Bulletin of Plankton Society of Japan Vol. 28, No. 2, pp. 111-120, 1981

Microplankton Distribution at an Oceanic Front Formed in the Sanriku Waters off Northeast Japan[1,2]

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Abstract

Distributions of phytoplankton and tintinnid species were examined along a transverse line crossing an ocean front in the Sanriku Waters, which had been formed about 60 miles off northeast Japan. The distribution patterns of these microplankton were analysed by referring to distrbution of pollen grains simultaneously examined. The results showed that there was a fairly sharp segregation between warm water species (e. g. *Asteromphalus hookerii, Ceratium fusus,* etc.) and cold water species (e. g. *Chaetoceros concavicorne, Acanthostomella norvegica,* etc.). While some cosmopolites (e. g. *Dinophysis fortii, D. infundibulus, Eutintinnus lususundae,* etc.) occurred commonly over the entire transverse line, some coastal species (e. g. *Nitzschia seriata, Thalassiosira* sp., *Helicostomella* sp., etc.) were abundant within the mid-frontal zone. The latter species might be of neritic origins and seemed to be transported from coastal areas into the front by a jet stream predominating at the boundary zone.

The Sanriku Waters east of northern Japan is the noticeable boundary area where many well-defined fronts are formed. The two most prevailing ocean currents in the western North Pacific, the warm Kuroshio Current from the south and the cold Oyashio Current from the north, converge there throughout the year. In addition to this, the less prevailing warm Tsugaru Current flows southward in a very narrow belt along the coastline of the area. Therefore, different types of fronts such as Oyashio Front, Kuroshio Front (KAWAI 1955a) and coastal fronts are formed between these currents and their derivative cold or warm rings (MUTO 1977).

In these frontal zones, the so-called "Shiome" or current rips are generally formed. Here, plankton and other floating materials are accumulated by converging water (UDA 1938) and intensive production of plankton occurs due to local upwelling induced by eddies (PINGREE et al. 1979). However, within a boundary area, a "jet stream" flowing along a front rather than a convergence of waters and eddies is the essential water movement (KAWAI 1955b). Therefore, at an oceanic front near the coast, the seeding of rich coastal plankton community by the jet stream effectively occurs and may overwhelm the accumulation of plankton by converging waters. Admixture of different water types may have also caused the growth of such persistent coastal species within the front (cf. SAVIDGE 1976). This paper discusses the seeding effect of the coastal jet stream intruding into the frontal zone and the active growth of the seeded coastal plankton within the front.

[1] Accepted 15 December 1981
[2] 三陸沖海域に発達した潮境における小型プランクトンの分布
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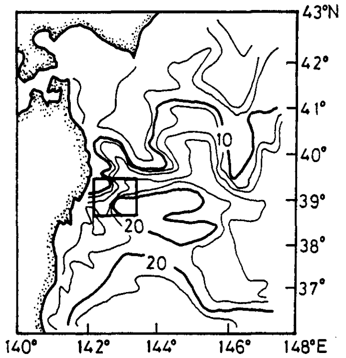
Materials and Methods

Plankton samplings and measurements of environmental factors were made in and around a sharp front in the area in June, 1979. We encountered the front on June 4 at 39°03′N and 142°30′E, and selected a 4 miles transverse sampling line crossing the front (Fig. 1). During low-speed cruising at 2.0 kts along this line, sea water was continuously pumped up from a depth of 3 m and pooled in a tank every 4 minutes as a composite sample over a 240 m, or 30 composite samples in total, were obtained from a 4 mile (7.2 km) line. The composite samples are advantageous in normalizing the deviation caused by micro-scale heterogeneity in the distribution of plankton and nutrient salts. Data on water temperature over the line were read from continuous records obtained from an under-water fluorometer (cf. WAKUI 1980) which was towed simultaneously.



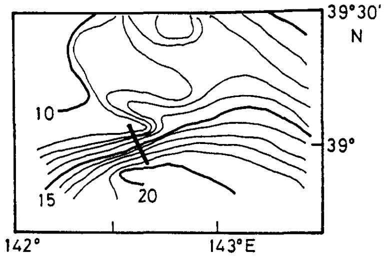


Fig. 1. Left: general pattern of isotherm distribution in the Sanriku Waters in June, 1979 (ANON. 1979) and location of the frontal area sampled (square). Right: the observation line across the front (squared area in left figure) on which samplings were made on June 4, 1979.

Three 1 liter subsamples were taken from each composite sample for determinations of (1) chlorophyll *a* crops (YENTSCH & MENZEL 1963), (2) cell number of phytoplankton and tintinnid ciliates by modified Utermöl methed (TANIGUCHI 1977), and (3) salinity and nutrient concentrations, e.g., phosphate, nitrate, nitrite, ammonia and silicate (SOLÓRZANO 1969 for ammonia; STRICKLAND & PARSONS 1968 for others).

Results

Significant changes in the physical environment were recorded across the front. Fig. 2 illustrates the sharp drop in both temperature and salinity from 16.2°C to 8.5°C and from 34.4‰ to 32.9‰, respectively, within only 1 mile at the front. From these changes, the observation line could then be subdivided into three segments, the warm water side, the cold water side and the frontal zone between these two. The first mile (Sample Nos. 1-7), the subsequent mile (Nos. 8-15) and the last 2 miles (Nos. 16-30) respectively, correspond to them.

In spite of these sharp changes in the physical properties, only a slight variation in nutrient concentrations was observed. Concentrations were at about the same level throughout the entire line, while slight irregularity was observed in the silicate concentration, and the phosphate concentration was likely to increase from warm water side to cold water side (Fig. 2). Higher values of ammonia concentrations obtained from the cold water side were due to an analytical error; washing of the flasks was insufficient.

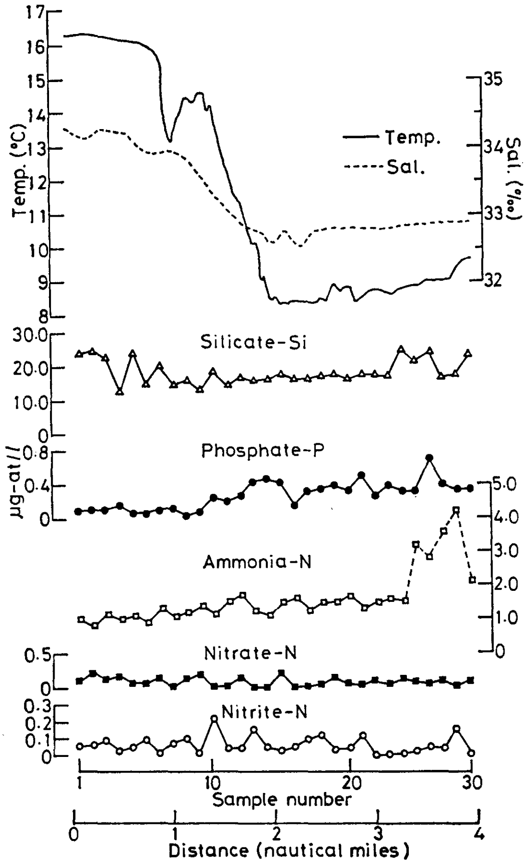


Fig. 2. Horizontal variations in temperature, salinity and concentrations of nitrate, nitrite, ammonia, phosphate and silicate on the observation line across the front.

Very large spatial variation was evident in chlorophyll *a* concentration (Fig. 3), being little higher in the warm water side (0.3 mg•m^{-3} on average) than in the cold water side (0.2 mg•m^{-3} on average), and much higher in the frontal zone (0.6-0.7 mg•m^{-3}).

Fig. 3 shows gross variation of densities of diatoms, dinoflagellates and tintinnids along the line. Diatoms predominated over the other two taxa throughout the entire line, being rich in the warm water side and poor in the cold water side but exceedingly high in the frontal zone. The abundance in the front was several times higher than those in the other sides. While *Chaetoceros concavicorne*+*C. convolutum* predominated in the cold water, *Nitzschia longissima*, *N. seriata* and small-sized (ca. 10 μm in diameter) *Thalassiosira* sp. dominated in both the warm water and the frontal zone (Fig. 4a). The dominance of the last species in the frontal zone was overwhelming. Though *C. concavicorne* is to be morphologically distinguishable from *C. convolutum*, their classification was not clear under inverted microscope. Samples obtained exhibited poor cell conditions.

Dinoflagellates tended to decrease from the warm water to the cold water (Fig. 3). *Ceratium fusus*, *C. lineatum* and *Protoperidinium trochoideum* were the leading species.

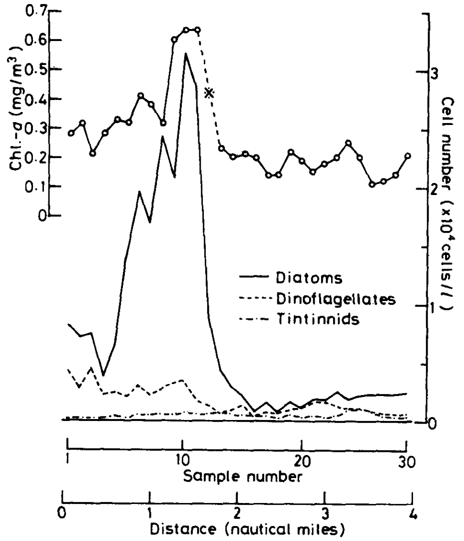
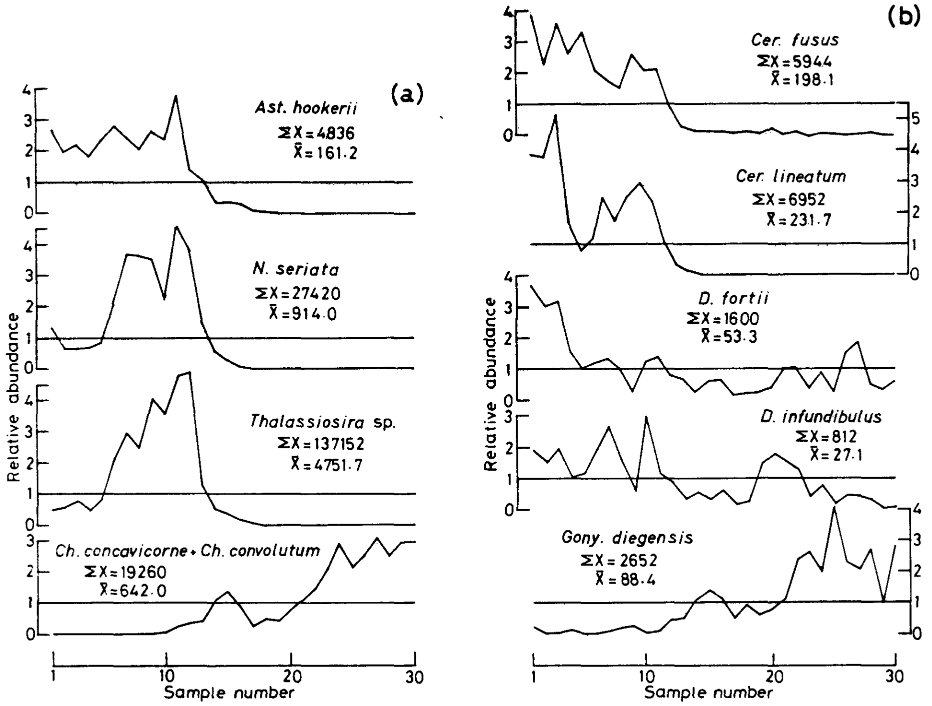


Fig. 3. Horizontal variations in chlorophyll *a* concentrations, and in total cell number of diatoms, dinoflagellates and tintinnids on the observation line across the front. ※ in chlorophyll *a* data denotes a missed sample.

Total lorica number of tintinnids had two slight peaks in the cold water side and the frontal zone (Fig. 3). *Achanthostomella norvegica* and *Parafavella jorgenseni* predominated in the cold water and *Helicostomella* sp. (cf. *sublata*) dominated in the warm water and the frontal zone (Fig. 4c).

Based on the above-mentioned distribution patterns, the dominant species could be grouped into four types as follows:

1) species which occurred abundantly in the cold water decreased gradually towards the front and finally disappeared in the warm water, 2) species exhibiting the reverse pattern, being abundant in the warm water and disappearing in the cold water, 3) common species which were evenly distributed over the entire line, and 4) species which attained their maximum density in the frontal zone. All species identified in this investigation were classified into these four types (Table 1). Most species belonging to types 1 and 2 have been generally recognized as the cold water species and the warm water species, respectively. Plankters included in type 3 have been reported to be the cosmopolites or widely distributed species



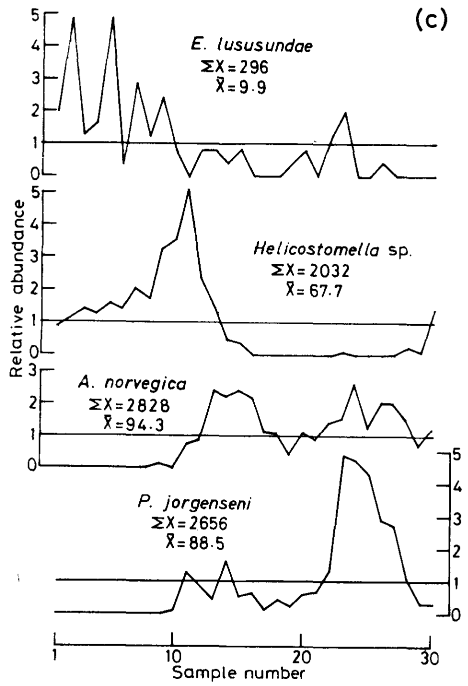


Fig. 4. Variations in the relative abundance of representative diatoms (a), dinoflagellates (b) and tintinnids (c) on the observation line across the front. ΣX and $\overline{X}$ denote total cell number summed up for the entire line (30 samples) and its average (cells l^{-1}) per sample.

over world oceans (cf. LEBOUR 1925, HADA 1937, WOOD 1954, MARUMO & AMANO 1956, KOKUBO 1975, ABÉ 1967, MARSHALL 1969). It is noticeable that most species belonging to type 4 are so-called neritic species (cf. KAWARADA et al. 1966, 1968).

TABLE 1. FOUR TYPES OF REPRESENTATIVE MICROPLANKTON SPECIES WHICH COULD BE DISTINGUISHED BY THEIR GROUPED DISTRIBUTION PATTERNS ON THE OBSERVATION LINE ACROSS THE FRONT. TYPE 1: COLD WATER SPECIES, TYPE 2: WARM WATER SPECIES, TYPE 3: COSMOPOLITES, TYPE 4: FRONTAL SPECIES.

	Diatoms	Dinoflagellates	Tintinnids
Type 1	*Asteromphalus robustus*	*Dinophysis arctica*	*Acanthostomella norvegica*
	Chaetoceros concavicorne	*Gonyaulax diegensis*	*Parafavella denticulata*
	C. convolutum	*Protoperidinium pellucidum*	*P. jorgenseni*
	Corethron hystrix		*P. obtusa*
	Denticula seminae		
Type 2	*Asteromphalus hookerii*	*Ceratium fusus*	
	Chaetoceros laciniosum	*C. lineatum*	
	Coscinodiscus oculus-iridis	*Protoperidinium claudicans*	
	C. radiatus	*P. trochoideum*	
	Lauderia borealis	*Pyrocystis lunula*	
	Rhizosolenia delicatula		
	R. hebetata f. *semispina*		
Type 3		*Dinophysis fortii*	*Eutintinnus lususundae*
		D. infundibulus	
		D. ovum	
		D. rotundata	
		Heterocapsa triquetra	
		Protoperidinium pallidum	
		P. pentagonum	
		P. roseum	
Type 4	*Asterionella glacialis*		*Favella taraikaensis*
	Eucampia zodiacus		*Helicostomella* sp. (cf. *sublata*)
	Nitzschia seriata		
	Rhizosolenia storterfothii		
	Skeletonema costatum		
	Thalassionema nitzschioides		
	Thalassiosira polychorda		
	Thalassiosira sp. (small cell)		

Discussion

Because we sampled the front near coast, all samples contained rich pollen grains, 57.7 l^{-1} on the average (Fig. 5), most of them were from pinaceous trees. Accumulation and dispersion of the pollens or non-growing floating particles are principally controlled by the water movements. It is surmised then that water movements can be determined by pollen distribution, because pollen itself does not grow in situ. However, no precise information about pollen transfer from land to sea area, floating ability and sinking rate of these pollens are available.

Nevertheless, the pollen distribution may be one of the most probable measurements of water movements as we could not measure it directly. Compared to pollen distribution, the specific distribution index (*Isd*) of dominant plankters at every sampling position (=sampling number) was calculated by an equation,

$$Isd = \frac{Xij}{Pj}$$

where Xij is relative abundance of given plankters of the ith species in the jth sample comparing to an average over the entire line of 30 samples, and Pj is the relative abundance of pollens in the jth sample. Any deviation from unity of this index can be ascribed to biological phenomena of the plankters. For instance, in areas where the plankters reproduce actively, there the index will exceed unity, and where mortalities of the plankters are high, the index will be lower than unity. If certain tintinnids regulate their distribution or navigate by themselves (cf. HARDY & GUNTHER 1935), these effects will also be reflected in this index.

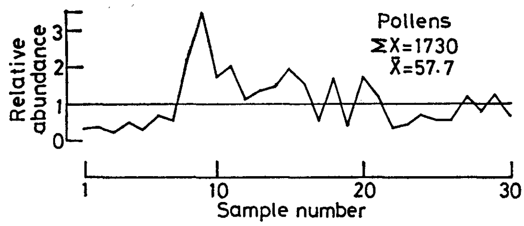


Fig. 5. Variation in the relative abundance of pollen grains on the observation line across the front. For ΣX and $\overline{\text{X}}$, see Fig. 4.

Fig. 6 illustrates the calculated indices for representative species. The positions of borders of the frontal zone coincide with sample numbers 8 and 15 (see arrows on the abscissae in Figs. 6a–d). Warm and cold water masses are on the left and the right of the front, respectively. Cold water species (type 1), e.g., *C. concavicorne*+*C. convolutum* and *Gonyaulax diegensis* (Fig. 6a) were more abundant than pollens in the cold water side and their *Isd* were less than unity in the frontal zone. Warm water species (type 2) such as *A. hookerii* and *C. fusus* (Fig. 6b) revealed the opposite tendency, *Isd* values were at the maximum in the warm water side and around unity in the frontal zone. As for cosmopolites (type 3), e.g., *D. fortii* and *E. lususundae* were observed as more or less evenly distributed over the observation line in untreated data (Figs. 4b and 4c). However, compared to the pollen distribution, it becomes clear that their specific indices, though high in both sides of the frontal zone, never exceeded unity in the frontal zone (Fig. 6c). The *Isd* values also showed that the frontal species (type 4) such as *N. seriata* and small-sized *Thalassiosira* sp. were rich in the warm water side like the type 2 warm water species but exceptionally abundant in the frontal zone (Fig. 6d).

From the above discussion, it was shown that species of types 1, 2 and 3 may be simply accumulated into the frontal zone together with pollens by water movements. These species do not have enough tolerance to sudden changes in environmental conditions within the front. However, it is most likely that type 4 species transported from the coast by a jet stream, which are essentially neritic species and may be tolerant enough, could be predominating in the frontal zone due to active growth and reproduction instead of physical accumulation.

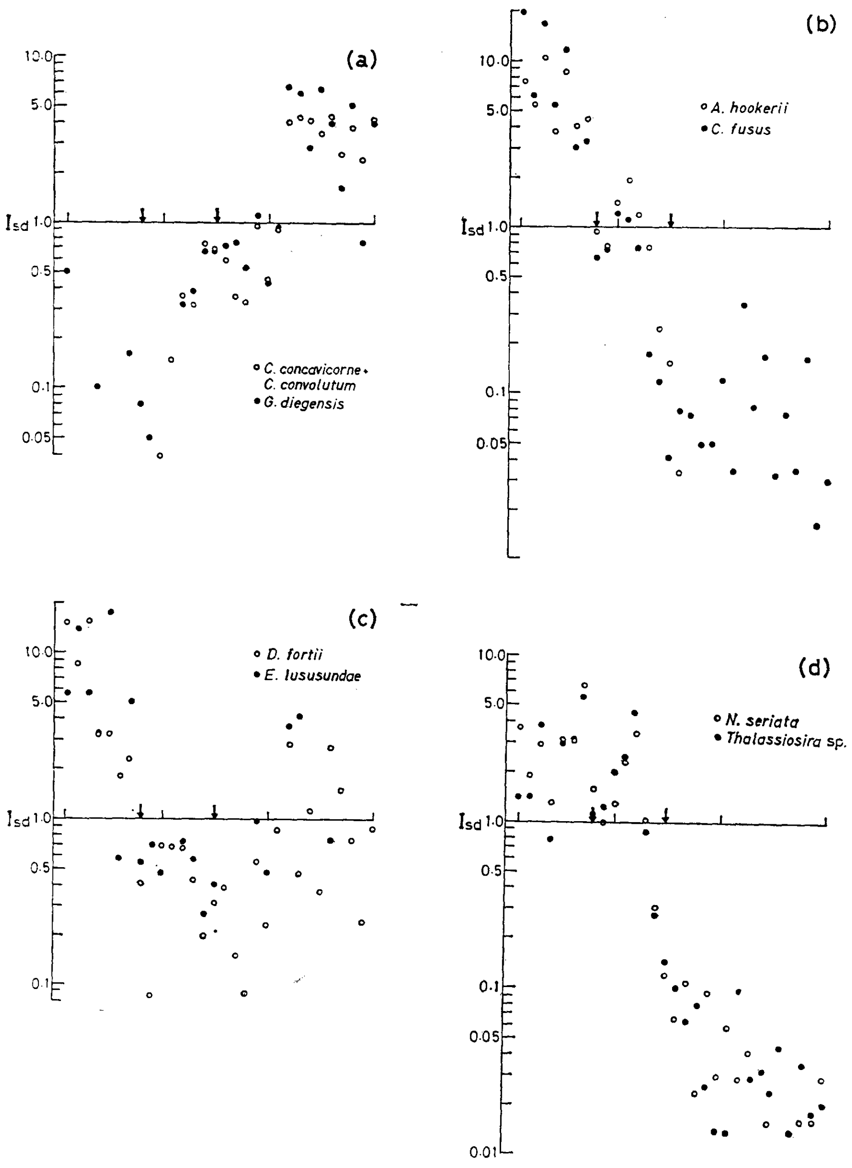


Fig. 6. Horizontal variations in the specific distribution index (*Isd*) of (a) cold water species, (b) warm water species, (c) cosmopolites, and (d) frontal species. Arrows on the abscissae denote the borders of frontal zone which coincide with sample numbers 8 and 15.

Concluding Remarks

SAVIDGE (1976) has mentioned that a marked increase in phytoplankton photosynthesis is caused by admixture of two waters, each containing different nutrients from both sides of the front. In the present case, however, concentrations of various nutrients were at about the same levels over the entire line crossing the front. Depletion process of nutrients and change in phytoplankton communities in the frontal zone, which happen during transportation from near coast to offshore, are of the related interest, while these are not within the scope of the present paper.

The pollen distribution is useful in distinguishing biological phenomena from physical ones. However, this involves other assumptions such as that the pollen grains are very much refractory and tend to suspend in the surface layer for a much longer period than the average longevity of microplankters. These seem to be quite possible assumptions (cf. HOPKINS 1950, TSUKADA 1974) though further investigations might be needed on the selective feeding of larger zooplankton on the pollens or on the phytoplankton and microzooplankton.

The species belonging to types 1 and 2 are judged respectively as useful indicator species of the cold and warm water masses. They could not survive in the frontal zone where there are sudden changes in environmental conditions. Type 3 species might have their origin from both sides of the front but they could not actively grow in the frontal zone (Fig. 6c). Only the neritic species of type 4 brought from the coastal area could actively grow in the frontal zone (Fig. 6d). Therefore, in the oceanic front where seeding effect of tolerant neritic species effectively occurs, the neritic species become predominant.

Acknowledgements

We are grateful to Drs. T. KAWASAKI and Y. ENDO for their valuable criticism on the early draft of the manuscript, and Dr. T. YASUI and Mr. J. WAKUI for their helpful cooperation in the field works. Facilities of R/V Wakataka Maru were kindly offered by the Tohoku Regional Fisheries Research Laboratory. We also thank Mrs. M.-A. BATONGBACAL for the correction of our English. This study was partially supported by the Grant-in-Aid for Scientific Research by the Ministry of Education, Science and Culture, Project Nos. 236017 and 486009.

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