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Inter-annual and spatial difference in hatch date and settlement date distribution and planktonic larval duration in yellow striped flounder *Pseudopleuronectes herzensteini*

Mikimasa Joh[a,*], Akihiko Wada[b]

[a] Mariculture Fisheries Research Institute of the Hokkaido Research Organization, 051–0013, 1-156-3 Funamicho, Muroran, Hokkaido, Japan
[b] Central Fisheries Research Institute of the Hokkaido Research Organization, 046–8555, 238 Hamanakacho, Yoichi, Hokkaido, Japan

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ABSTRACT

Hatch date and settlement date distribution and planktonic larval duration (PLD) in yellow striped flounder in nursery grounds in the northern Japan Sea and in the Okhotsk Sea around Hokkaido (Northern Japan Sea–Okhotsk Sea population) were investigated. We examined the relationship between the ecological features and water temperature in these two locations where oceanographic conditions considerably differ. For both nursery grounds, the timing of hatch was early in a warm year and late in a cold year, indicating the strong link between water temperature and the timing of hatch in this population. Although spatial difference in hatch date in 2007 was not significant, hatching and settlement of juveniles collected in the Okhotsk Sea nursery (Okhotsk Sea subpopulation: OSS) occurred later than in those collected in the Japan Sea (Japan Sea subpopulation: JSS); in the spring, the water temperature of the Japan Sea rises earlier in the southern area. The precise area where eggs of both subpopulations originated is unknown; however, this study indicates that eggs that become the JSS may be produced further south than those for the OSS. Comparing on the same date, the water temperature around potential spawning area of OSS in 2006 was ca. 2 °C lower than in 2007 and 2009; however, the overall difference in water temperature at the median date of hatching was 0.7 °C. This result indicates that a spring rise in water temperature probably determines the timing of spawning and larval hatch of this population. Spatiotemporal differences in the PLD were affected by water temperature in which juveniles were exposed during pelagic phase. The PLDs were shorter in warmer years and for warmer subpopulation. The PLD of OSS was longer than that of JSS and spatial difference was statistically significant in 2006. Water temperature in which OSS was exposed in later pelagic phase was relatively low, and the growth of pelagic larvae of OSS was probably slow, and consequently, the PLD of OSS may become long. The eggs originating the OSS are spawned in the Japan Sea and transported a long-distance to their nursery ground in Okhotsk Sea. Generally, a slow growth rate is considered a negative factor for the early survival of fish, although it may be that the slow growth and long PLD of the OSS juveniles confers an advantage upon them during their long-distance transportation. For yellow striped flounder, this study primarily reports on hatch date and settlement date distribution and PLD of juveniles. For flatfish species, the study of the link between those features and water temperature is limited. This study expands the knowledge of the early life-cycle in flatfish, information on which is currently limited.

1. Introduction

Hatch-date distribution is an important parameter in fish early life stages because it often affects early survival. For many bilaterally-symmetric teleost fish, hatch-date distribution has been estimated and the match/mismatch between the main hatch season and suitable environmental factors for larval survival has been well studied (Cushing and Dickson, 1976; van Deurs et al., 2009; Wright and Bailey, 1996). Otolith microstructure analysis is indispensable to the estimation of hatch date. In teleost fish, there are 3 pairs of otoliths in the head, of which the sagittae are mainly used for otolith microstructure analysis. However, in flatfish, secondary primordia are formed on the margin of larval sagittae during metamorphosis (Campana, 1984; Modin et al., 1996), complicating the morphology in juvenile sagittae; therefore, otolith microstructure analysis throughout the larval and juvenile stages requires more time and expertise. Despite this difficulty, two studies have examined hatch-date distribution of flatfish juveniles using sagittae (Fox et al., 2007; Gunnarsson et al., 2010). Other studies have

* Corresponding author.
E-mail address: joh-mikimasa@hro.or.jp (M. Joh).

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reported that, in some flatfish species, lapilli do not form secondary primordia and that daily rings are also formed (Joh et al., 2005; Joh et al., 2011; Joh et al., 2014; May and Jenkins, 1992; Sogard, 1991). Thus, for flatfish, otolith microstructure analysis throughout the larval and juvenile stages is more easily performed using lapilli. The nutritional transition date (some days after hatching) and the distribution of marbled flounder *Pseudopleuronectes yokohamae* larvae and juveniles have been estimated in Hakodate Bay, Japan, and the date-selective mortality was detected in an extremely cold water temperature environment (Joh et al., 2009). However, studies on hatch-date distribution in juvenile flatfish are scarce.

At metamorphosis, flatfish larvae undergo a drastic shift of habitat, from the 3-dimensional water column to the 2-dimensional sea floor. Simultaneously, a remarkable change in morphology—eye migration—occurs. Therefore, the early juvenile stage is also thought to be critical for survival in flatfish (Joh et al., 2013), the settlement date distribution and the relationship between it and environmental factors need to be clarified, although few studies have addressed these factors (Fedewa et al., 2016; May and Jenkins, 1992).

The yellow striped flounder *Pseudopleuronectes herzensteini* distributes in the coastal area of the temperate northwestern Pacific, constituting an important fishery resource. Around Hokkaido Island, Japan, the Northern Japan Sea–Okhotsk Sea population of this species distributes in the Japan Sea and the Okhotsk Sea, between which lie the Shakotan and Shiretoko Peninsulas (Fig. 1). This population was utilized by gill net fishery in coastal Japan Sea and by gill net and bottom set net in coastal Okhotsk Sea, and the mean of total catch of this population was c.a. 2400 ton during 2001–2015. The Fishery Research Institute of Hokkaido Research Organization has assessed stock condition of this population by the virtual population analysis, and the level of this stock has continued to be medium level from 1995 to 2012, but thereafter it declined to low level during 2013–2015 (Fisheries Research Institute of Hokkaido Research Organization, 2017). The adults of this population spawn in the wide coastal area of the Japan Sea in May–June, although mature adults are scarce in the Okhotsk Sea around Hokkaido (Nishiuchi, 1989). Although some eggs and larvae from them settle in the Japan Sea and spend all life in there (Japan Sea Subpopulation: JSS), other eggs and the pelagic larvae that are produced in the Japan Sea are transported to and settle in the Okhotsk Sea (Okhotsk Sea Subpopulation: OSS). They later migrate toward the Japan Sea at maturation and remain there, not migrating back to the Okhotsk Sea again (those data obtained in 1960–1970s, reviewed in (Shimoda et al., 2006)). Thus, although this population has 2 nursery areas in different sea areas, spawning occurs only in the Japan Sea after which the 2 subpopulations are mixed. Therefore, it is reasonable to consider these 2 subpopulations as a single population. In the Japan Sea, the Tsushima Warm Current flows from southwest to northeast, and the strength of this current seasonally fluctuates. Off the west coast of Hokkaido, the northward transported volume of the current is at its minimum and maximum in April and August, respectively (Nakata and Tanaka, 2002). In the Okhotsk Sea, from spring to autumn, Souya Warm Current, a branch of the Tsushima Warm Current, flows from northwest to southeast, raising the summer water temperature in the coastal area of the Okhotsk Sea. But in winter, the Souya Warm Current weakens and East Sakhalin Cold Current flows from northeast to southwest, bringing with it drifting sea ice. Thus, with the 2 nursery grounds being located in highly contrasting sea areas, this population is an ideal candidate population for examining the effect of environmental factors on the early life ecology of flatfish.

In this study, the juveniles were collected in both nursery grounds for 3 years; hatch and settlement date distribution and planktonic larval duration (PLD) were estimated. We collected information on the water temperature of the environments from ship observations and from data supplied by the Japan Meteorological Agency. The relationship between the spatiotemporal trend in those ecological features and the water temperature environment was examined. This study reveals information essential to the understanding of the early life ecology of this species and contributes to the currently insufficient knowledge of hatch date and settlement date distribution of juvenile flatfish.

2. Materials and methods

2.1. Sampling and measurement

In this study, nursery ground was defined based on following 2 features: (1) the location in which the abundance of juveniles is larger than other area because we thought the relatively higher abundance of juveniles were caused by adequate environment for juveniles life, and (2) the abundance of young flounder in this area can be used as the indicator of fishery recruitment level. Previous studies show the nursery grounds for the Japan Sea Subpopulation (JSS) to be located in the Japan Sea off Obira, and those for the Okhotsk Sea Subpopulation (OSS) to be located in the Okhotsk Sea off Oumu; and that the year class strength of the Northern Japan Sea–Okhotsk Sea population can be estimated by the abundance of 0- or 1-year-old flounder caught in both nurseries (Nishiuchi, 1989; Shimoda et al., 2006). In our study, juveniles of yellow striped flounder were collected in both nursery grounds in August 2006, 2007, and 2009, from 20 and 27 sampling stations in Obira and Oumu, respectively, each station being set into a grid at a water depth between 10 and 50 m (Fig. 1). At each station, a small dredge net (mouth opening: 180 × 30 cm, mesh aperture of cod end: 5 mm) was towed on the sea floor for 10 min (Kobayashi et al., 2015); collected juveniles were preserved in 90% ethanol solution. In the laboratory, standard length (mm) was measured and specimens for otolith microstructure analysis were subsampled. Subsampling was carried such that the shape of the histogram for standard length between collected and subsampled juveniles matched. A summary of sampling is shown in Table 1.

We used blind-side lapilli for otolith microstructure analysis (Joh et al., 2011). The lapilli were extracted under a dissection microscope and mounted on glass slides with epoxy resin. Thereafter, lapilli were polished with aluminum oxide lapping film (9 μm) until the otolith rings formed around the center of the lapilli could be observed. Microstructural images were obtained under a light microscope with ×40 or ×100 objective lenses; otolith ring count and width measurement were carried out with otolith daily ring image analysis system (APR Ver. 5.00, Ratoc System Engineering Co.).

2.2. Estimation of hatch date, planktonic larval duration (PLD), and settlement date of juveniles

In yellow striped flounder, daily ring formation and the patterns of otolith growth with somatic developments were reported in Joh et al. (2011). A check is formed in the center of the lapilli at the timing of yolk sac absorption (inner check) and clear rings form outside the check. The relationship between the number of days after hatching and the number of rings formed outside inner check was linear; and the slope of this line did not differ with 1 significantly. Therefore, the date when the yolk sac was absorbed was estimated by subtracting the number of rings from the sampling date. From rearing experiments, it is known that the number of days between hatching and the formation of inner check reduces with an increase in water temperature; in the water temperature is close to that in spawning season of this population, this period equated to 8 days; therefore, the hatch date was estimated by subtracting as 8 days from the yolk-sac-absorption date.

For yellow striped flounder, clear rings were formed on the lapilli during pelagic life; and a sequence of obscure rings is observed during metamorphosis (metamorphosing zone: MZ). Therefore, the timing of settlement and onset of juvenile life can be said to be at the end of the MZ. Thus, the settlement date of juveniles was estimated by subtracting the number of rings outside the MZ from the sampling date. The PLD was estimated by subtracting the hatch date from the settlement date.