日水研報告，(37)：13—19，1987.
Bull. Jap. Sea Reg. Fish. Res. Lab., (37)：13—19, 1987.

Vertical Distribution of Chlorophyll *a* along the PM Line in the Japan Sea

Hiroshi Nagata[1] and Kozo Kitani[1]

Abstract

In the Japan Sea, a maximum of chlorophyll concentration (subsurface chlorophyll maximum) is sometimes found at deep layers as in many other seas. We have examined environmental conditions relating to it using the previous data reported by the Maizuru Marine Observatory. As a result, the following features concerning subsurface chlorophyll maxima were revealed;

1) A subsurface chlorophyll maximum was found in almost every spring and in some winters, but scarcely in summer and autumn. Besides, there was a tendency for it to appear in offshore areas in spring.

2) A well-developed subsurface chlorophyll maximum (more than 0.5 μg Chl-a/l) was found in May in 1977, '79, '80, '84, whereas the volume transport by Tsushima Current in these months was extremely low compared with the same months in other years except for 1977.

3) A chlorophyll maximum corresponded to such depth as the nitrate-N and the phosphate-P were notably dense.

4) Chlorophyll maximum layers were sometimes deeper than 150 m. Though in these layers, the percentages of chlorophyll *a* in total pigments were often higher than 70–80%, especially in May in 1977, '79 and '80. Such layers were apparently below the euphotic zone, it was thought to be quite a severe condition for the photosynthetic phytoplankton.

Key words chlorophyll *a*, Japan Sea, PM line, subsurface chlorophyll maximum

I. Introduction

It is necessary to obtain information on the phytoplankton standing crop and its distribution to understand primary production in the sea. The concentration of chlorophyll *a* is often measured in routine marine observations as the phytoplankton standing crop. Generally, since light is an essential factor for photosynthetic phytoplankton, the distribution of phytoplankton is often restricted to near the surface layer. But in recent years when observational data have been accumulated, it has been revealed that phytoplankton is distributed not only in the surface layer but in

Received: 21 October, 1986. Contribution A No. 440 from the Japan Sea Regional Fisheries Research Laboratory.
1) Japan Sea Regional Fisheries Research Laboratory, Suido cho, Niigata, 951, Japan.

a lower one, and the maximum layers are sometimes found at greater depths than 100 m. These concentrations of chlorophyll *a* (standing crop of phytoplankton) in deep layers are called "subsurface chlorophyll maxima."

In these layers, the concentrations of chlorophyll *a* increase by a factor of 2 to 20 times the value in the surface layer, and much larger increases have been reported (PARSONS *et al.*, 1984). There are many reports on subsurface chlorophyll maxima (for example, MENZEL and RYTHER, 1960; LORENZEN, 1967; SAIJO *et al.*, 1969; VENRICK *et al.*, 1973; KOZASA, 1979), but further investigations are necessary to clarify the mechanism of the formation and their ecological importance.

In the Japan Sea, though the existence of the subsurface chlorophyll maximum has been known from oceanographic observations by the Maizuru Marine Observatory, further analysis of it has not been done, so far. In the present paper, we have examined environmental conditions relating to the subsurface chlorophyll maximum using the previous data reported by the Maizuru Marine Observatory, and discussed some characteristics of it in the Japan Sea.

II. Materials

The Maizuru Marine Observatory has carried out oceanographic observations along some set lines (e.g. PM, F, G line) in the Japan Sea in February, May, July, and September. At each station, temperature, salinity, dissolved oxygen, nutrient salts, plant pigments etc. are observed. The results are published as "Oceanographic Prompt Reports" from the Maizuru Marine Observatory four times a year and detailed data are reported in "The Results of Marine Meteorological and Oceanographical Observations" published by the Japan Meteorological Agency. The data used in the present paper are;

1. "Oceanographic Prompt Reports" Nos. **268–351.**
2. "The Results of Marine Meteorological and Oceanographical Observations" Nos. **53–76.**

Since the subsurface chlorophyll maximum layer itself has not been defined clearly yet, here, for the purpose of convenience, we defined it as the layer where the concentration of chlorophyll *a* was higher than both 0.2 $\mu g/l$ and twice the upper minimum layer, and existed in zones deeper than 100 m.

III. Results and Discussion

The appearance of subsurface chlorophyll maxima from 1973 to 1984 along the PM line (Fig. 1) are summarized in Table 1. It is suggested that the existence of such layers in the Japan Sea is not an unusual phenomenon. They are most frequently found in May and sometimes in February, but very rarely in July and September (Fig. 2A). Especially, well-developed maximum layers (more than 0.5 μg Chl-a/l) existed in May 1977, '79, '80, '84. These months are correlated to ones when the volume of transport to the north by the Tsushima Current was extremely low, except for 1977 (Fig. 3).

Table. 1. Appearance of subsurface chlorophyll maxima on the PM line (Fig. 1) from data of the Maizuru Marine Observatory

		Sta.	Depth (m)	Chl-*a* (μg/*l*)	Chl%* (%)			Sta.	Depth (m)	Chl-*a* (μg/*l*)	Chl%* (%)
1973	May	3	100	0.22	20.5	1979	Feb.	NF			
		6	173	0.24	30.0		May	6	132	1.54	73.3
	July	5	125	0.25	41.0			8	99	1.94	85.1
	Sep.	NF						9	145	0.21	44.7
1974	Feb.	4	150	0.31	29.8		July	NF			
		5	150	0.30	35.3		Sep.	NF			
		8	105	0.38	33.6	1980	Feb.	3	118	0.30	28.8
	May	11	256	0.30	37.0		May	2	142	0.35	71.4
	July	7	150	0.31	24.6			5	126	0.91	78.4
	Oct.	NF						6	147	0.94	81.7
1975	Feb.	6	208	0.36	62.1			7	122	0.90	79.6
		7	142	2.55	72.2			8	148	0.80	78.4
	May	5	142	0.21	53.8			9	141	1.06	89.1
	July	NF					July	NF			
	Sep.	NF					Sep.	NF			
1976	Feb.	8	125	0.20	27.0	1981	Feb.	2	114	0.73	24.3
	May	3	124	0.25	11.2		May	5	125	0.37	61.7
		7	125	0.43	46.2			6	158	0.42	63.6
	July	NF						7	191	0.28	63.6
	Sep.	NF					July	NF			
1977	Feb.	NF					Sep.	NF			
	May	2	219	0.98	82.3	1982	Feb.	NF			
		3	130	0.68	84.0		May	NF			
		4	125	0.93	89.4		July	2	147	0.21	31.3
		5	150	0.92	86.0		Sep.	NF			
		6	144	1.71	88.6	1983	Feb.	NF			
		7	200	1.92	87.7		May	3	150	0.41	78.8
		8	125	2.26	87.3			4	119	0.27	84.4
		9	90	3.52	85.6			9	114	0.22	68.8
	July	2	147	0.26	28.9		July	2	300	0.39	23.8
	Sep.	NF					Sep.	NF			
1978	Feb.	7	95	1.14	55.6	1984	Feb.	NF			
		9	112	1.01	60.5		May	9	162	0.51	79.7
	May	5	113	0.20	57.1		July	NF			
		7	144	0.36	92.3		Sep.	NF			
	July	NF									
	Sep.	NF									

*Chl. *a*/(Chl. *a*+Phaeophytin) NF: Not Found

Data are from "The Results of Marine Meteorological and Oceanographical Observations" Nos. 53-76.

Chlorophyll maximum layers were found at all stations in the PM line except for PM–1 and PM–10, but they had a tendency to appear at offshore stations (from PM–5 to PM–9) in spring (Fig. 2B).

The vertical distribution of chlorophyll *a*, temperature, salinity, nutrients (nitrite-N, nitrate-N and phosphate-P) at Sta. D-11 (38°40′N, 133°00′E, Fig. 1) in April 26, 1984 were shown in Fig. 4 (NAGATA and KITANI, unpublished). Though concentrations of nutrients were very low at the surface layer, they showed a notable increase at depths greater than 75 m. VENRICK *et al.* (1973) mentioned the importance of a nutrient regime for development and maintenance of the chlorophyll maximum layer. They also suggested that the depth of the nitrite maximum and the position of the "nutricline" were closely related to the depth of the chlorophyll maximum layer. PARSONS *et al.* (1984) reported that the depth of the chlorophyll

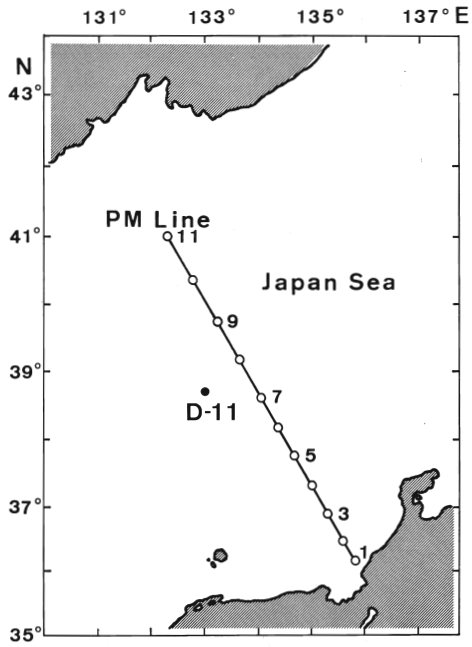

Fig. 1. Location of 11 stations on the PM line and a supple mented station D-11.

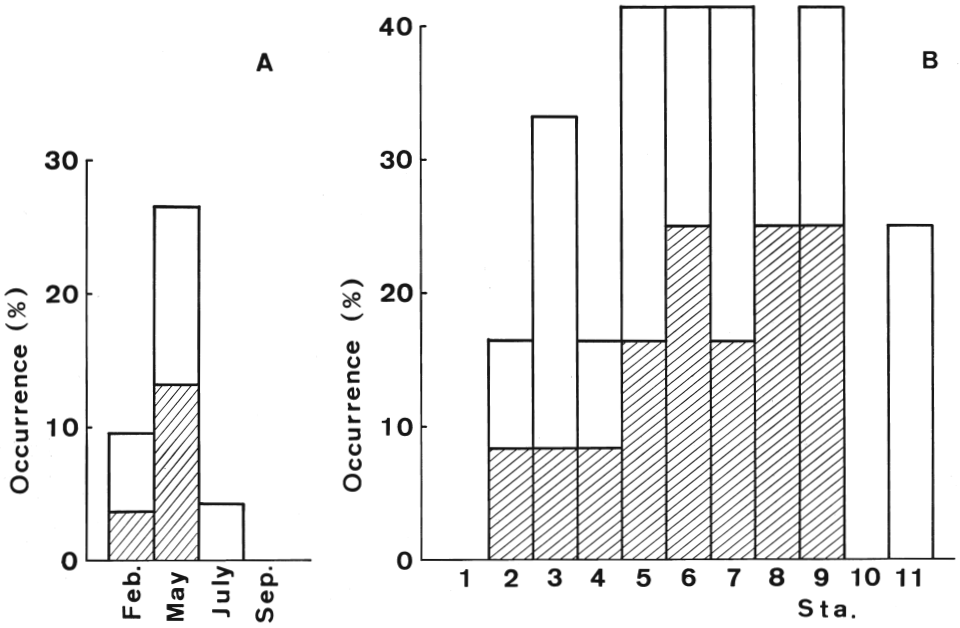

Fig. 2. A. Seasonal occurrence of subsurface chlorophyll maxima, as revealed from data collected at 11 stations on the PM line during 1973–1984. B. Station-to-station variations on the PM line of the occurrance of subsurface chlorophyll maxima in May from the same data. Shaded are the occurrance of a remarkable subsurface chlorophyll maxima ($>0.5\,\mu g/l$).

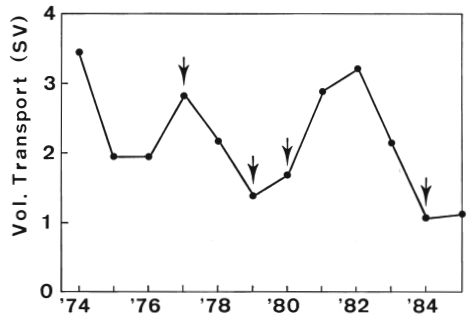

Fig. 3. Change of transport volume of the Tsushima Current crossing the PM line in May from 1974 to 1985. Arrows indicate times when conspicuous subsurface chlorophyll maxima were observed. Current data are from "Oceanographic Prompt Reports" Nos. 268–351.

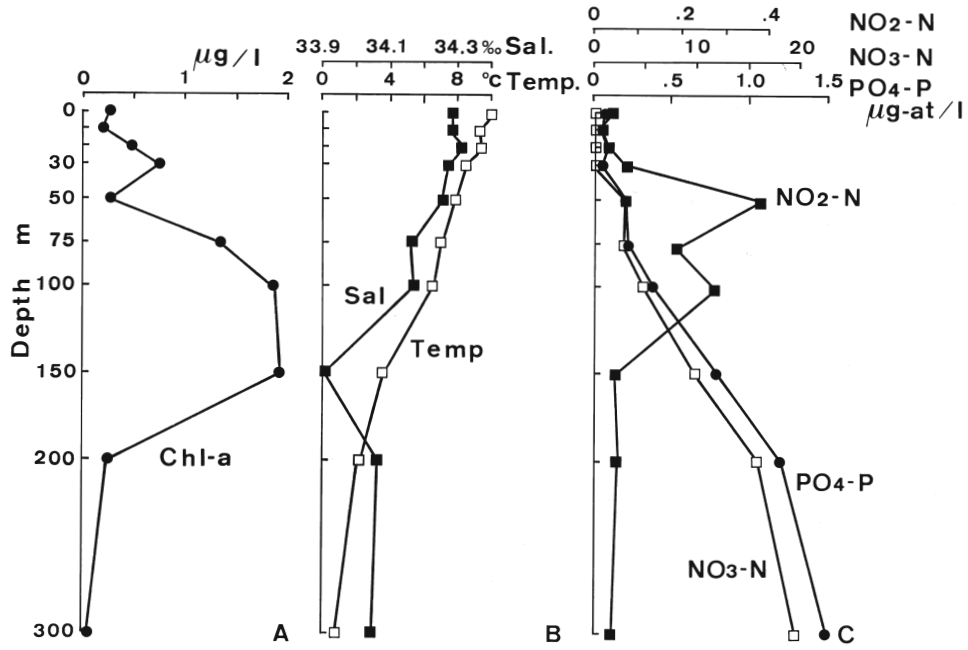

Fig. 4. Vertical distribution of chlorophyll *a* (A), temperature, salinity (B), and nutrients (C) at Sta. D–11 (38°40′N, 133°00′E, Fig. 1) in April 26, 1984. (NAGATA and KITANI, unpublished)

maximum layer associated with the layer that showed the maximum change in nitrate. In our case, the depths for maximum values of nitrite-N and chlorophyll were different, but the chlorophyll maximum layers corresponded to the layers which showed notable increases of other nutrients (such as nitrate-N and phosphate-P).

Chlorophyll maximum layers are sometimes found at depths greater than 150 m (Table 1). The depth where primary production by photosynthesis is equal to consumption by respiration is called the "compensation depth", and it is usually taken as the depth where 1% of the surface light penetrates. ARUGA and MONSI (1963)

estimated that it is 2.67 times of transparency. The average transparency in the PM line in May in 1977 was 17 m (from data of the Japan Meteorological Agency), therefore, the compensation depth (the thickness of the euphotic zone) was estimated to be only 45 m at that time.

At the subsurface chlorophyll maximum, especially in May 1977, '79, '80, a high percentage (more than 70–80%) of chlorophyll *a* was often observed (Table 1). It may be the result of adaptation to photosynthesis of the cells in low light intensities by an increase in their chlorophyll content in nutrient-rich water (ANDERSON, 1969) or rapid sinking without enough time to decompose chlorophyll *a*. There are some reports suggesting the importance of phytoplankton under the euphotic zone for primary production in the oceans (BURKHOLDER and MANDELLI, 1965; ANDERSON, 1969; VENRICK *et al.*, 1972). In this case, though it is not clear whether these phytoplankton can actually carry out photosynthesis in such a deep layer or not, it must be quite a severe condition for photosynthetic phytoplankton in spite of the rich nutrients.

Acknowledgements

The authors express their sincere thanks to Mrs. H. Katagiri for her technical assistance and to Miss C. Saito for typing the manuscript.

References

ANDERSON, G. C. (1969) Subsurface chlorophyll maximum in the Northeast Pacific Ocean. *Limnol. Oceanogr.*, **14**, 386–391.

ARUGA, Y. and M. MONSI (1963) Chlorophyll amount as an indicator of matter productivity in bio-communities. *Plant & Cell physiol.*, **4**, 29–39.

BURKHOLDER, P. R. and E. F. MANDELLI (1965) Carbon assimilation of marine phytoplankton in Antarctica. *Proc. Natn. Acad. Sci.*, **54**, 437–444.

KOZASA, E. (1979) Distribution of chlorophyll in the East China Sea-I. Characteristic for July 1978 measured with a type II Variosens fluorometer. *Bull. Plankton Soc. Japan*, **26**(2), 87–95.

LORENZEN, C. J. (1967) Vertical distribution of chlorophyll and phaeo-pigments: Baja California. *Deep-Sea Res.*, **14**, 735–745.

MENZEL, D. W. and J. H. RYTHER (1960) The annual cycle of primary production in the Sargasso Sea off Bermuda. *Deep-Sea Res.*, **6**, 351–367.

PARSONS, T. R., M. TAKAHASHI and B. HARGRAVE (1984) *Biological Oceanographic Processes.* 3rd Edition, Pergamon Press, Oxford, 330 pp.

SAIJO, Y., S. IIZAWA and O. ASAOKA (1969) Chlorophyll maxima in Kuroshio and adjacent area. *Mar. Biol.*, **4**, 190–196.

VENRICK, E. L., J. A. McGOWAN and A. W. MANTYLA (1973) Deep maxima of photosynthetic chlorophyll in the Pacific Ocean. *Fishery Bulletin*, **71** (1), 41–52.

日本海ＰＭ線上におけるクロロフィル *a* の鉛直分布

長田　宏・木谷浩三

日本海においても，他海域と同様，表層より下方にクロロフィルの極大層（亜表層クロロフィル極大）が出現することがある．著者らは舞鶴海洋気象台のＰＭ線のデータを解析し，日本海の亜表層クロロフィル極大に関して次のような知見を得た．

1) 亜表層クロロフィル極大層は，日本海では春季に最も多くみられ，夏季や秋季には稀であった．また，この極大層は沿岸よりも沖合ほど出現する割合が多かった．

2) 春季における顕著な極大層は，1977，'79，'80，'84年にみられたが，1977年を除いては，いずれも例年の春季に比べ，対馬暖流の北上流量が少ない時期であった．

3) 鉛直的にみると，クロロフィル極大層は硝酸態窒素，燐酸態燐濃度が著しい増加をはじめる水深に対応していた．

4) 春季においてはクロロフィル極大層が150*m* 以深にある場合でも，しばしばクロロフィル *a* の全植物色素（クロロフィル *a* ＋フェオフィチン）に対する割合が70～80％以上と高い値を示した．これは植物プランクトンの活性を示唆するが，このような深層において光合成が行われているかどうかは現在のところ不明である．