Possible Causes of Annual Change in the Year Class Strength of Flathead Flounder *Hippoglossoides dubius* (Pisces, Pleuronectiformes) in Funka Bay, Hokkaido

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To elucidate the mechanism for the annual fluctuation of year class strength of flathead flounder *Hippoglossoides dubius* in Funka Bay, Hokkaido, annual changes in age composition, spawning period, egg abundance, food availability at the first feeding stage, and hydrographic conditions were investigated from 1988 to 1999. Strong year classes occurred in 1989, 1991, and 1995. Comparison between annual fluctuations of commercial catch of flathead flounder and the abundance of eggs suggests that there is no relationship between the spawning size and the resultant year class strength of flathead flounder in Funka Bay. The density of copepod nauplii, the primary food for larval flathead flounder, was 7.8 individuals$\cdot l^{-1}$ in January and then increased in February (18.1 individuals$\cdot l^{-1}$) and March (12.9 individuals$\cdot l^{-1}$) in 1991. High densities of copepod nauplii in January were also found in 1994 (13.1 individuals$\cdot l^{-1}$) , 1995 (12.3 individuals$\cdot l^{-1}$), and 1996 (13.8 individuals$\cdot l^{-1}$). However, the strong year class of flathead flounder did not occur in 1994 and 1996. Therefore, the high density of copepod nauplii does not determine the magnitude of the year class strength of flathead flounder in this area. During the study period, the spawning period varied widely among years from January to March and early spawnings were found in the years when the high water temperatures were observed from November to December. The high water temperatures at the surface layer in January were observed in 1991. Relatively warm water were also observed from January to February in 1995, while temperatures during January and February were low in 1989. From the results, it is considered that the early spawning and relatively high water temperature affect the magnitude of the year class of flathead flounder in this area. For the 1989-yaer-calss, high water temperature in mid December 1988 might reduce the mortality during the early life period of flathead flounfer in Funka Bay in spite of low temperature after the intrusion the Oyashio Coastal Water (cold water) in January.

Key words: *Hippoglossoides dubius*, Funka Bay, abundance of eggs, food availability of larvae, year class strength, water temperature

Introduction

In Funka Bay, Hokkaido, flathead flounder *Hippoglossoides dubius* have a great biomass of demersal fishes, being a key species in the detritus food web (Yokoyama *et al.*, 1989). In recent years, the annual harvest in the bay has fluctuated from a minimum of 559 metric tons in 1990 to a maximum of 2,607 metric tons in 1996. The annual change in catch is considered to reflect the population size, which is determined by the strength of each year class. A large fluctuation of the year class strength of this species has been observed in Funka Bay. Before 1990, the strong year classes occurred in 1980 and 1983 (Nakatani *et al.*, 1990).

In general, it is considered that year class strength of fish is strongly affected by mortality during the early life stages. The spawning of flathead flounder in Funka Bay occurs from January to April (Yokoyama *et al.*, 1991). In this period, hydrographic conditions in the bay are controlled by the cooling and convectional mixing of Tsugaru Warm Water (TWW; ≧6°C, ≧33.8 PSU) stagnated in winter and intrusion of the Oyashio Coastal Water (OCW; 1–3°C, 33.0–33.3 PSU) (Ohtani and Akiba, 1970; Ohtani, 1991, Ohtani and Kido, 1980). The oceanography in Funka Bay is subject to interannual variability of ocean conditions outside of the bay (Isoda *et al.*, 1998), which probably affects the spawning period of flathead flounder. The annual variability of environmental factors may also affect mortality and hence recruitment of flathead flounder.

Suzuuchi (1983)* and Miyamoto *et al.* (1993) found that flathead flounder eggs were mainly distributed in the inner area of the bay. To find the spawning period of flat-

Received November 26, 2001; Accepted September 5, 2002.
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head flounder, we examined the monthly change in abundance of eggs in and around Funka Bay from January to March. Furthermore, annual change in hydrographic conditions was also examined.

Cushing (1973) and Cushing and Dickson (1976) discussed that the overlap between a distribution of larval production and that of their food might indicate the magnitude of the subsequent year class. Lasker (1981) found that food of first-feeding larval anchovies *Engraulis mordax* became limiting when storms or drastic upwelling occurred which diluted food aggregation. Therefore, the food availability for larvae at the initial feeding stage was thought to be important factors affecting the size of year class.

In this paper, we focus on the relation between the survival of larval flathead flounder and the various factors including spawning size and period, food condition, and hydrographic conditions.

Materials and Methods

Surveys were conducted from 1988 to 1999 by *R/V* Ushio Maru and T/S Oshoro Maru, Faculty of Fisheries, Hokkaido University in and around Funka Bay (Fig. 1). Flathead flounder eggs were collected at 6–28 stations per cruise by vertical hauls from the sea bottom to the surface with a Norpac net (45 cm in diameter, 0.33 mm mesh size) or a plankton net (80 cm in diameter, 0.33 mm mesh size) in 1989 and from 1991 to 1998. Samples were immediately preserved in 5% buffered formarin seawater.

Miyamoto *et al.* (1993) found that eggs were mainly distributed at surface (0 m). Although no information of the vertical distribution of the larvae was available, it was considered that flathead flounder larvae stayed within a surface layer (e.g. top 30 m) as observed with pollock larvae (Kamba, 1977; Nakatani, 1988). For this reason, seawater was sampled from the depth of 15 m with a 20 L Van Dorn bottle from 1996 to 1998. The water sample was filtered with a 40 μm mesh sieve to collect copepod nauplii which are the primary food for larval flathead flounder (Miyamoto *et al.*, 1993). Samples were also preserved in 5% buffered formalin sea water.

Flathead flounder (≧one year old) were concentrated in the central area of Funka Bay in summer (Yokoyama *et al.*, 1991). Therefore, samples to examine the year class strength were collected at several stations in the central area of the bay by bottom trawlings from late August to early September. Age was determined by counting the ring number of otolith under a binocular dissect microscope. Relative abundance of each year class was calculated as CPUE (individuals per 15 minutes hauling of experimental trawling) relative to the1987 value.

At the sampling stations, water temperature and salinity were measured with a CTD. To clarify possible relationships between water temperature and year class strength of flathead flounder, water temperatures in the center of the bay (Station 30) from 1988 to 1998 were obtained throughout a year from the "Ushio Maru Data Record of CTD Observations, Faculty of Fisheries, Hokkaido University (1988–1998)".

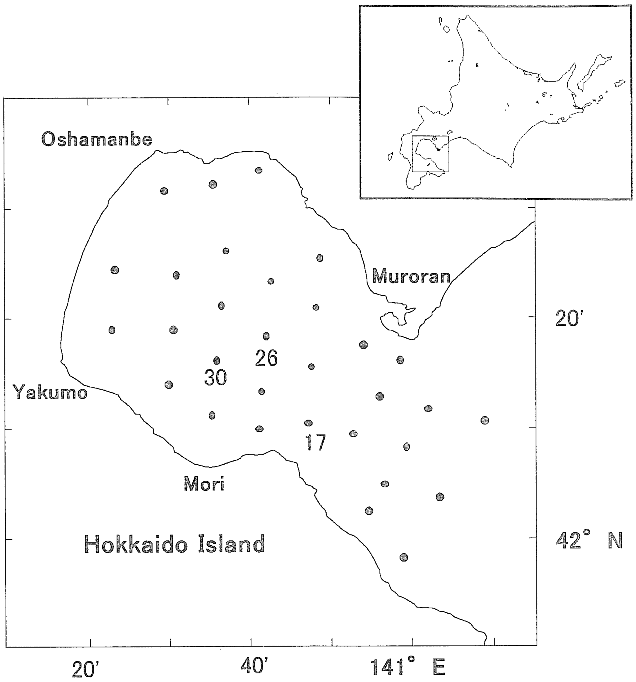

Figure 1. Position of sampling stations in and around Funka Bay.

Results

Annual change in age composition of flathead flounder

The age composition of flathead flounder in Funka Bay from 1990 to 1999 was observed (Fig. 2). It is apparent that the strong year classes occurred in 1989, 1991, and 1995. Main spawners (≧4-year-old fish) in 1991 were 4-year-old fish, while those in 1995 were 4 and 6-year-old fish.

Hydographic conditions

Figure 3 indicates the annual change in bottom water temperature in the center of the bay (Station 30) during the prespawning period (August to November) through the main spawning period (January to March). From spring to late summer, cold water (OCW) remained and then bottom water temperature was raised by the intrusion of TWW. After December, cooling and convectional mixing produce a vertically homogenous structure of the water column. Hydrographic conditions during spawning period differed among years. Temperatures in January were high in '90/'91 season (30 January; 6.74°C) and relatively warm in '94/'95 season (25 January; 5.77°C). Bottom temperatures from

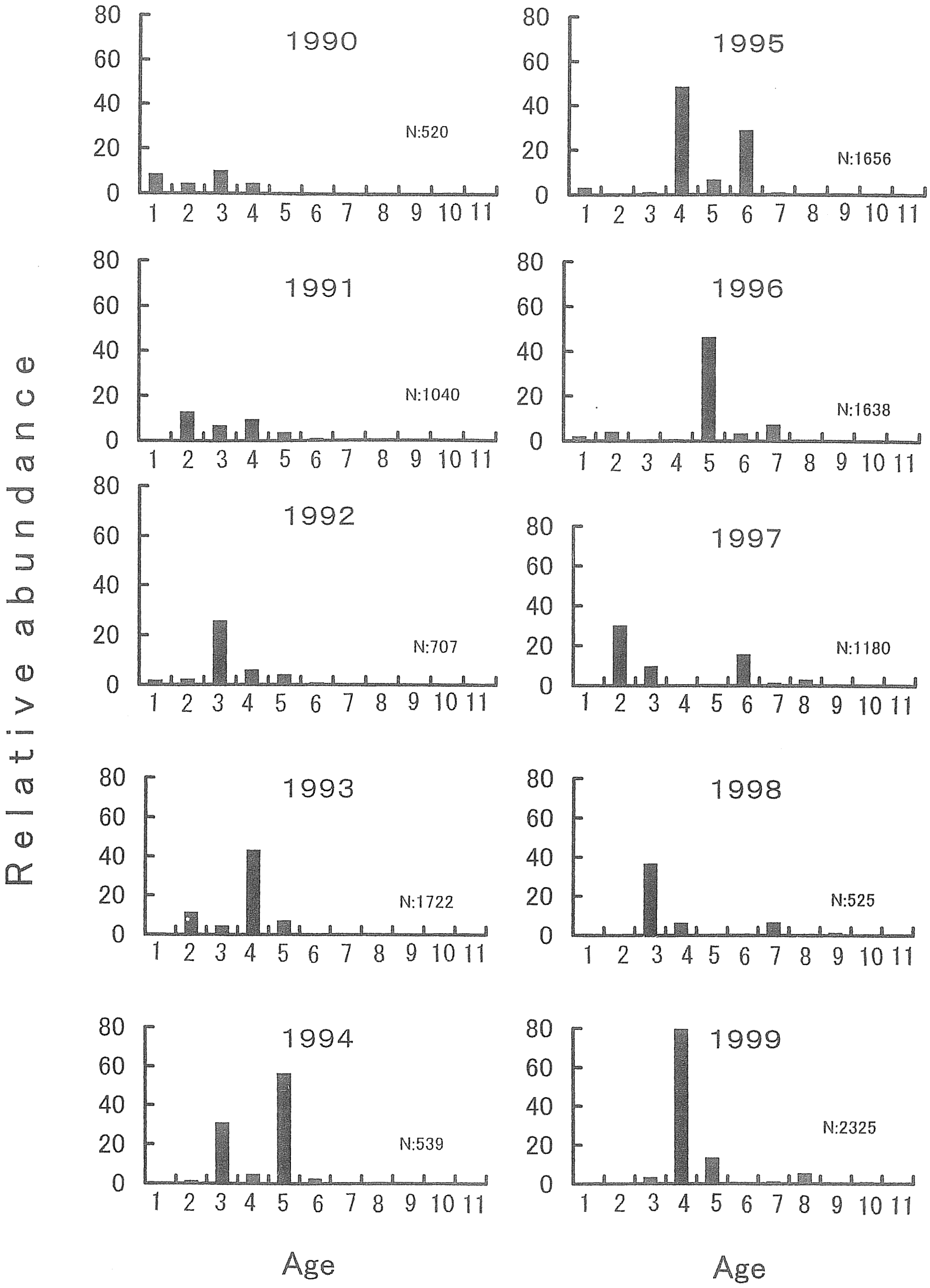

Figure 2. Age composition of *Hippoglossoides dubius* collected in Funka Bay in summer. Relative abundance was calculated as CPUE (inds./15 min. haul) relative to the 1987 value.

November to December just before spawning which may affect the gonadal maturation of flathead flounder also fluctuated among years. The highest temperature was observed in '96/'97 season (20 November; 9.03°C; 3 December; 8.99) followed by '89/'90 season (11 December; 8.73°C) and '88/'89 season (30 November; 6.17°C; 13 December; 7.65°C). While, low temperatures at the sea bottom were observed in '95/'96 season (14 November; 3.35°C; 1 December; 4.05°C) and '97/'98 season (14 November; 5.89°C).

The water temperature at the depth of 10 m in winter from 1989 to 1998 was shown in Fig. 4. All of the years, the decline of water temperatures have been observed from January to March after the intrusion of OCW. Among years,

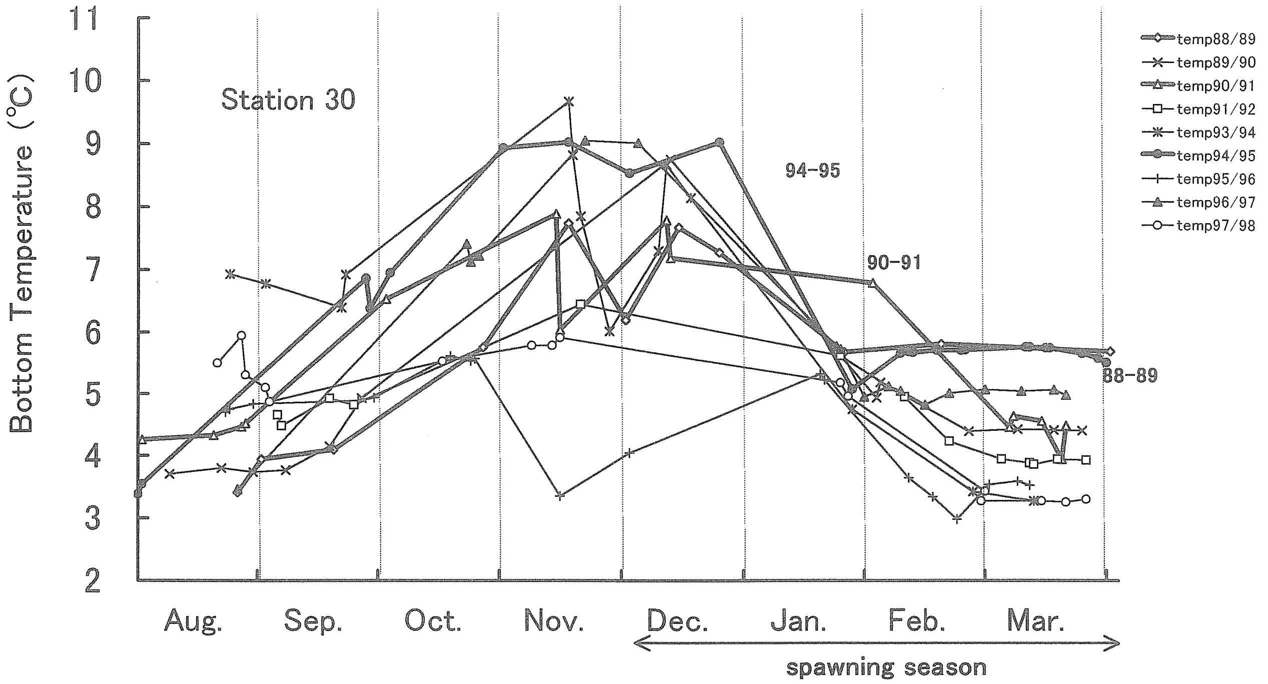

Figure 3. Bottom water temperature at Station 30 from August to March from 1988 to 1998. Bold lines corresponding to the years with strong year class.

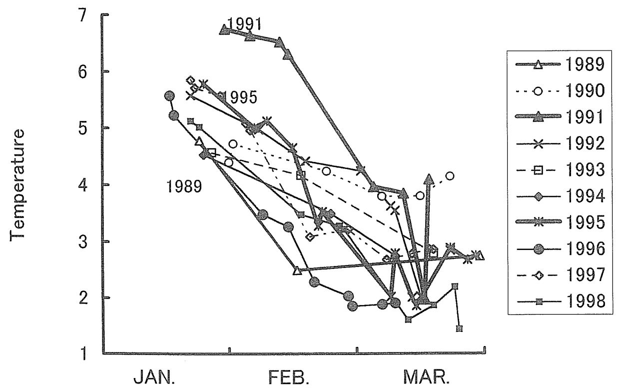

Figure 4. Winter water temperature at a depth of 10 m at Station 30 (Station 27 on 24 January 1998; Station 31 on 31 January 1990), 1988 to 1998. Bold lines corresponding to the years with strong year class.

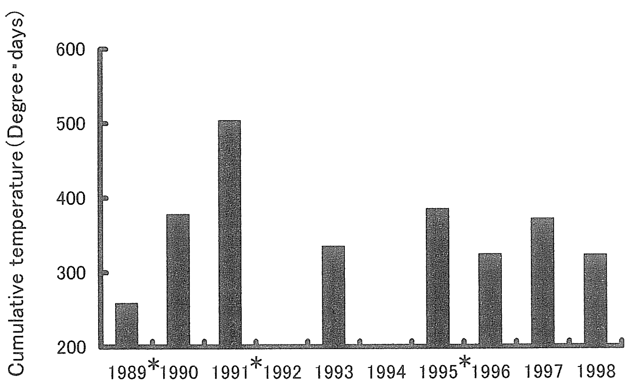

Figure 5. Cumulative water temperatures (degree・days) at the depth of 10–20 m from January to March. *: indicating the years with strong year class.

the highest temperature from January to early February was observed in 1991. To assess the impact of hydrographic conditions on the survival of flathead flounder during the early life stage, cumulative temperatures were calculated (Fig. 5). These values were obtained from mean water temperature from 10 to 20 m depth multiplied by the number of days corresponding to the duration between mid-days of two measurements. These values were considered as an indicator of cumulative temperature experienced during the ichthyoplanktonic stage of flathead flounder from January to March. Cumulative temperatures at a depth of 10–20 m ranged from 257.8 (°C・days) in 1989 to 502.6 (°C・days) in 1991. In 1995, the cumulative temperature is as high as 384.5 (°C・days).

Monthly change in abundance of the eggs

To confirm the spawning period, the monthly change in the abundance of eggs was examined. In winter 1989 and from 1991 to 1998, flathead flounder eggs were collected in and around the mouth of Funka Bay (Table 1). In 1989, a high abundance of eggs was found from January to March. The peaks of the egg abundance in January were observed in

Table 1. Annual change in abundance of *Hippoglossoides dubius* eggs (inds·m^{-2}) from January to March in and around Funka Bay. Figures in parentheses indicate the numbers of samples.

Year	January				February				March			
	First quartile	Median	Third quartile		First quartile	Median	Third quartile		First quartile	Median	Third quartile	
*1989	0.00	12.58	23.58	(18)	0.00	6.29	17.29	(18)	0.00	6.29	20.43	(28)
*1991	0.00	3.15	11.01	(14)	0.00	0.00	1.57	(8)	0.00	0.00	0.00	(19)
1992	0.00	0.00	0.00	(19)	0.00	0.00	0.00	(10)	0.00	0.00	0.00	(10)
1993	0.00	0.00	0.00	(7)	0.00	0.00	0.00	(13)	0.00	0.00	0.00	(9)
1994	0.00	0.00	0.00	(12)	3.15	6.29	6.29	(4)	0.00	0.00	9.44	(11)
*1995	1.99	9.95	25.37	(12)	5.97	8.95	12.43	(20)	1.49	2.98	3.98	(8)
1996	0.00	0.00	1.50	(6)	6.00	23.90	39.80	(13)	8.00	11.90	15.90	(7)
1997	1.50	19.90	68.18	(12)	0.50	3.00	5.00	(6)	0.00	1.00	2.00	(16)
1998	4.00	8.95	16.90	(6)	0.00	3.00	6.00	(19)	12.40	35.80	58.20	(15)

* the years with strong year classes.

1991 and 1997. In 1995, many eggs were collected from January to February and then decreased in March. In contrast, the peak abundance in 1998 was found in March. A low abundance of the eggs was observed in 1992 and no eggs were collected in winter in 1993. Figure 6 indicates the relationship between the annual commercial catch in tons of flathead flounder by bottom gill net in the inner area of Funka Bay and the egg abundance in the following year (maximum of medians from January to March). Most of commercial catch are considered as spawners. Obviously the egg abundance correlates the size of spawning stock (Spearman's rank correlation coefficient, $r_s=0.703$, $P<0.05$, $n=10$). However, no specific pattern is observed between egg abundance and year class strength.

Annual change in food availability of larval flathead flounder at the initial feeding stage

To assess the availability of larval food, copepod nauplii, which were primary foods for the larvae at the initial feeding stage (Miyamoto *et al.*, 1993), samples were collected at the depth of 15 m in the inner area of the bay (Station 26 and 30), where flathead flounder larvae were distributed (Table 2). In general, a low density of copepod nauplii was found in January. The concentration of nauplii increases after the intrusion of OCW. After the phytoplankton bloom, a high density of nauplii occurred in late March. In contrast, many copepod nauplii were collected in January and then decreased from February to March in 1997. In 1993, low densities of copepod nauplii from January to March were observed. As stated before, strong year classes were produced in 1991 and 1995. Densities of copepod nauplii ranged from 7.8 to 18.1 individuals·l^{-1} in 1991 and from 12.3 to 35.1 individuals·l^{-1} in 1995, respectively. In 1994 and 1996, copepod nauplii were also abundant.

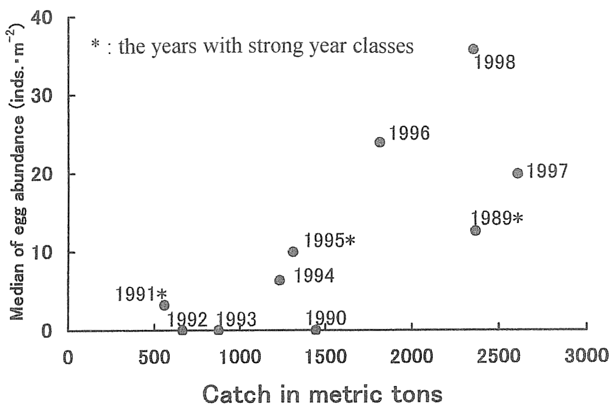

Figure 6. Relationship between the annual commercial catch (tons) and the abundance of flathead flounder eggs (median, individuals·m^{-2}) from 1989 to 1989.

Discussion

In Funka Bay, many flathead flounder eggs were collected from January to March. Their abundance correlates to the commercial catch in the inner area of the bay (Fig. 6). However, as shown in Fig. 6, it is considered that the fecundity of flathead flounder is not the main factor to determine the resultant year class strength in this area.

As shown in Table 1, the main spawning period of flathead flounder in Funka Bay largely differed among years from January to March. The eggs were mostly collected in January in 1997. Judging from the age composition (Fig. 2), the main spawners in 1997 were 6-year-old fish. A high water temperature at the sea bottom (8.99°C on 3 December 1996) was observed just before spawning. The early spawnings were also observed in 1989 and 1991, and water temperatures at the sea bottom just before spawning were

Table 2. Density of copepod nauplii (indiv $\cdot l^{-1}$) collected at a depth of 15 m at St. 30.

Year	January	February	mid March	late March
1991*1	7.8 (Station 26)	18.1 (Station 26)	12.9 (Station 26)	no-data
1993*2	3.9	5.9	7.7	no-data
1994*2	13.1	15.2	18.4	37.2
1995*2	12.3	12.4	17.0	35.1
1996	13.8 (Station 17)	17.2	22.4	no-data
1997	9.7	5.6	2.3	no-data
1998	6.0	4.3	14.4	no-data

*1 Nakatani (1995).
*2 Sugimoto, unpublished data.

relatively high (7.65°C on 13 December 1988; 7.16°C on 11 December 1990). While in 1996, the eggs were collected mostly in February and March. The main spawners of this year were 5-year-old fish followed by 7-year-old fish. The bottom temperature in December 1995 was as low as 4.05°C. The main spawners in 1991 were 4-year-old fish and many eggs were collected in January. In contrast, the main spawners in 1998 were 7-year-old fish (1991 year class). In this year, many eggs were collected in March. The bottom water temperature just before spawning was low (5.89°C on 14 November 1997) compared with that in 1996. From these results, it is considered that there is no relation between the spawning period and the age of main spawners. However, it is considered that the relatively warm water at the sea bottom just before spawning affects the spawning period of flathead flounder in Funka Bay.

Miyamoto *et al.* (1993) observed the food contents of larval flathead flounder and found that copepod nauplii were the primary food. As shown in Table 2, a small fluctuation of the density of copepod nauplii was found in January (6.0–13.8 individuals $\cdot l^{-1}$) except in 1993 (3.9 individuals $\cdot l^{-1}$). In February of 1991, 1994,1995 and 1996, high concentrations were observed. Compared with the food availability between 1994 and 1995, the densities of copepod nauplii were quite similar from January to March. However, a strong year class did not occur in 1994. These results indicate that the high abundance of copepod nauplii does not always result in the strong year class of flathead flounder in Funka Bay.

In order to investigate the hydrographic conditions during the early life stage of flathead flounder, surface temperatures (10 m depth) were compared among years (Fig. 4). Relatively warm water from January to February were observed in 1991, 1995, and 1997. Cumulative temperatures from January to March in 1991 and 1995 were also high (Fig. 5). Isoda *et al.* (1998) analyzed that the hydrographic conditions in winter from 1974 to 1994 and found warm surface water in early winter in 1980, 1983, 1990, and 1991. As stated before, the strong year classes occurred in 1980, 1983 (Nakatani *et al.*, 1990), and 1991. Paul (1983) found that the water temperature appeared to be relatively important in determining the percent of larval pollock, *Theragra chalcogramma*, which initiated feeding. Bailey (2000) described that the instantaneous mortality rate of larval pollock is inversely correlated with sea-surface temperature (SST) during the early feeding period. Therefore, it can be considered that the relatively warm water results in a high survival of larval flathead flounder at the initial feeding stage, though the abundances of larval flathead flounder could not be compared among years because a very few numbers of specimen have been collected. However, the strong year class of flathead flounder was also produced in the cold winter in 1989. In this year, the early intrusion of OCW was observed. Before the intrusion of this water in December, the high water temperature was found in the surface layer (8.12°C, on 13 December 1988). From the results, it can be concluded that the high water temperature in early winter and the early spawning may reduce the mortality of flathead flounder during the early life stages in Funka Bay.

Acknowledgements

The authors are grateful to Dr. Napp, Alaska Fisheries Science Center/NOAA for critical reading and many useful comments. Our thanks go to Nagaya, Umezaki and Ide, students of Faculty of Fisheries, Hokkaido University for counting copepod nauplii. The authors would like to thank the members of **HUBEC** (**H**okkaido **U**niversity, su**B**-arctic **E**cosystem dynamics & **C**limate) and students of our laboratory for field samplings. Thanks are also due to the captain and the crew of the *R/V* Ushio Maru and T/S Oshoro Maru for their kind assistance.

References

Bailey, K.M. (2000) Shifting control of walleye Pollock *Theragra chalcogramma* after a major climatic and ecosystem change.

Mar. Ecol. Prog. Ser., **198**, 215–224.

Cushing, D.H. (1973) The natural regulation of fish populations. In. Sea Fisheries Research, ed. F.R.H. Jones, 399–411.

Cushing, D.H. and R.R. Dickson (1976) The biological responsein the sea to climatic changes. Adv. Mar. Biol., **14**, 1–122.

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

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

Lasker, R. (1981) Factors contributing to variable recruitment of the northern anchovy (*Engraulis mordax*) in the California current: contrasting years, 1975 through 1978. Rapp. P.-v. R_un. Cons. Int. Explor. Mer, **178**, 375–388.

Miyamoto, T., T. Takatsu, T. Nakatani, T. Maeda and T. Takahashi (1993) Distribution and food habit of eggs and larvae of *Hippoglossoides dubius* in Funka Bay and its offshore waters, Hokkaido. Bull. Japan. Soc. Fish. Oceanogr., **57**, 1–14 (in Japanese with English abstract).

Nakatani, T. (1988) Studies on the early life history of walleye pollock *Theragra chalcogramma* in Funka Bay and vicinity, Hokkaido. Mem. Fac. Fish. Hokkaido Univ., **35**, 1–46.

Nakatani, T., H. Koizumi, S. Yokoyama, T. Maeda, T. Takahashi, H. Matsushima (1990) Age and growth of Pleuronectid flounder *Hippoglossoides dubius* in Funka Bay, Hokkaido. Nippon Suisan Gakkaishi, **56**, 893–901. (in Japanese with English abstract)

Nakatani, T. (1995) 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.

Ohtani, K. and Y. Akiba (1970) Studies on the change of 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 the Funka Bay II. Characteristics of the waters occupying the Funka Bay. Bull. Fac. Fish. Hokkaido Univ., **22**, 58–66. (in Japanese with English abstract)

Ohtani, K. and K. Kido (1980) Oceanographic Structure in Funka Bay. Bull. Fac. Fish. Hokkaido Univ., **31**, 84–114. (in Japanese with English abstract)

Paul, A. J. (1983) Light, temperature, nauplii concentrations, and prey capture by first feeding pollock larvae *Theragra chalcogramma*. Mar. Ecol. Prog. Ser., **13**, 175–179.

Yokoyama, S., T. Maeda, T. Takahashi, T. Nakatani, T. Takahashi and H. Matsushima (1989) Temporal and spatial distributions of demersal fish in Funka Bay and offshore, Hokkaido. Bull. Fac. Fish. Hokkaido Univ., **40**, 8–21. (in Japanese with English abstract)

Yokoyama, S., T. Maeda, T. Takahashi, T. Nakatani, T. Takahashi and H. Matsushima (1991) Annual life cycle of Adult *Hippoglossoides dubius* in Funka Bay, Hokkaido. Nippon Suisan Gakkaishi, **57**, 1469–1476. (in Japanese with English abstract)

Ushio Maru Data Record of CTD Observations (1988–1998) Fac. Fish. Hokkaido Univ. (in Japanese)

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噴火湾におけるアカガレイ年級群強度の変動要因

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アカガレイ *Hippoglossoides dubius* は噴火湾における産業的重要種であり，顕著な年級群変動を示すことが知られており，1980年および1983年に卓越年級群が発生している．年級群強度を決定する要因を明らかにする目的で，1989年から1999年までの期間，噴火湾においてアカガレイを採集し，海洋環境を測定した．調査期間中，卓越年級群は1989，1991，および1995年に発生した．これらの年において年級群強度と産卵群の来遊量および産み出された卵の豊度との間に相関がみられないことから，当海域において年級群強度の決定に産卵来遊量および産卵量は大きな影響を及ぼさないと考えられる．摂餌開始期の仔魚の主要餌生物である橈脚類ノープリウスの豊度は1月から3月にかけて増加するが，その逆の年も認められた．橈脚類ノープリウスの豊度と年級群強度との関係から，生活史初期の餌生物環境が年級群強度を支配しているとは考えられない．調査期間中，産卵盛期は1月から3月まで変化しており，産卵直前の11月から12月にかけての海底水温が高い年には産卵期が早くなる傾向が確認された．卓越年級群が発生した年の産卵盛期はいずれも1月で，1月の表層水温は1991年で高く，1995年も比較的暖かかったが，1989年は低かった．過去の調査結果から卓越年級群が発生した1980年および1983年も冬期間の表層水温が高かったことから，摂餌開始期仔魚にとって水温が高いことが生き残りに重要な影響を持つと考えられる．1989年は沿岸親潮の流入が早く，1月の水温が低かったが，前年12月の水温が高かったことから，早期に産み出された仔魚の生き残りが高かったのではないかと予想される．

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