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**ABSTRACT**

Thin, polished sections were made from otoliths of 287 juvenile and young pollock, ranging in fork length from 33.2 to 238.2 mm, which were collected from the eastern Bering Sea continental shelf from August to September in 1989. The daily growth increments were examined and counted with a light microscope. The mean number of counts of daily growth increments of otoliths of 160 juvenile pollock aged 0 (ranging in length from 33.2 to 94.5 mm) was approximately 110, and the hatching dates estimated by back-calculating the counts of daily growth increments from the collecting date showed an extended hatching period from late April to early June, and the peak of hatching was estimated to be in mid May. Taking account of the days required from spawning to hatching, spawning was estimated to have had a peak in late April. This spawning period was in accord with the spawning period in the southeastern Bering Sea continental shelf. Although it is known that spawning of pollock takes place from February to March in the Basin area surrounding Bogoslof Island, juvenile pollock which are considered to be spawned in this period were not observed.

The relation between fork length (FL) and age in days (t) for juveniles was regressed by the least squares method, and the following linear regression was obtained:

\[
FL = -217.7 + 62.51n(t)
\]

\[r^2 = 0.622\]

The early growth equation of the fish ranging in fork length from 33.2 to 94.5 mm was obtained.
1. Introduction

Walleye pollock (Theragra chalcogramma) is particularly abundant either catch (in number) or catch (in weight) among fishes in the Bering Sea. It is important not only for commercial fisheries but also as a key organism in the ecosystem in the Bering Sea. As a result of many studies of the resource, it was determined that the fluctuation of biomass of pollock is largely dependent upon the strength of the year-classes. However, there are still many unknown aspects in the reproduction process including the early life history from spawning to recruitment to the resources as juvenile fish through larval period which are most important to determine the strength of the year-class.

Recently, the otoliths of many species were shown to have a concentric microstructure formed on a daily basis. This structure is called the daily growth increment and is used to obtain information about the early life history. It is reported that the daily growth increments are also formed in the otolith of larval and juvenile pollock (Nishimura and Yamada 1984; Bailey and Stehr, 1988).

In this study, we tried to estimate the age in days after hatching by examining the daily growth increments of juvenile pollock collected from the eastern Bering Sea and to clarify the early growth from the relationship between the age in days and fork length. In addition, the objectives of this study were to consider the relationship between the surviving juvenile fish and the spawners from the results of estimated hatching date by area.

2. Materials and Methods

Sampling of juvenile fish was conducted at 38 stations in the eastern Bering Sea including the Aleutian Basin during the period between July and October in 1989. It was conducted using a midwater trawl of the landbased dragnet trawler Seiju maru No. 28 (350 GT) chartered as a research vessel. A net of 4 mm mesh size was attached inside the cod-end to collect larvae and juveniles and the sampling was carried out within a few hours after sunset using this net as a sampling net. The sampling was carried out by trawling in the sub-surface layer at which the depth of the headrope was set at about 20 m. In addition, some of the juvenile fish specimens were obtained by a multi-net and a midwater trawl for adult fish. Some of the collected juvenile fish were frozen for taking otolith samples and the remaining were preserved in alcohol. After the frozen specimens were stored for almost one year, the fish were thawed in the laboratory, and the measurement of the body length and body weight was made for 40 fish randomly selected from each sampling group and the otoliths were removed.

Otoliths of the collected fish (287 fish) obtained from 10 stations were measured along the long axis direction, embedded in epoxy resin on a glass slide, and ground with waterproof carbon paper (#800–#1,000), perpendicular (frontal) to the otolith surface along the long axis. From the ground otolith specimens from each station, specimens were selected, which
included the otolith nucleus on the ground surface and which had a thickness that permitted the transmission of light when they were examined by a light microscope. These selected specimens were mirror-ground with a lapping paste, and cleaned with xylene using an ultrasonic cleaner, and etched with 0.2 Mol EDTA for 4 minutes. The specimens obtained were observed under the light microscope at 300 to 600 x magnification, the images observed were reflected on a television monitor of 11 inches, and the number of daily growth increments was counted on the picture. It is reported from the results of the observations by the scanning electron microscope the first otolith growth increment of pollock is formed at the outer margin of the nucleus on the day of hatching, and thereafter, growth increments are deposited on a daily basis during larval and juvenile stages (Nishimura and Yamada 1984). Thus, all growth increments formed outside of the nucleus were counted in this study to obtain the counts of daily growth increments.

3. Results

Juvenile and young pollock sampled during the survey period between July and October had modes at 70 mm and 150 mm in body length, and showed the length composition of the bimodal type which was obviously divided into two at about 120 mm in length (Fig. 1). Although the small-sized fish which had a mode at about 70 mm in length were distributed extensively on the continental shelf in the eastern part and the continental slope area, in the Basin area, the small-sized fish were sparse in the southeastern part, and in waters west of the central part, few were observed. On the other hand, the large-sized fish which had a mode at about 150 mm in body length had a centre of distribution in the northwestern part on the eastern continental shelf area, and some fish were distributed in the southeastern part, but they were not sampled in the central part of the continental shelf and the Basin areas (Fig. 2). For the small-sized fish sampled (there was a mode at 70 mm in body length), the otolith specimens were made from 160 fish (ranging between 33.2 mm and 94.5 mm in length) which were selected from 5 stations on the southern continental shelf, 2 stations on the northern continental shelf, and 1 station in the southeastern Basin area (Fig. 3). In addition, for the large-sized fish (there was a mode at 150 mm in body length), the otolith specimens were made from the 127 fish (ranging between 124.9 mm and 238.2 mm in length) which obtained from two stations on the northern continental shelf.

The otolith nucleus of about 20 µm diameter was observed under the light microscope of the ground otolith specimens at the central part of the otolith, and the growth increments (fine ring marks) were deposited concentrically around the otolith nucleus. Because of the narrow width of a few daily growth increments near the otolith nucleus, the growth increments were not always observed clearly by the light microscope. As the days elapsed, the increment width widened gradually, and at about the 10th growth increment from the nucleus, the increments were clearly observed under the light microscope (Fig. 4). When we observed the otolith of small-sized fish under the light microscope, the otolith was observed as brown and opaque, 60 to 139 daily growth increments were observed from the otolith nucleus to the outer edge of the otolith. Therefore, these fish were determined to be aged 0
fish, two to four months having elapsed since hatching. The width of the growth increments was greatest at about the 100th growth increment and thereafter the width of growth increments became gradually narrower. A range and mean of the estimated hatching period which was obtained by back-calculating from the collecting date for each individual area shown in Table 1. Despite the differences in sampling dates and stations, all groups observed this time were estimated to be hatched at almost the same period from late April to early June, and the middle of the hatching period was estimated to be in mid-May, and no differences among groups were observed. The frequency distribution of the hatching date of all aged 0 fish showed a unimodal distribution (Fig. 5).

The relationship between the estimated age in days after hatching, and body length for each individual of aged 0 fish, is shown in Fig. 6. Using samples of juveniles of 33.2 to 94.5 mm in fork length which age in days was assessed at this time and the relationship between fork length (FL) and age in days (t) regressed by the least squares method, following linear regression was obtained:

\[ FL = -217.7 + 62.5 \ln t \]
\[ r^2 = 0.622 \]

The growth equation was shown within the range of body length of samples.

The otolith (about 7 mm) of the large-sized fish which had a mode at 150 mm in fork length was larger than the otolith (about 3 mm) of the small-sized fish, and alternations of two different zones, an opaque zone which was observed by the light microscope observation (transmitted light) as brown and a translucent zone which was observed as white translucent. Although the otolith daily growth increments showed almost the same structure with that of the small-sized fish up to about 120, after that, the width of daily growth increment became gradually narrower, and at last the daily growth increments became difficult to observe by the light microscope. The middle part of the otolith where the daily growth increment was observed corresponded to the opaque zone, while the outer part at which the observation of daily growth increments was difficult corresponded to the translucent zone. As soon as the formation of the translucent zone was finished, the formation of the opaque zone begins again at the outer edge of the otolith, and in contrast to this, it was observed that the width of daily growth increments gradually widened. From such correspondence with the structure of daily growth increments, the clear translucent zone which formed in the outermost edge which is observed in the otolith of large-sized fish was considered to be a winter ring (annual ring) which was formed during the winter when the fish growth slows down. As the observation of daily growth increments of these aged 1 fish became difficult, because of the existence of the winter rings, we could not conduct the back-calculation of the hatching date. Two clear winter rings were formed on the otoliths of two individuals of 216.1 mm and 238.2 mm in fork length, they were determined to be aged 2 fish.
The relationship between fork length (FL) and otolith length (OL) is in conformity with the linear equation within the range of 33.2 mm to 238.2 mm in fork length, and the following linear regression was obtained (Fig. 7):

\[ OL = 0.050FL - 0.718 \]

\[ r^2 = 0.988 \]

4. Discussion

Nishimura and Yamada (1984) observed the diurnal formation of otolith growth increment of larval pollock reared in the laboratory, which were spawned in the Funka Bay, Hokkaido, located in the western North Pacific Ocean, using a scanning electron microscope. They clarified that the otolith growth increment was formed diurnally, after the day of hatching. However, the diurnal formation of growth increment was not observed under the light microscope because of the narrow width of growth increments formed near the nucleus, and it was shown that counting error did. Bailey and Stehr (1988) incubated the eggs obtained from the eastern Bering Sea in the laboratory. They found that it was possible to observe accurately daily growth increments with the light microscope, when the hatched larvae feed sufficiently and their growth was satisfactory. However, under conditions of low growth, they showed that the width of growth increments was narrower and it was impossible to observe the growth increments with the resolving power of the light microscope, and that a counting error might occur. In order to count accurately the number of daily growth increments, it is desirable to use the scanning electron microscope, but preparation for the scanning electron microscope specimens takes much time and effort. On the other hand, counting with the light microscope is easily operated, and its efficiency is good when analyzing many specimens. Although some counting errors might occur, depending on growth, because of the limited resolving power of the light microscope, it may not greatly affect the result of the analysis if the counting errors are only a few daily growth increments. Therefore, it is worth obtaining more data on daily growth increment counting with the light microscope.

Pollock collected in this study were obviously divided into the small-sized group which have a mode at about 70 mm in fork length and the large-sized fish group which have a mode at about 150 mm in fork length. Of those, the small-sized fish group were determined to be aged 0 fish from the number of daily growth increments observed, and the hatching period estimated by back-calculating from the counts of daily growth increments was ranging from late April to early June, and the middle date was estimated to be in mid May for all specimens.

The number of days required from spawning to hatching of this species was estimated to be about 25 days in water temperatures of 3° to 4°C (Okada 1986), and about 14 days in water temperatures of 5° to 6°C (Haynes and Ignell 1983; Nakatani and Maeda 1984; Nishimura and Yamada 1984). According to Ingraham (1981), the conditions of water temperature in this area during
the winter (January to March) is about 2°C at the surface layer, and increases to 3° to 5°C toward May, and he indicated that the water temperature at the bottom layer from winter season to May was approximately 3°C. Therefore, on the assumption that the hatching water temperature of eggs is about 3°C, it is assumed that the number of days required from spawning to hatching is about 25 days, and the specimens observed at this time are considered to be the group which had the peak of spawning from mid- to late April. The spawning period of pollock in the eastern Bering Sea is assumed to be from February to March for the Basin area surrounding Bogoslof Island, and form March to June for the continental shelf area from Unimak Island to the Pribilof Islands (Dunn and Matarese 1985), and the spawning period estimated in this study was coincident with the spawning period on the continental shelf area.

Based on the observations conducted from January to March in 1983, Okada (1986) estimated that eggs spawned in the southeastern Basin area were carried by the current toward the east and were swept away 150 miles toward the eastern or northeastern direction until they hatched. In addition, it is reported that there is a current which moves toward the northwestern direction on the eastern continental shelf and the continental slope area (Kinder and Schumacher 1981; Coachman 1986). Considering these information, it is assumed that the eggs hatched in the Basin area were swept away to the eastern continental shelf area and after that, were carried away on the current of the continental shelf area toward the northward direction. However, in this study there were no juvenile pollock collected in the eastern continental shelf area which were assumed to be spawned in the Basin. Even though there may be counting errors of several daily growth increments, they do not adversely affect the spawning period estimated here. The results indicate that there is a possibility that larvae and juveniles originating from the spawners in the Basin area where a large concentration of spawning was identified don't recruit to the larval and juvenile pollock stocks in the eastern Bering Sea, and there is a problem in the reproductive mechanisms for maintaining the population. However, it only was the results about juveniles and young fish originated in the eastern Bering Sea in 1989, and from now on we should continue the observations, and it is necessary to obtain samples from the northwestern Bering Sea to confirm the results.

Regarding the early growth of pollock in the eastern Bering Sea, the analysis of growth of the juveniles of 50 mm in length and smaller fish was conducted using the daily growth increments of otolith (Walline 1980; Kendall et al. 1987; Yoklavich and Bailey 1989), however, there were no comparable results about the length range surveyed in this study. Nishimura and Yamada (1987) showed by back-calculating the daily growth increments for the existence geographical differences of early growth in the western Pacific, Sea of Japan, and southern Okhotsk Sea, and they showed that the growth of larvae in the southern Okhotsk Sea was the fastest growth occurred during the first six months after they were born. The growth estimated from the relationship between the fork length and age in days of collected juveniles in the eastern Bering Sea obtained in this study was faster than that in the southern Okhotsk Sea. Such features of the early growth pattern is recorded on the otoliths, as it was, and it is possible to estimate by for the early growth pattern on
the adult fish specimens by dealing with the otoliths appropriately. Therefore, if there are differences in the early growth patterns of spawners, it is possible to use this information for identification of the stocks. However, because the analysis of growth conducted in this study has not yet proceeded sufficiently, and we dealt equally with all juveniles and young fish, it may be possible that the results included different growth patterns.

The high correlation observed between the fork length and otolith length shows that an individual that has a good body growth also has good otolith growth. Judging from the high correlations found in the otolith length and fork length and the existence of daily growth increments on the otolith, the width of growth increments on the otolith is considered to be an index of the body growth per day in their early life stage and the possibilities to apply to this information growth analyses were shown. It is possible that detailed information pertaining to the early life history such as growth and survival of larval and juvenile pollock including pollock spawned in the Basin will be available by analyzing the results of the observations of more samples in the future.

References, Table 1 and Figs. 1 to 7 are in English in the Japanese document.

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