *A. macrochir* in the survey area appeared to be at an young immature stage, based on the fact that low GSIs below 1.0 were observed through the year in the area investigated. Two females with exceptionally high GSI caught in June 2000 appeared to be considerably older than these young fish.

The importance of micronektons as the food for demersal fish on the continental slope has been argued by many authors (Pearcy and Ambler, 1974; Sedberry and Musick, 1978; Mauchline and Gordon, 1984, 1985; Houston and Haedrich, 1986; Yamamura and Inada, 2001). *A. macrochir* mainly consumed organisms such as *Euphausia pacifica*, *Sergestes similis*, *Diaphus theta* and *Leuroglossus schmidti*; these were also all micronektons and subarctic (Sawamoto, 1997; Hayashi, 1997; Nakabo, 2000; Aizawa and Hatooka, 2000).

Following the research conducted by Shimizu *et al.* (2001), Fujiwara *et al.* (2005) analysed the distribution of mixing rates of Oyashio and Kuroshio waters in the waters off Tohoku area. They showed that the bottom layer of the southern waters was under the influence of the Oyashio waters more than of the Kuroshio waters through the year, contrasting to the seasonal alternation in the influential waters at the surface layer. This indicates that *A. macrochir* migrated into the waters with subarctic environmental conditions from the southern warm water areas to feed on abundant subarctic micronekton. Additionally, the wide and abrupt changes in density of *A. macrochir* in the waters off southern Tohoku suggest that the fish migrated in a school strongly directed toward the waters. This also supports our discussion that the migration of *A. macrochir* described here is a feeding migration by young immature individuals, as found in the conger eel, *Conger myriaster* (Katayama, 2004).

The present study described only the seasonal distribution of young immature *A. macrochir* in the waters off southern Tohoku in relation to their life history. Ecological aspects covering the entire life history should be investigated in the southern warm water areas to reveal the mechanisms of the population dynamics of this species.

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東北沖太平洋の大陸斜面上部におけるテナガダラの分布の季節変化と生物特性

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東北沖太平洋の大陸斜面上部（水深200–500 m）において，底魚群集で優占しているテナガダラの分布の季節変化を調べた．10月には高い密度で分布していたが，4月にはほとんど分布していなかった．操業船の漁獲記録から周年の分布密度を調べると，秋季から冬季に多く分布して，冬季から春季にかけて分布密度が減少することがわかった．東北海域に多く分布する10月の標本の年齢を調べると0＋，1＋，2＋がほとんどであった．生殖腺指数は周年1%以下を示し，若齢で未成熟個体が東北海域に分布していると思われた．秋季に東北海域に来遊するテナガダラは，ツノナシオキアミ，キタノサクラエビ，トドハダカといった亜寒帯種のマイクロネクトンを捕食していた．したがって，亜熱帯種であるテナガダラは，亜寒帯種の餌生物を索餌するために，黒潮の勢力が強まる秋季に東北海域へ来遊していることが示唆された．

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