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Distribution of chaetognaths in the Japan Sea in the winter of 1997 and in the autumn of 1999

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Abstract—There was no remarkable difference of chaetognath biomass among station in winter (10.6 mg/m^3 in mean) in the Japan Sea. Biomass in autumn ranged from 1.4–45.4 mg/m^3 (16.1 mg/m^3 in mean) and high biomass was recognized in southern Japan Sea below than 38°N. Two genera ten species was collected in the autumn 1999. Warm water species were not collected in the winter 1997. Many warm water species were transported into the Japan Sea from the south by the Tsushima Current in the autumn and distributed in wide waters of the middle Japan Sea. The proportion of the number of sampling stations located in mixed water and warm water was 75.8% but 11.1% in the winter. *Sagitta elegans* was the dominant species and distributed below the thermocline in autumn and winter but abundance was high in the 0–100 m layer in the northern Japan Sea where the surface layer was not coveved by Tsushima Current water.

Key words: Japan Sea, chaetognath, biomass, distribution

Introduction

The Japan Sea is a semi-isolated marginal sea with an average depth of 1350 m and a maximum water depth of approximately 3700 m in the northern basin. It is connected with the Sea of Okhotsk, the North Pacific and the East China Sea through 4 shallow straits. The only important current flowing into the Japan Sea today is the Tsushima Current, a branch of the warm Kuroshio Current, which enters through Tsushima Strait between Kyushu and Korea and flows out to Pacific through Tsugaru Strait and Soya Strait. Water of Japan Sea proper occupies the deeper parts of the Japan Sea (below 200 m) and is characterized by low temperature (0.1–0.3°C), low salinity (34.0–34.1 PSU) and high dissolved oxygen contents (Zenkevitch 1963).

Sixteen species of pelagic chaetognaths in 3 genera have been reported from the Japan Sea (Kitou 1974), there are many reports that describe the distribution of these pelagic chaetognaths (Park 1970; Terazaki and Marumo1979; Kotori and Kobayashi 1979; Terazaki 1993a, 1993b; Nishihama et al. 1995; Nishihama and Hirakawa 1997, 1998). However, we have no data for the winter season. Fortunately, zooplankton surveys were carried out at 18 stations during the winter of 1997 and also at 33 stations during autumn 1999 in the eastern Japan Sea.

The object of this study is to compare the horizontal and vertical distribution of chaetognaths between winter and autumn in the Japan Sea.

Materials and Methods

Samples were collected with a NORPAC net (mouth diameter 0.45 m; 333 μm mesh: Motoda 1957), an ORI-VMPS (Vertical Multiple Plankton Sampler); aperture of 50 cm×50 cm; 330 μm mesh: (Terazaki and Tomatsu 1997) and a MOCNESS-1 (1 m×1 m; 333 μm mesh: Wiebe et al. 1976) during the Japan Sea Expedition of the R/V Kaiyou Maru, Japan Fisheries Agency and the KH-99-4 Cruise of the R/V Hakuho Maru, Ocean Research Institute, University of Tokyo (Table 1). The NORPAC net was used to collect 18 samples from 500 m to the surface in the winter of 1997 and 33 samples from 200 m to surface in the autumn of 1999. When bottom depth was less than 500 m or 200m, the net was hauled from near the bottom. A flowmeter was installed at the mouth of the net to estimate the volume of water filtered. MOCNESS-1 was used to collect samples from 16 different stratums; 0–10, 10–20, 20–30, 50–75, 75–100, 100–150, 150–200, 200–300, 300–400, 400–500, 500–600, 600–700, 700–800, 800–900 and 900–1000 m at Stations C8, I9, J7 in

Table 1. Zooplankton sampling records in the Japan Sea.

Station	Lat. (N)	Log. (E)	Date	Net	Sampling layer (m)
B4	40–35	139–00	9 Jan. 1997	NORPAC	0–500
C1	40–35	137–00	10 Japn. 1997	NORPAC	0–500
C4	41–30	137–00	10 Japn. 1997	NORPAC	0–500
C6	42–00	137–15	10 Japn. 1997	NORPAC	0–500
C8	42–30	137–30	11 Japn. 1997	MOCNESS	0–10, 10–20, 20–30, 50–75, 75–100, 100–150, 150–200, 200–300, 300–400, 400–500, 500–600, 600–700 700–800, 800–900, 900–1000 (day and night)
C10	43–00	137–50	12 Jan. 1997	NORPAC	0–500
C12	43–30	138–10	12 Jan. 1997	NORPAC	0–500
C14	44–00	138–30	12 Jan. 1997	NORPAC	0–500
G1	39–30	139–30	15 Jan. 1997	NORPAC	0–500
G8	39–40	135–00	17 Jan. 1997	NORPAC	0–500
H1	39–20	134–20	17 Jan. 1997	NORPAC	0–500
H2	39–20	135–00	17 Jan. 1997	NORPAC	0–300
H3	38–45	137–41	17 Jan. 1997	NORPAC	0–450
I2	38–30	138–00	23 Jan. 1997	NORPAC	0–500
I8	38–30	135–00	24 Jan. 1997	NORPAC	0–500
I9	39–00	135–00	24 Jap. 1997	MOCNESS	0–10, 10–20, 20–30, 50–75, 75–100, 100–150, 150–200, 200–300, 300–400, 400–500,500–600, 600–700, 700–800, 800–900, 900–1000 (day and night)
J2	35–45	132–20	26 Jan. 1997	NORPAC	0–200
J7	37–00	131–30	26–27 Jan. 1997	MOCNESS	0–10, 10–20, 20–30, 50–75, 75–100, 100–150, 150–200, 200–300, 300–400, 400–500, 500–600, 600–700, 700–800, 800–900, 900–1000 (day and night)
D1	40–31	139–30	26 Sept. 1999	NORPAC	0–200
D3	41–30	138–30	26 Sept. 1999	NORPAC	0–200
D5	41–30	138–00	27 Sept. 1999	NORPAC	0–200
D6	41–30	137–00	27 Sept. 1999	NORPAC	0–200
A2	42–10	137–30	27 Sept. 1999	NORPAC	0–200
A4	42–50	138–00	28 Sept. 1999	NORPAC	0–200
A6	43–30	138–30	28 Sept. 1999	NORPAC	0–200
A8	44–10	139–00	28 Sept. 1999	NORPAC	0–200
A11	44–50	139–30	29 Sept. 1999	NORPAC	0–200
S1	45–25	140–25	29–30 Sept. 1999	NORPAC	0–200
				VMPS	0–50, 50–100, 100–200, 200–300, 300–400, 400–500 (3 times)
B3	43–30	140–00	1 Oct. 1999	NORPAC	0–200
S3	42–50	138–17	2 Oct. 1999	NORPAC	0–200
C3	42–30	139–00	2 Oct. 1999	NORPAC	0–200
S5	40–00	137–00	4–5 Oct. 1999	NORPAC	0–200
				MOCNESS	0–10, 10–20, 20–30, 50–75, 75–100, 100–150, 150–200, 200–300, 300–400, 400–500, 500–600, 600–700, 700–800, 800–900, 900–1000 (day and night)
E2	40–00	138–00	6 Oct. 1999	NORPAC	0–200
E4	40–00	139–00	6 Oct. 1999	NORPAC	0–200
F4	39–00	138–05	12 Oct. 1999	NORPAC	0–200
F7	39–40	137–20	12 Oct. 1999	NORPAC	0–200
G3	39–47	136–24	14 Oct. 1999	NORPAC	0–200
G6	39–36	135–49	14 Oct. 1999	NORPAC	0–200
S6	39–00	134–00	15 Oct. 1999	NORPAC	0–200
H4	38–44	134–54	16 Oct. 1999	NORPAC	0–200
H8	37–52	135–01	17 Oct. 1999	NORPAC	0–200
H11	37–06	136–01	17 Oct. 1999	NORPAC	0–200
H13	36–36	136–20	18 Oct. 1999	NORPAC	0–200
S9	37–15	134–26	18 Oct. 1999	NORPAC	0–200
J4	38–16	133–43	19 Oct. 1999	NORPAC	0–200
J7	37–43	133–31	19 Oct. 1999	NORPAC	0–200
J10	37–11	133–21	19 Oct. 1999	NORPAC	0–200
J14	36–26	133–04	20 Oct. 1999	NORPAC	0–200
J18	35–43	132–49	20 Oct. 1999	NORPAC	0–200
K1	35–00	131–15	20 Oct. 1999	NORPAC	0–200
T1	34–13	129–24	21 Oct. 1999	NORPAC	0–90

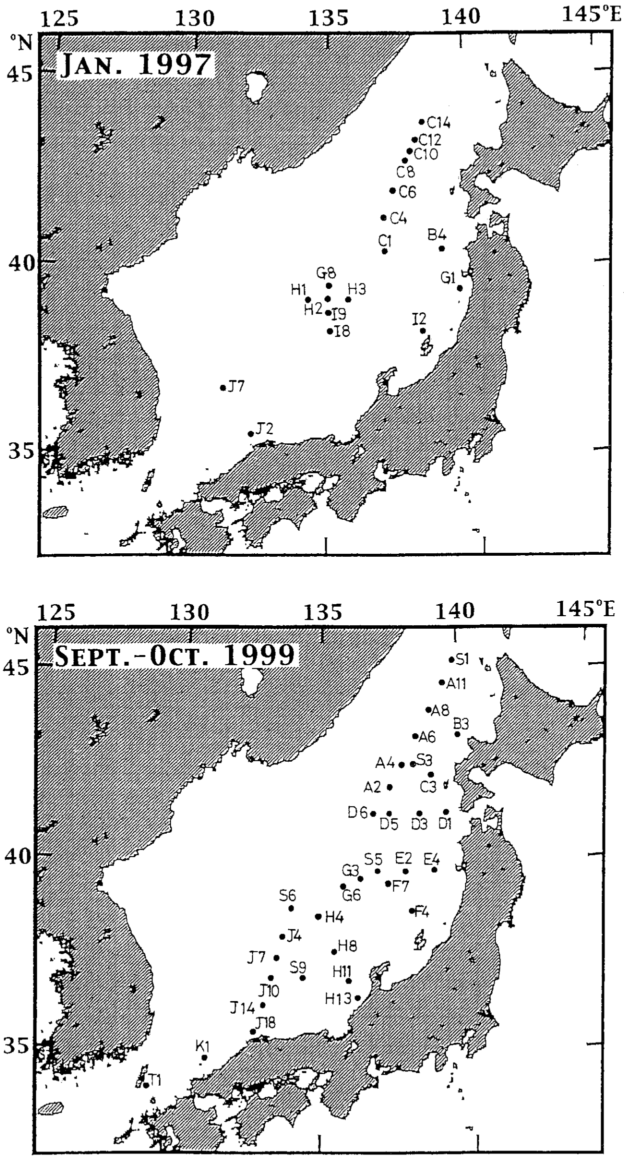

Fig. 1. Maps of sampling stations in the Japan Sea.

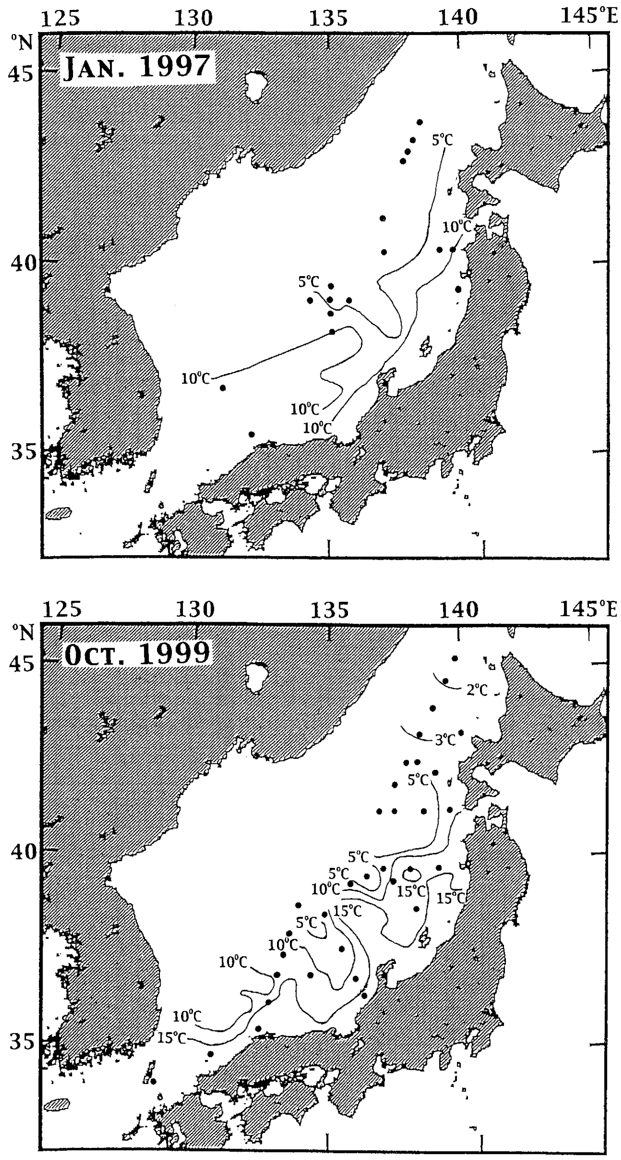

Fig. 2. Contours of isotherm (°C) at 100 m depth in January 1997 and October 1999.

the winter and S5 in the autumn (Fig. 1). Time series samples with the ORI-VMPS were conducted at S1 on 29–30 September during the KH-99-4 cruise and sampled 5 different stratums; 0–50, 50–100, 100–200, 200–300, 300–400 and 400–500 m. Water temperature and salinity data was collected by CTD casts at each station.

Samples were fixed with a 10% buffered formalin and seawater solution. Chaetognaths were separated out and sorted to species after measuring the wet weight.

Results

Hydrographic condition

Countours of isotherm (°C) at 100 m depth in January 1997 showed the warm water mass caused by the Tsushima Current existed in the southern Japan Sea and in coastal waters along the mainland of Japan. On the other hand, hydrographic conditions in autumn 1999 were more complex due to the meandering of the Tsushima Current. Warm water above 10°C covered the wide area in the eastern Japan Sea (Fig. 2). Remarkable thermocline was recognized in the 0–100 m layer at S1 and S5 in autumn 1999 (Fig. 3). However the influence of the Tsushima Current at C8 was small compared with I9 and J7 in winter 1997. The Japan Sea Proper Water (below 1°C) occupied the layer below 200 m at all stations.

Chaetognath biomass

The proportion of chaetognath biomass in the total zooplankton biomass was 2.0–22.1% (11.5% in mean) in the winter 1997 and 5.1–46.5% (34.5% in mean) in the autumn 1999. Chaetognath biomass in winter ranged from 1.9–19.2 mg/m^3 (10.6 mg/m^3 in mean). There was no remarkable dif-

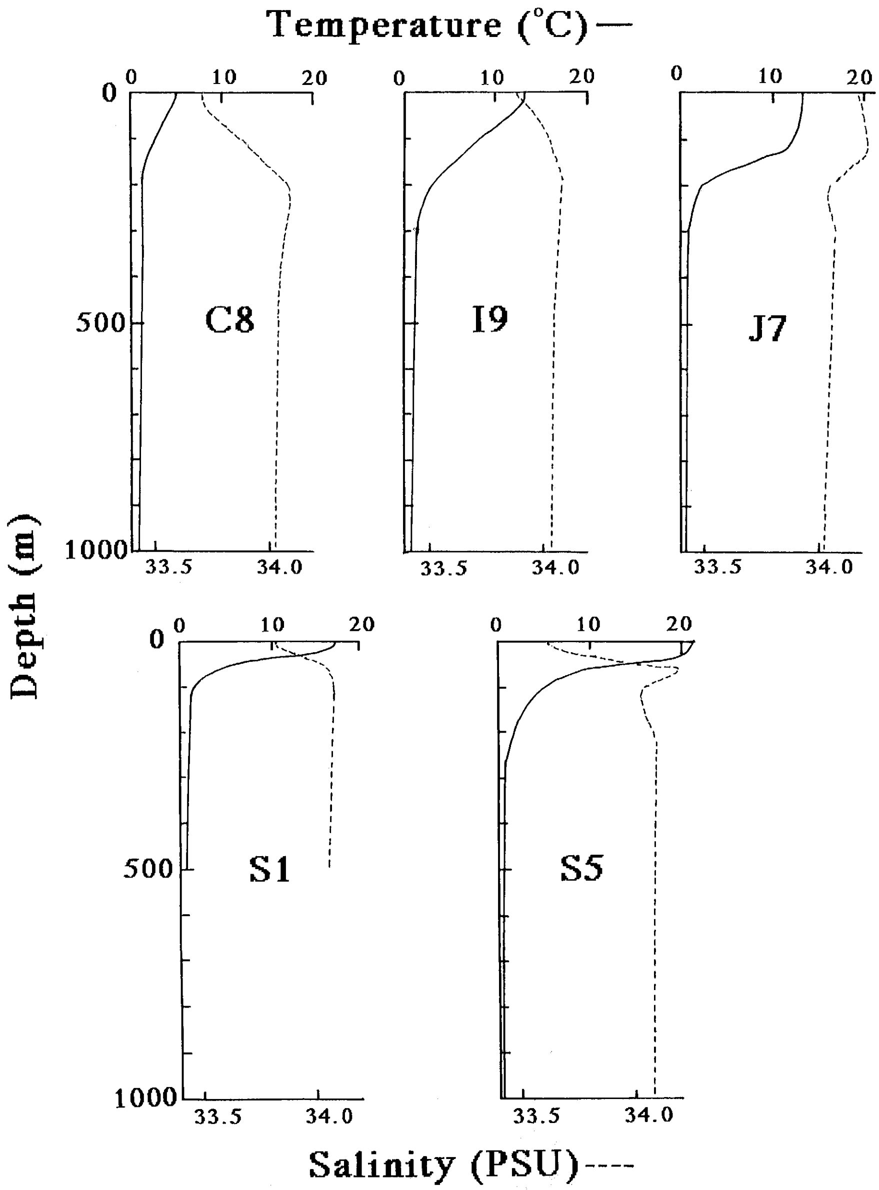

Fig. 3. Vertical profiles of water temperature (°C) and salinity (PSU) at five stations (C8, I9, J7, S1 and S5) in the Japan Sea.

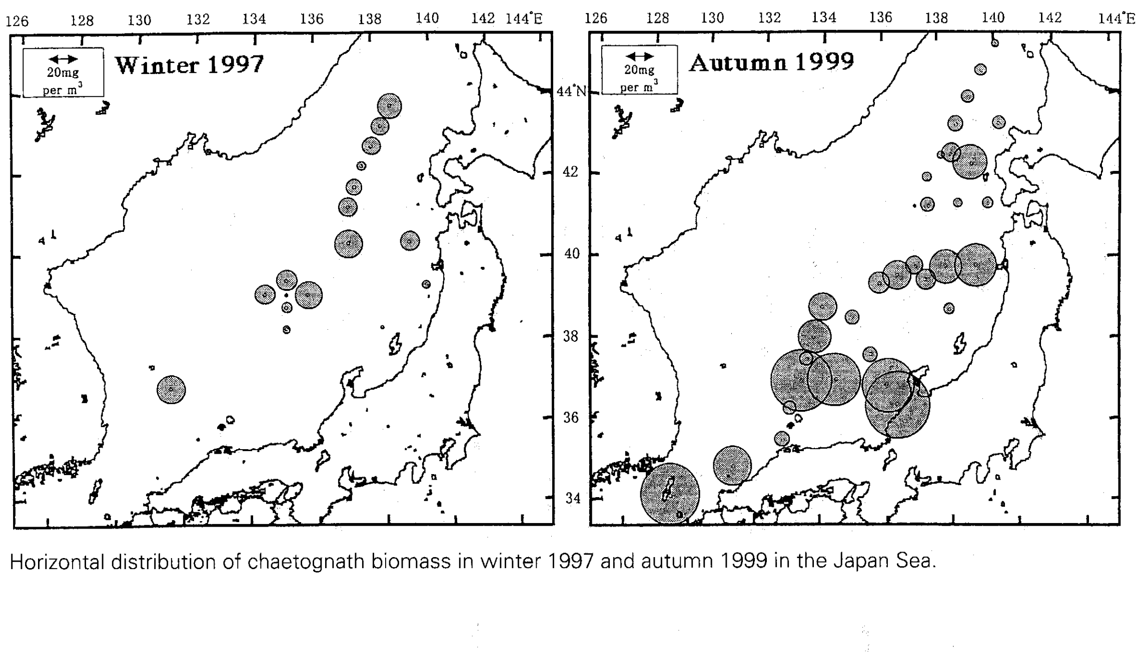

Fig. 4. Horizontal distribution of chaetognath biomass in winter 1997 and autumn 1999 in the Japan Sea.

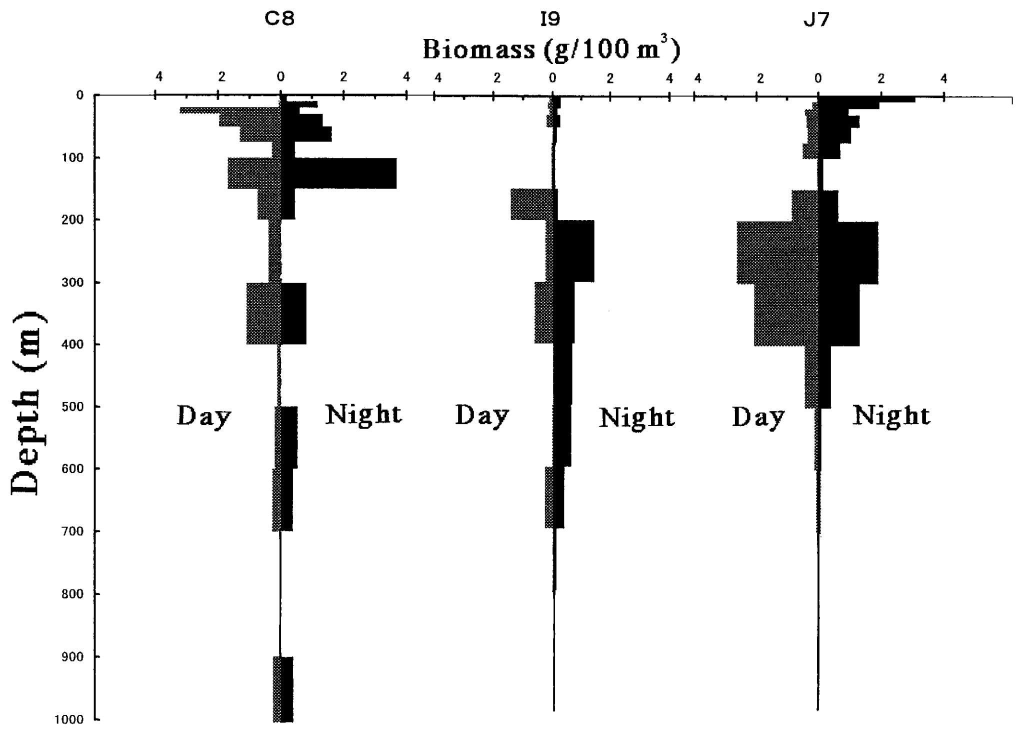

Fig. 5. Vertical distribution of chaetognath biomass at three stations (C8, I9 and J7) on January 1997 in the Japan Sea.

Table 2. Classification of sampling stations by specific composition of chaetognaths.

Water mass	Winter 1997	Autumn 1999
Cold water	B4, C1, C4, C6, C8, C10, C12, C14, G1, G8, H1, H2, H3, I8, I9, J2	D1, D3, D5, D6, A2, A4, A11, S1, S3
Mixed water	I2, J7	A6, A8, B3, C3, S5, E2, E4, F4, F7, G3, G6, S6, H4, H8, H13, S9, J4, J7, J10, J14
Warm water		H11, J18, K1, T1

ference in chaetognath biomass among stations in winter in the Japan Sea (Fig. 4). Biomass in the autumn was ranged from 1.4–45.4 mg/m^3 (16.1 mg/m^3 in mean) and high biomass was recognized below 38°N in southern Japan Sea (Fig. 4).

Chaetognath biomass was high in the epipelagic layer at station C8 and decreased with depth. But biomass was high in the upper mesopelagic layer between 200 m and 400 m in the southern Japan Sea (stations I9 and J7). Especially, high biomass was observed in the epipelagic layer at station J7 during the night (Fig. 5).

Horizontal distribution

Two species from two genera; *Sagitta elegans*, *S. minima*, *S. nagae*, *S. enflata*, *S. neglecta*, *S. regularis*, *S. pacifica*, *S. ferox*, *S. robusta* and *Pterosagitta draco*, were collected in autumn 1999. In the winter 1997, warm water species such as *S. neglecta*, *S. regularis*, *S. ferox* and *S. robusta*, were not collected. All sampling stations were classified by the occurrence of cold water species or warm water species. A single cold water species, *S. elegans* appeared at 12 stations (A2, C1, C4, C6, C8, C10, C12, C14, D3, D5, G8 and H2) during both cruises. A warm water station was defined when warm water species such as *S. enflata S. neglecta*, *S. regularis*, *S. pacifica*, *S. ferox*, *S. robusta* and *P. draco* occupied more than 50% of the total number of individuals. Mixed water station is defined when the proportion of warm and cold water species was less than 50%. There was no warm water station and all stations except stations I2 and J7, were classified as cold water area in winter 1997 (Table 2).

On the other hand, 19 stations were classified as mixed water area in autumn 1999. Nine cold water stations were located north of 40–30°N and 4 stations belonged to the coastal waters of southern mainland and Kyushu.

S. elgans was distributed in all waters of eastern Japan Sea in winter 1997 but was abundant in the northern Japan Sea in autumn 1999 and not occurred at stations E4, F7, H-13 S9, J4, J7 and K1 located in the southern Japan Sea (Fig. 6). *S. elegans* was collected from station T1 near the Tsushima Island in autumn 1999. *S. enflata* was abundant in the middle

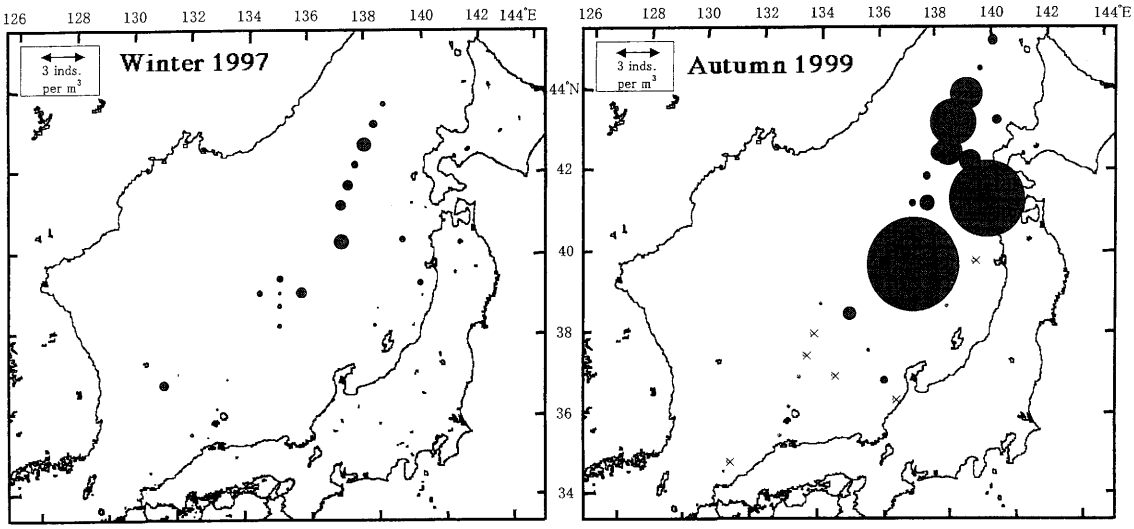

Fig. 6. Horizontal distribution of *Sagitta elegans* in winter 1997 and autumn 1999 in the Japan Sea.

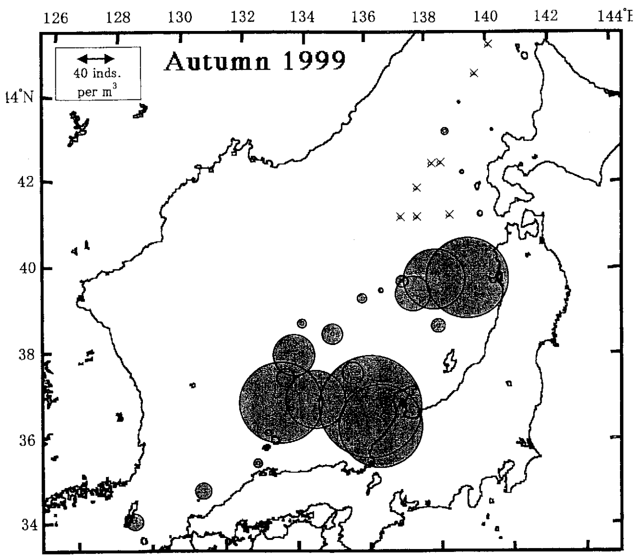

Fig. 7. Horizontal distribution of *Sagitta enflata* in autumn 1999 in the Japan Sea.

Japan Sea between 37°N and 40°N (Fig. 7). But *S. enflata* occurred at one station (J7) in winter 1997.

Vertical distribution

During autumn 1999, the maximum distribution layer of *S. nagae*, *S. enflata* and *S. neglecta* at station S5 was the upper 0–25 m layer above the thermocline where the Tsushima Current covered the surface. *S. minima* was distributed in the 0–75 m layer and abundant below 25 m depth (Fig. 8). In the winter 1997, *S. pacifica*, *S. enflata*, *S. minima*, *S. nagae* and *P. draco* were distributed mainly above the thermocline (0–100 m) at stations I9 and J7. *S. elgans* was distributed below the thermocline in autumn and winter but abundance was high in the 0–100 m layer at station C8 where the surface was not coveved by the Tsushima Current did not cover the surface (Fig. 9). Adult of *S. elegans* inhabited in the

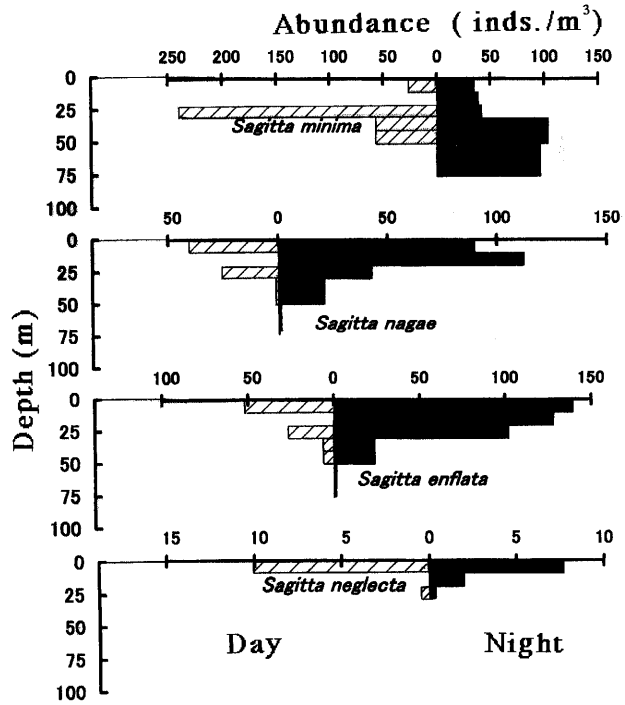

Fig. 8. Vertical distribution of *Sagitta minima*, *S. nagae*, *S. enflata* and *S. neglecta* at station S5 on 4–5 October 1999 in the Japan Sea.

deeper layers compared with juvenile or immature individuals.

Discussion

The flow of the warm current through the Tsushima Strait attains its peak in September. The warm current in the Japan Sea is estimated to be at its strongest during the period from September to October. Because the stream belts of the warm current, especially the offshore ones, are free from the stress of any uniform drift currents, they begin to meander on

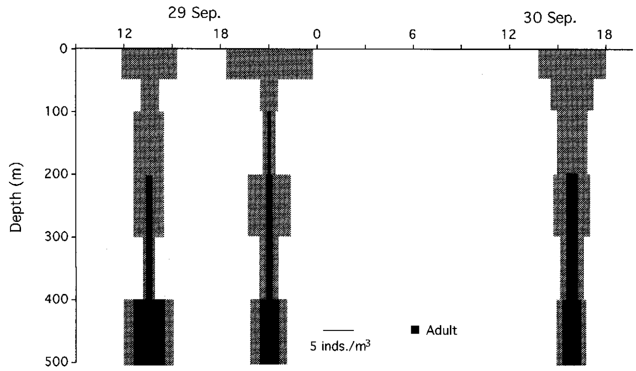

Fig. 9. Vertical distribution of *Sagitta elegans* at station C8 on 11 January 1997 in the Japan Sea.

account of the increased lateral shear imposed by a high velocity. The development of meandering brings about several cyclonic and anticyclonic eddies of large scale along either side of the warm current stream belts. The formation of several cold water and warm water areas along the main stream of the Tsushima Current are observed clearly in late summer to autumn (Terazaki 1999). The results of our survey were influenced by those complex hydrographical condition in the Japan Sea. Many warm water species such as *S. enflata*, *S. neglecta*, *S. regularis S. pacifica*, *S. ferox*, *S. robusta* and *P. draco* were transported into the Japan Sea from the south by the Tsushima Current in the autumn and distiributed in wide waters of the middle Japan Sea. The proportion of the number of sampling stations located in mixed water and warm water was 75.8% but 11.1% in the winter. According to Park (1970), *S. elegans* occurred in the Yellow Sea and we could collect this species from station T1 (90 m in depth). This fact suggests that the Japan Sea Proper Water reaches Tsushima Strait in the bottom layer. The abundance of *S. elegans* in autumn 1999 was higher than it in winter 1997. There is no remarkable seasonal variation on abundance of *S. elegans* in Yamato Bank, central Japan Sea (Nishihama et al. 1995). In Toyama Bay, the abundance of *S. elegans* was highest in the summer and low in the winter (Terazaki 1993a). The breeding season of *S. elegans* are March–May and August in Toyama Bay (Terazaki 1993a), spring in Yamato Bank (Nishihama and Hirakawa 1997) and autumn in the water off Tsugaru Peninsula (Terazaki unpubl.). There were many juvenile (less than 10 mm in body length) in samples collected in autumn 1999. It is not easy to compare the abundance of *S. elegans* between winter 1997 and autumn 1999 because of different sampling layers, but it might be suggested that high abundance in the autumn is caused by mass occurrence of juvenile after the spawning.

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