13. Survival of Walleye Pollock in Early Life Stages in Funka Bay and the Surrounding Vicinity in Hokkaido

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Introduction

The waters at the mouth of Funka Bay, Hokkaido, extending out of the bay on the eastern side, serve as spawning grounds for walleye pollock, *Theragra chalcogramma*. This species inhabits the northwestern Pacific from Hokkaido to the Tohoku region (the northernmost part of Honshu Island). From October to March, spawning walleye pollock are caught commercially by demersal gill nets and offshore bottom trawl nets. Recently, annual catch in this area ranged from 42,832 metric tons in 1976 to 109,226 metric tons in 1987. Such fluctuations in catch are likely to be controlled by the strength of year classes. Year class strength based on cumulative numbers(≧age 4) in the commercial catch ranged from 58.6×10^6 (1972 year class) to 248.7×10^6 (1980 year class) (Mihara et al., 1994). Relatively large landings from 1984 to 1987 were supported by the strong year classes from 1980 (248.7×10^6) to 1983 (125.8×10^6). In order to clarify the factors affecting year class strength, we examined the relationship between spawning strategy and the survival of walleye pollock in the early life stages in Funka Bay and surrounding vicinity in Hokkaido.

Results

General hydrographic conditions in Funka Bay in winter

The hydrographic conditions in the bay are regulated chiefly by the characteristics of two major water masses, the Tsugaru Warm Water and Oyashio Water, and by their periodic replacement (Ohtani and Akiba, 1970). In winter, the Tsugaru Warm Water in the bay is cooled by heat conduction and evaporation, and gradually becomes homogeneous and cold (3.5°C) (Ohtani, 1971). In general, the minimum surface temperature occurs in February/March as a result of intrusion of Oyashio Water. In late January and early February 1995, water temperatures at 15 m depth in the inner area of the bay were 5.8 and 4.7-5.7°C respectively (Sugimoto, unpublished data). After intrusion of Oyashio Water, the minimum temperature was 2.3°C on 15 March 1995.

Spawning

Spawning occurs from November and/or December to March in Funka Bay and the surrounding area (Maeda et al., 1979, 1980; Yoon, 1981). As shown in Fig. 1A, eggs in the early developmental stage (from fertilization to early blastula stage) were collected at the mouth of the bay and the northeastern coastal areas out of the bay (Nakatani and Maeda, 1989). Based on the distribution of Oyashio Water (Fig. 2, 33.0-33.2 psu), these eggs appear to be transported to the bay mouth by this water. In contrast, newly hatched larvae were concentrated in the inner area of the bay and the bay mouth (Fig. 1B). It is likely that these larvae were transported to the bay by two vortices, which were generated by the combination of the predominantly northwesterly winds in winter and the parabolic bottom topography of Funka Bay (Shimizu and Isoda, 1997).

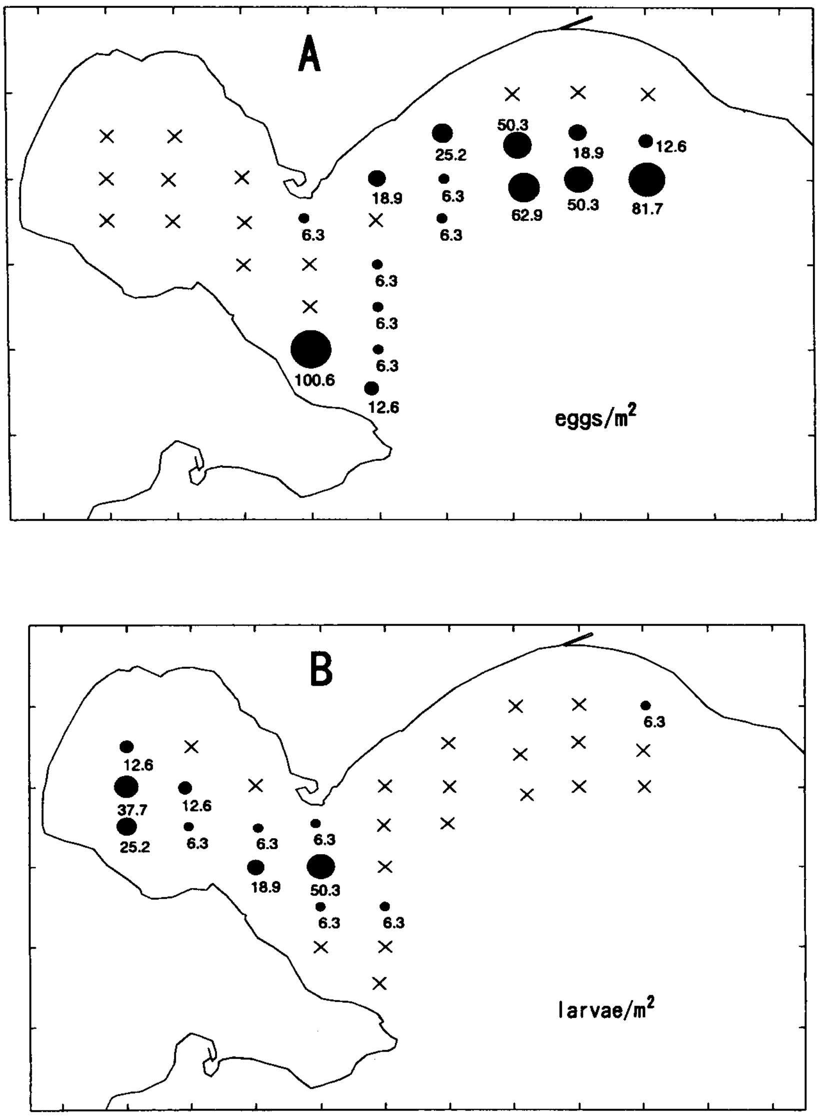

Fig.1. Horizontal distributions of walleye pollock eggs from fertilization to early blastula stage (A), and larvae (B) on February 21~25, 1988. Samples were collected by vertical hauls from 150 m depth or near bottom where the depth of bottom was less than 150 m with a Norpac net. (Nakatani and Maeda 1989)

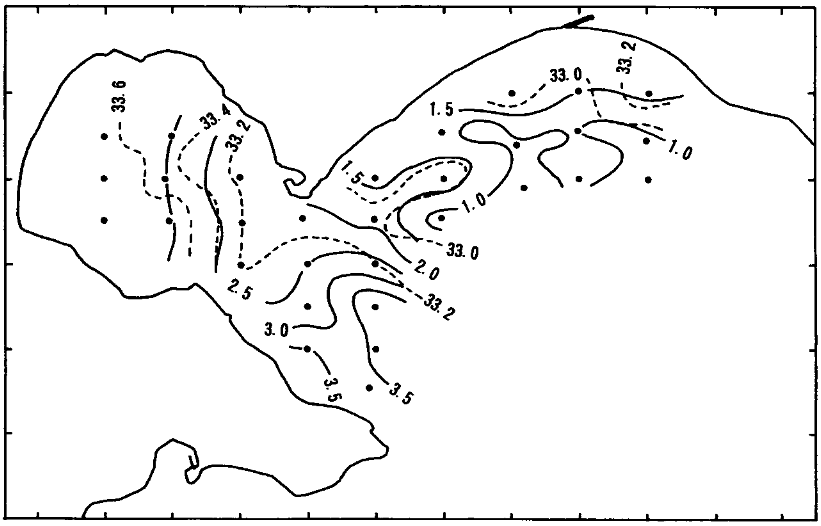

Fig. 2. Horizontal distributions of water temperature (solid lines°C,) and salinity (dotted lines, PSU) at 10 m depth on February 21~25, 1988. (Nakatani and Maeda 1989)

Food of Larvae and Juveniles

Once transported into the bay, the newly hatched larvae initiate feeding, primarily on copepod nauplii (Kamba, 1977; Nakatani and Maeda, 1983; Nakatani, 1995b). An ontogenetic change in preferred food organisms occurs with larval development. That is, larvae larger than 7 mm in total length (TL) feed on small copepodids such as *Pseudocalanus* spp. These are abundant from March to April, and then decrease in June (Nakatani and Maeda, 1987). Juveniles larger than 30 mm TL take large sized copepodids such as *Neocalanus plumchrus*. According to Nishimura and Yamada (1984), it takes approximately 82 days from hatching to reach 30 mm TL. Therefore, the larvae hatched in March may suffer from a low density of copepodids of Pseudocalanus spp. because they are probably too small to feed on *N. plumchrus*. Juveniles larger than 70 mm TL switch to feeding on large sized crustacean zooplankton prey, such as *E. bungii*, (Nakatani and Maeda, 1987). The abundance of *N. plumchrus* and *E. bungii* increased from June to July in deep layers in the bay (Nakatani and Maeda, 1987).

Seasonal Change in Vertical Distribution with Growth

Walleye pollock larvae collected with MTD horizontal closing nets (Motoda, 1971) from March to May were distributed from the surface to 50 m depth, with the highest concentration at about 10-20 m depth (Kamba, 1977). From April to June, larvae and juveniles were found mostly in the surface and subsurface layers of the bay (Nakatani and Maeda, 1987). In July, juveniles were concentrated on the bottom (100 m depth) of the bay

Table 1. Monthly change in density of copepod nauplii (indiv./l) collected at Stations A, B, and C using a 40 μm mesh sieve in Funka Bay and surrounding vicinity, from January to March 1991 (Nakatani, 1995-a)

Station	29-30 JAN.			21 FEB.			14 MAR.		
	A	B	C	A	B	C	A	B	C
Calanus	0.30	0.38	0.26	0.27	1.49	0	1.31	0.41	0.11
Paracalanus	2.17	1.68	1.97	0.69	0.96	0	0.19	0.28	0.11
Pseudocalanus & Metridia	0.88	0.66	0.97	3.83	1.87	0.86	2.86	4.57	2.13
Acartia	0	0.14	0.10	0.39	0.32	0	0.51	0.69	0.05
Oithona	4.18	8.61	8.59	12.80	13.52	11.28	7.99	2.14	5.78
Oncaea	0.11	0.21	0.35	0.07	0.48	0.26	0	0.06	0
others	0.16	0.05	0.45	0	0	0	0	0.10	0.06
total	7.80	11.75	12.70	18.05	18.65	12.40	12.85	8.25	8.25

and in August, a portion were found on the deep sea bottom (300 m depth) in the eastern area out of the bay (Nakatani and Maeda, 1987). In late August, total lengths and standard deviations of juveniles collected by bottom trawl net were 105.6±13.23mm in 1989 (Nakatani, 1991), 130.9±8.9 mm in 1993 (unpublished data), and 108.6±13.1 in 1995 (unpublished data). The vertical migration of juveniles with growth was closely associated with suitable temperature conditions and food availability (Nakatani and Maeda, 1987).

Monthly Change in Density of Copepod Nauplii

In order to elucidate the availability of food for walleye pollock larvae in the initial feeding stage, copepod nauplii were collected from a depth of 15 m in the inner area (station A), mouth (station B), and outside the bay (station C) from January to March, 1991 (Table 1;

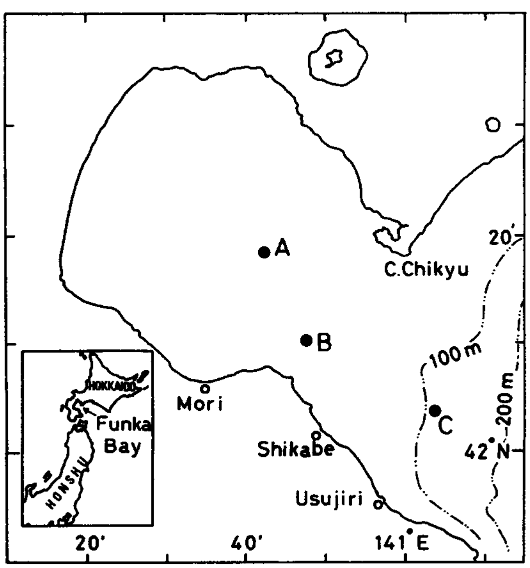

Fig. 3. Location of Van Dorn sampling stations and bottom contours from January to March in 1991.

Nakatani, 1995a). In January, the density of *Oithona* nauplii were 4.18(St. A), 8.61(St. B) and 8.59(St. C), respectively. Here, 41.2-59.7% of the *Oithona* nauplii available as food for walleye pollock larvae at the initial feeding (≧84 μm in body width, Nakatani, 1995a) were as low as 1.85-3.85/l. Pseudocalanus and Metridia were low in numbers in January (0.66-0.97/l), and then increased in March (2.13-4.57/l). Most were larger than 84 μm in body width. Monthly changes in species composition of copepod nauplii also occurred in 1993 and 1995 (Sugimoto, unpublished data), although changes in copepod nauplii density occurred between years.

Spawning Strategy of Walleye Pollock in Funka Bay and the Surrounding Vicinity

Newly hatched larvae were abundant in the surface layer of Funka Bay and the surrounding vicinity from January to February. The number of larvae collected with plankton nets decreased rapidly in March (Nakatani, 1996). According to the hatching frequency of juveniles, based on otolith growth increments, many juveniles hatched in January/February were captured by the experimental bottom trawl in summer in the inner area of the bay in 1995 (Sugimoto, unpublished data). In January/February, copepod nauplii larger than 84 μm in body width, available as food for initial feeding larvae, were low in number but increased following the intrusion of Oyashio Water in March (unpublished data). In general, the timing of spawning is considered closely related to the survival of the offspring in the early life stages.

Sherman et al. (1984) demonstrated that peak spawning for several important species off the northeastern United States is in synchrony with increasing abundance levels of their seasonally-dominant copepod prey. Bollens et al. (1992) showed a distinct temporal 'mismatchi' between the seasonal abundance patterns of fish larvae and their prey in Dabob Bay, Washington, suggesting that food limitation in the early larval stages may not be the dominant force constraining the timing of spawning and subsequent abundance patterns of fish larvae. In Auke Bay, southeastern Alaska, walleye pollock larvae consistently appeared at about the time of maximum copepod abundance (Haldorson et al., 1993). Thus pollock can be categorized as a 《synchronous species》 in this area. In contrast, the peak abundance of walleye pollock larvae was found in January/February in Funka Bay(Nakatani, 1996), while large sized copepod nauplii increased in late March (Nakatani, 1995a, unpublished data). Thus, they were categorized as 《early》 strategists in this area. Pseudocalanus is a predominant copepod nauplii eaten by walleye pollock larvae over the southeastern Bering Sea shelf, in Auke Bay, Shelikof Strait, and Resurrection Bay (Clayton et al., 1997). While Oithona nauplii were found in stomachs of walleye pollock larvae smaller than 7 mm TL in January and February in Funka Bay, this species was not found in larval guts in March (Nakatani, 1995b). Such monthly changes in species composition in the stomach content of walleye pollock larvae may reflect the succession of the community of copepod nauplii in response to the hydrographic conditions in the bay.

Paul et al. (1991) demonstrated that some of the weekly cohorts over four years had adequate prey concentrations for rapid growth. Such food availability can be expected to relate to protracted spawning. In the eastern area outside Funka Bay, there is also protracted spawning (from December to March) of walleye pollock. Such spawning strategy in this species might compensate the food availability for walleye pollock larvae. Bailey et al. (1993) found that gammarid amphipods and euphausiids were important predators on eggs and yolk-sac larvae, respectively. Cheatognaths are also known to be predators on larval fish (Tanaka, 1983). It is assumed that they are transported into the bay by the Oyashio Water. As stated before, a strong year class occurred in 1980. Late winter to early spring of 1980 were characterized by strong winds and warm water temperatures (Isoda et al., 1998. Compared with normal years, there were many larvae in Funka Bay and the surrounding vicinity in March (Nakatani and Maeda, 1983; Nakatani, 1996). From the independently determined mortality rates, Theilacker et al. (1996) suggested that high prey levels were crucial for survival of larval walleye pollock. It is supposed that rapid growth at high water temperatures with abundant food organisms is good for the early life stages of walleye pollock. In addition, low densities of carnivorous zooplankton due to the delay of the Oyashio Water intrusion into Funka Bay might reduce larval mortality by predation in winter and early spring in 1980. Based on these findings relative to the hydrographic and biological conditions and distribution of walleye pollock larvae, it can be concluded that water temperature, affected by meteorological conditions, as well as the abundance of large-sized copepod nauplii and the timing of the Oyashio Water intrusion, control the mortality of early life stages of walleye pollock in Funka Bay and the surrounding area off Hokkaido.

References

Bailey, K. M., Brodeur, R. D., Merati, N. and Yoklavich, M. M. (1993). Predation on walleye pollock *(Theragra chalcogramma)* eggs and yolk-sac larvae by pelagic crustacean invertebrates in the western Gulf of Alaska. *Fish. Oceanogr.*, **2** , 30-39.

Bollens, S. M., Frost, B. W., Schwaninger, H. R., Davis, C. S., Way, K. J. and Landsteiner, M. C. (1992). Seasonal plankton cycles in a temperate fjord and comments on the match-mismatch hypothesis. *J. Plankton Res.*, **14**, 1279-1305.

Clayton, L. A., Paul, A. J. and Paul, J. M. (1997). Timing of occurrence and length frequency profiles of walleye pollock larvae in Resurrection Bay, Alaska, spring 1991. *Alaska Fishery Research Bulletin* **4**, 54-61.

Haldorson, L., Pritchett, M., Sterritt, D. and Watts, J.(1993). Abundance patterns of marine fish larvae during spring in a southeastern Alaskan bay. *Fish. Bull., U.S.*, **91**, 36-44.

Isoda, Y., Shimizu, M., Ueoka, A., Matsuo, Y., Ohtani, K. and Nakatani, T. (1998). Interannual variations of oceanic conditions related to the walleye pollock population around the Pacific sea area, south of Hokkaido. *Bull.Jpn. Soc. Fish. Ocean.*, **62**, 1-11. (in Japanese with English abstract)

Kamba, M. (1977). Feeding habits and vertical distribution of walleye pollock, *Theragra chalcogramma* (PALLAS), in early life stage in Uchiura Bay, Hokkaido. *Res. Inst. N. Pac. Fish., Hokkaido Univ.*, **Spe.Vol.**,175-197.

Maeda, T., Nakatani, T., Takahashi, T. and Ueno, M. (1979). Transport and migration of the pollack larvae in the coastal waters. *Bull. Jpn. Soc. Fish. Oceanogr.*, **34**, 81-85. (in Japanese)

Maeda, T., Nakatani, T., Takahashi, T. and Ueno, M.(1980).On the population and the developmental fluctuation of the Alaska Pollock at the southern area off the Hokkaido in the Pacific Ocean. *Bull. Jpn. Soc. Fish. Oceanogr.,*. **37**, 29-33. (in Japanese)

Mihara, Y., Ueda, Y. and Natsume, M. (1995). Observation report of walleye pollock fishery in the south region of Hokkaido, Pacific, 1995. Hakodate Fish. Exp. St., Muroran Branch, 1-16. (in Japanese)

Motoda, S. (1971). Devices of simple plankton apparatus V. *Bull. Fac. Fish. Hokkaido Univ.*, **22**, 101-106.

Nakatani, T. and Maeda, T. (1983).Distribution of walleye pollock larvae and their food supply in Funka Bay and the adjacent waters, Hokkaido. *Bull.Japan.Soc.Sci.Fish.*, **49**, 183-187. (in Japanese with English abstract)

Nakatani, T. and Maeda, T. (1987).Distribution and movement of walleye pollock larvae *Theragra chalcogramma* in Funka Bay and the adjacent waters, Hokkaido. *Nippon Suisan Gakkaishi*, **53**, 1585-1591.(in Japanese with English abstract)

Nakatani, T. and Maeda, T. (1989). Distribution of copepod nauplii during the early life stage of walleye pollock in Funka Bay and vicinity, Hokkaido. *Proc. Int. Symp. Biol. Mgmt. Walleye Pollock Nov. 1988, Anchorage, Alaska. Alaska Sea Grant Report* **89**, 217-240.

Nakatani, T. (1991).Copepod nauplii as food of walleye pollock larvae (Pisces:Gadidae) in Funka Bay, Japan. *Proc. Fourth Int. Conf. Copepoda; Bull. Plankton Soc. Japan*, **Spec.Vol.**,515-525.

Nakatani, T. (1995a). Monthly changes in density and size structure of copepod nauplii as the primary food for fish larvae in winter in Funka Bay and surrounding vicinity in Hokkaido. *Fish. Sci.*, **61**, 382-386.

Nakatani, T. (1995b). Monthly change in food size of larval walleye pollock *Theragra chalcogramma* at the initial feeding stage in Funka Bay and surrounding vicinity in Hokkaido. *Fish. Sci.*, **61**, 387-390.

Nakatani, T. (1996). Annual change in abundance of walleye pollock in the south region of Hokkaido, Pacific. *Kaiyo Monthly*, **28**, 86-91. (in Japanese)

Nishimura, A. and Yamada, J. (1984). Age and growth of larval and juvenile walleye pollock,*Theragra chalcogramma* (Pallas), as determined by otolith daily growth increments. *J. Exp. Mar. Biol. Ecol.*, **82**, 191-205.

Paul, A. J., Coyle, K. O. and Haldorson, L. (1991). Interannual variations in copepod nauplii prey of larval fish in an Alaskan Bay. *ICES J. mar. Sci.*, **48**, 157-165.

Ohtani,K. and Akiba,Y. (1970). Studies on the change of the hydrographic conditions in the Funka Bay I. The annual change of the water of the bay. *Bull. Fac. Fish. Hokkaido Univ.*, **20**, 303-312. (in Japanese with English abstract)

Ohtani,K.(1971). Studies on the change of the hydrographic conditions in Funka Baya II. Characteristics of the waters occupying the Funka Bay. *Bull. Fac. Fish. Hokkaido Univ.*, **22**, 58-66. (in Japanese with English abstract)

Sherman,K., Smith,W., Morse,W., Berman, M., Green, J. and Ejsymont, L.(1984). Spawning strategies of fishes in relation to circulation, phytoplankton production, and pulses in zooplankton off the northeastern United States. *Mar. Ecol. Prog. Ser.*, **18**, 1-19.

Shimizu, M. and Isoda, Y. (1997). The transport process of walleye pollock eggs into Funka Bay in winter. *Bull. Jpn. Soc. Fish. Oceanogr.*, **61**, 134-143.(in Japanese with English abstract)

Tanaka, M. (1983). Feeding and survival in marine fish larvae-VIII. Predation on eggs and larvae (1). *Aquabiology* **5**, 344-351. (in Japanese with English abstract)

Theilacker, G. H., Bailey, K. M., Canino, M. F. and Porter, S. M. (1996). Variations in larval walleye pollock feeding and condition: a synthesis. *Fish. Oceanogr.*, **5** (Suppl. 1), 112-123.

Yoon, T. (1981). Reproduction cycle of Female walleye pollock, Theragra chalcogramma (Pallas), in the adjacent waters of Funka Bay, Hokkaido. *Bull. Fac. Fish. Hokkaido Univ.*, **32**, 22-38. (in Japanese with English abstract)