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Société franco-japonaise d'océanographie, Tokyo

南極海における水温，塩分および濁度の分布*

森　永　　　勤**

Distributions of Temperature, Salinity and Turbidity in the Antarctic Ocean*

Tsutomu MORINAGA**

Abstract: In the FIBEX (First International BIOMASS Experiment) navigation of the T/S Umitaka-Maru, Tokyo University of Fisheries, from November 11, 1980 to March 11, 1981, observations of turbidity (beam transmission) were carried out simultaneously with those of temperature and salinity in the upper layer of the Antarctic Ocean both along 125°E and 160°E from 53°S to 65°S. The beam attenuation coefficient of the Sub-Antarctic Surface Water was 0.24-0.26 m^{-1} which is approximately twice that of the Kuroshio, while in the Antarctic Surface Water (Summer Water) it was 0.10-0.22 m^{-1}, indicating the seawater being clear. In the upper layers of 0-50 m deep, particles smaller than 2.0 μm in size were abundant in the water near the Antarctic Convergence Zone, while in the water near the Antarctic Divergence Zone particles larger than 8.0 μm were abundant. The concentration of suspended matter was 0.20-0.30 mg/l in the former and 0.40-0.50 mg/l in the latter. High turbidity layers were observed near the thermocline in the area north of 60°S and near the halocline in the southern area. In such high turbidity layers a proper correlation was found between the vertical stability of watermass and the gradient of turbidity with depth. This suggests that the vertical gradient of density plays an important role in the formation of the high turbidity layer. This kind of optical study is very useful to explain the complicated mechanism of such oceanic fronts as the Antarctic Convergence and Divergence Zones.

1. 緒　言

海洋，特に潮境を中心とした濁度の分布に関する研究は，懸濁粒子自体の集中拡散現象のみならず，複雑なフロント機構の解明に資するものであり，また，一般的には海洋における物質循環の基礎として役立つものである（MATSUIKE and MORINAGA, 1977）。

南極海は鯨やナンキョクオキアミの好漁場で，栄養塩が多く，夏季においては生産力が高い。また，顕著な海洋前線が北と南に存在し，かつ海底地形が複雑で，海水の流動からも興味ある海域といえる。

従来，南極海における水塊構造に関してはかなり多くの研究がある。DEACON (1937) と SVERDRUP *et al.* (1946) は南氷洋の水塊分類や鉛直循環のダイナミックスを，ISHINO (1963) は南極海全域に及ぶ水温，塩分および σ_t の鉛直，水平分布から Antarctic Circumpolar Water に関する水塊の特徴や海水の動きを，それぞれ研究した。また，GORDON (1975) は Antarctic Circumpolar Current が海底地形の影響をうけるとして Campbell Plateau 周辺の流速を地衡流の計算から推測した。最近，本報告の調査と同じ海域において，ISHINO *et al.* (1979) はオキアミが棲息する物理的環境を混合層や温度逆転層の深さから把握しようと試みた。

一方，南極海の濁度に関する研究については，

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その報告がみられず，未知の状態といえる。しかし，照度の鉛直分布については，MATSUIKE and SASAKI (1968) により研究されている。彼等はロス海を含むニュージーランド南方の水深 200 m 以浅において，青色光の消散係数は亜南極，南極および南極収斂線の各水域で顕著に異なり，赤色光の場合には大差ないことを見出した。また，南極収斂線の潮境では，消散係数(青色光)は著るしく大きく，黒潮の 3〜4 倍に匹敵すると報告している。

著者は 1980 年 11 月 11日から 1981 年 3 月 11 日までの間，東京水産大学海鷹丸に乗船し，南極海第 1 回 BIOMASS 国際共同調査（FIBEX）に参加した。この調査における海洋物理・化学的観測結果については MATSUURA *et al.* (1982) に詳述されている。本論文では水温，塩分および濁度の鉛直分布と表層水の連続記録を用いて，水温，塩分および σ_t からみた亜表層（水深 150 m 以浅）の水塊構造，各水塊における濁度分布および水塊構造と濁度分布との関連性について検討した。

2. 観測点および観測方法

南極海における観測点分布を Fig. 1 に示す。観測は 1980 年 12 月 20 日から 1981 年 1 月 16日，および 1 月21日から 2 月 14日までの 2 期間において行なわれた。前者は 125°E線上，53°Sから65°S まで，後者は 160°E 線上，53°S から 65°S までであり，それぞれ Leg 1 および Leg 2 と呼ぶことにする。観測点間隔は 15マイルから60マイルであるが，南極収斂線（Antarctic Convergence Zone）や南極発散域 (Antarctic Divergence Zone) の各付近では密な観測が行なわれた。また，最南端観測点は Leg 1 の場合では，パックアイスに接近しており，Leg 2 の場合ではバレニー諸島から北西約 180 マイルの距離にあった。

観測方法は，水温，塩分に関しては STD (Plessy Environmental Profiling System Model-9040) および XBT（鶴見精機㈱）による 1,500 m 深および 450 m 深までの鉛直観測と，表層 S-T Meter (ユニオン電子) による航走連続観測を併用した。濁度に関しては，現場用光束透過率計 (Martek Model-XMS, 光路長 1 m, 重心波長 486 nm) による 150 m 深までの鉛直観測，およびフローセル型濁度計（石川産業㈱，光路長 0.5 m，重心波長 460 nm）による航走連続観測（水温，塩分のセンサーを通過した海水の）が行なわれた。これらの観測と同時に，各測点の表層，50 m,

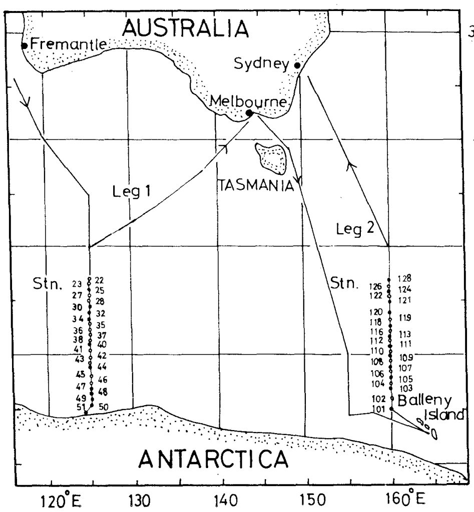

Fig. 1. Observation stations in the Antarctic Ocean. Solid circles show the STD stations and open circles the XBT stations.

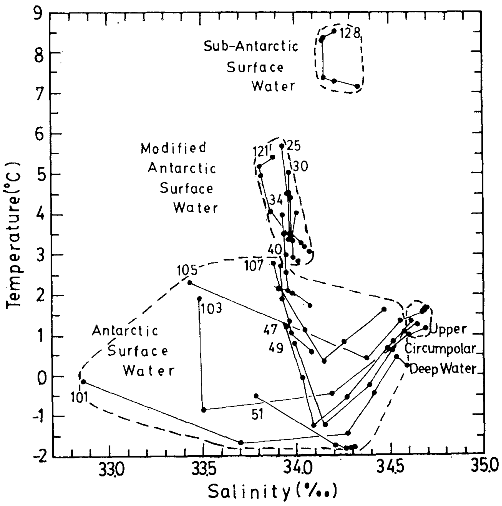

Fig. 2. Temperature-salinity diagram based on the data in Leg 1 and Leg 2. Numbers show the observation stations. Area enclosed with dotted line shows each watermass.

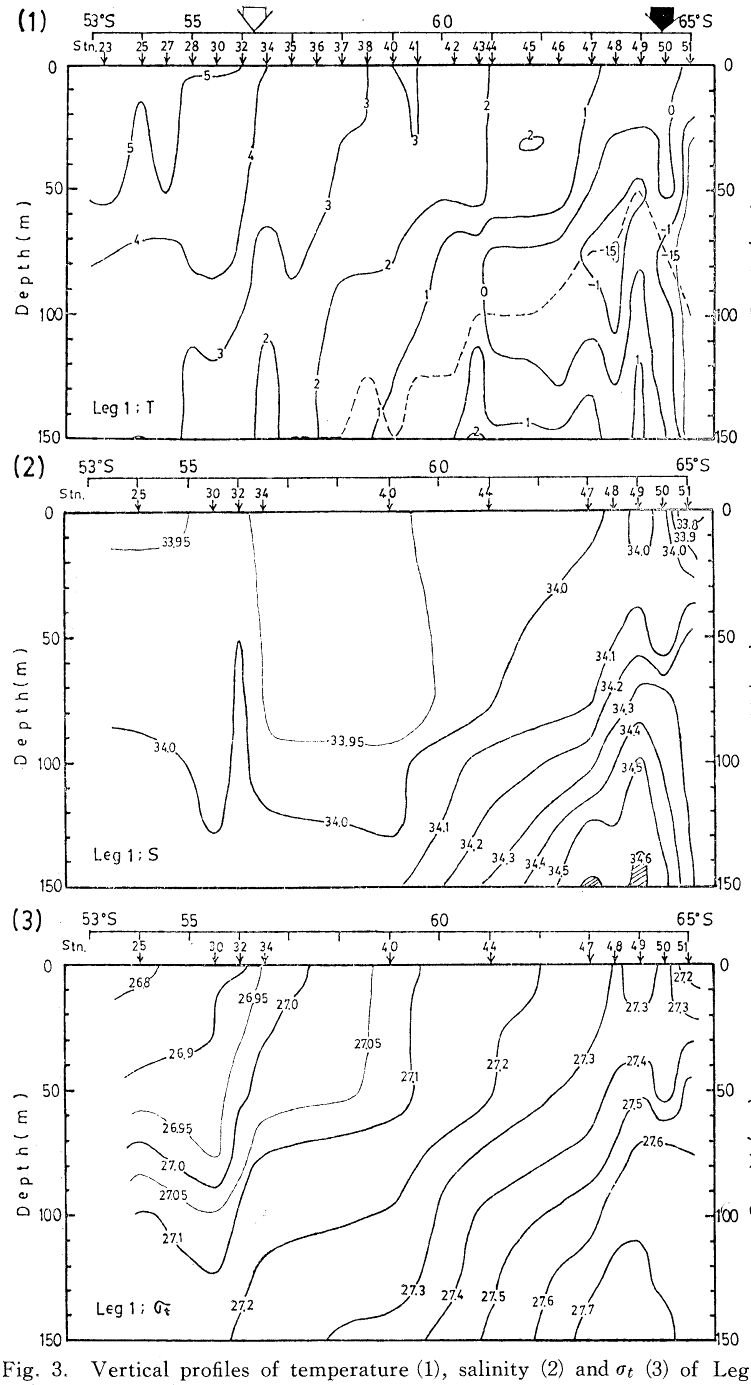

Fig. 3. Vertical profiles of temperature (1), salinity (2) and σ_t (3) of Leg 1. Dotted line in the temperature profile (1) shows the temperature-minimum layer. Hatched areas in the salinity profile (2) indicate the Upper Circumpolar Deep Water. The open arrow and the solid one show the Antarctic Convergence Zone and the Antarctic Divergence Zone, respectively.

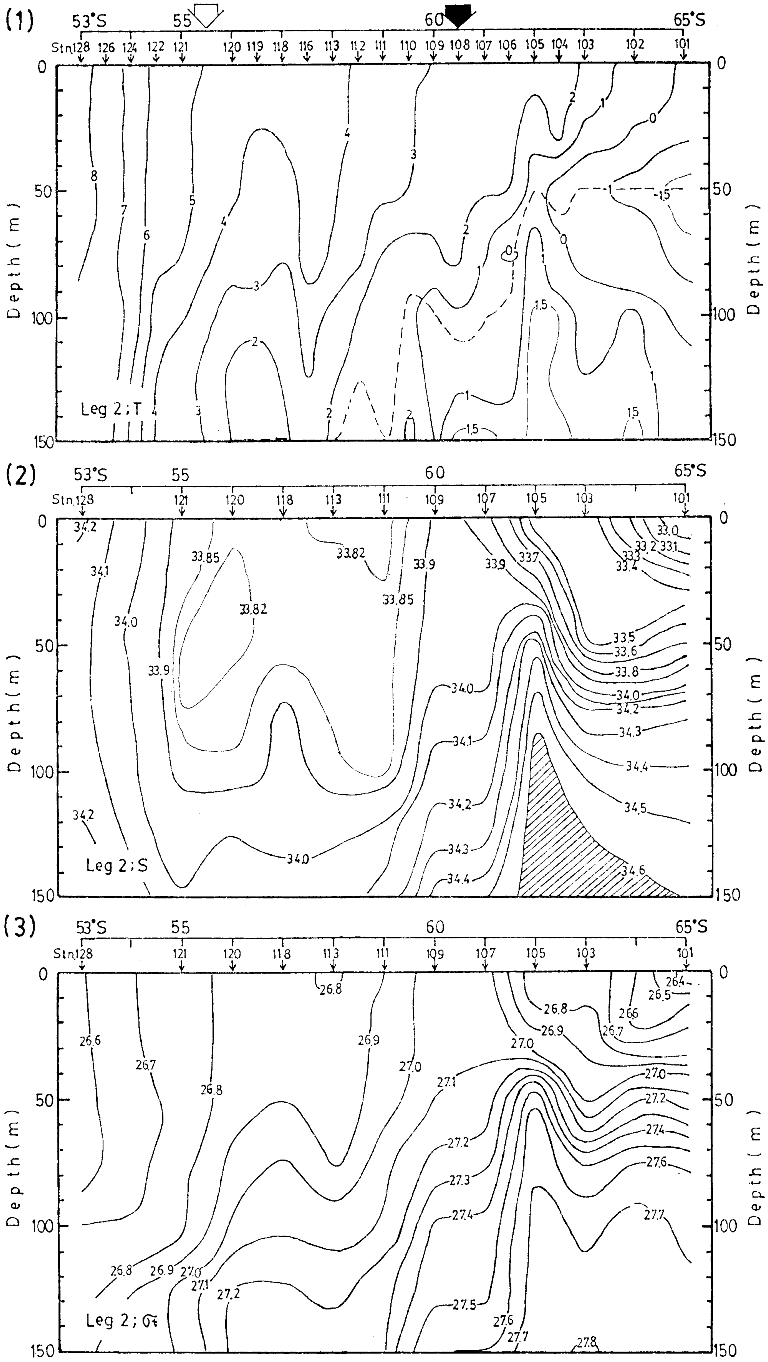

Fig. 4. Vertical profiles of temperature (1), salinity (2) and σ_t (3) of Leg 2. Dotted line in the temperature profile (1) shows the temperature-minimum layer. Hatched area in the salinity profile (2) indicates the Upper Circumpolar Deep Water. The open arrow and the solid one show the Antarctic Convergence Zone and the Antarctic Divergence Zone, respectively.

100 m，150 m，500 m，1,000 m および 1,500 m 深から採取した試水について，コルター・カウンター（Coulter Counter Model-ZBI，アパーチャー径 50 μm）による粒径分布の測定と，Whatman GF/C フィルター（孔径1.0 μm）でろ過して採集した海中懸濁物の乾重量の測定を行った。

3. 結果と考察

3-1 水塊構造

測定海域の T-S ダイヤグラムを Fig. 2 に示す。これは STD データのうち，表層から水深 150 m までの基準層の値をプロットしたものである。GORDON (1975) が報告した 170°E 線における水塊分類の表示に従うと，水深 150 m 以浅の当該海域は亜南極表層水 (Sub-Antarctic Surface Water)，混合南極表層水 (Modified Antarctic Surface Water)，南極表層水 (Antarctic Surface Water)，および周極深層水 (Upper Circumpolar Deep Water) の 4 つの水塊に分類できる。このうち，混合南極表層水は亜南極表層水と南極表層水が混合したものであると考えられる。

Fig. 3 (1), (2) および (3) と Fig. 4 (1), (2) および (3) は Leg 1 および Leg 2 の水温，塩分および σ_t の鉛直断面分布図である。亜南極表層水は Leg 2 の 53°S (Stn. 128) 以北，混合南極表層水は Leg 1 の 53°S から 56°30′S (Stn. 22 から Stn. 34) および Leg 2 の 53°30′S から 55°30′S (Stn. 126 から Stn. 121)，南極表層水は Leg 1 の 56°30′S 以南 (Stn. 35 から Stn. 51) および Leg 2 の 55°30′S 以南 (Stn. 120 から Stn. 101) のそれぞれ約 150 m 以浅に分布している。また，周極深層水は Fig. 3(2)，Fig. 4(2) に斜線で示してあるように，Leg 1 の 64°S (Stn. 49) の 140 m 深および Leg 2 の 62°S (Stn. 105) の 90 m 深まで上昇している。そのうち，南極表層水中では Fig. 3(1)，Fig. 4(1) の水温図中の破線で表示したように，Leg 1 の 64°S (Stn. 49) および Leg 2 の 62°S (Stn. 105) 以南の 50 m 以深に顕著な水温極小層があり，ここでは塩分の急激な増加がみられる。この水塊は冬季水 (Winter Water) と呼ばれ上層の夏季水 (Summer Water) と区別されている (MOSBY, 1934)。

混合南極表層水域では，特に南北方向に対する水温の変化が急激であり，等値線がほぼ鉛直に連らなっている。この水温分布と表層水の水温の連続記録 (Fig. 5 の太い実線) における急変箇所 (Leg 1 では 5°C→4°C，Leg 2 では 6°C→5°C) から判断して，南極収斂線の中心(白矢印) は Leg 1 では約 56°15′S，Leg 2 では約 55°30′S であるといえる。

南極発散域の従来の研究では，観測点間隔がかなり大きいため，表層水の水温，塩分の分布から位置を判断することが困難であるので，周極深層水の上昇している真上として取扱われてきた。Fig. 3 と Fig. 4 からわかるように，この定義によれば南極発散域は Leg 1 では約 64°S，Leg 2 では約 62°S にある (MATSUURA *et al.*, 1982)。一方，表層水の塩分の連続記録 (Fig. 5 の細い実線) をみると両 Leg において極大現象 (黒矢印) が観測され，34.03～34.04 ‰の高塩分値を示して

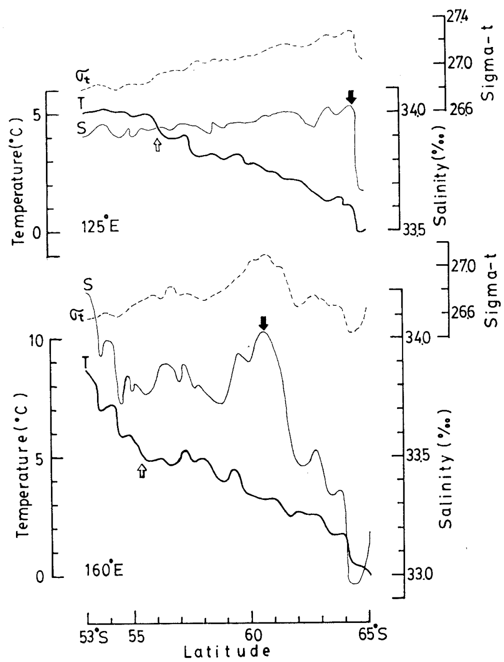

Fig. 5. Continuous records of temperature, salinity and σ_t of the surface water in Leg 1 and Leg 2. The open arrows and the solid ones show the Antarctic Convergence Zone and the Antarctic Divergence Zone, respectively.

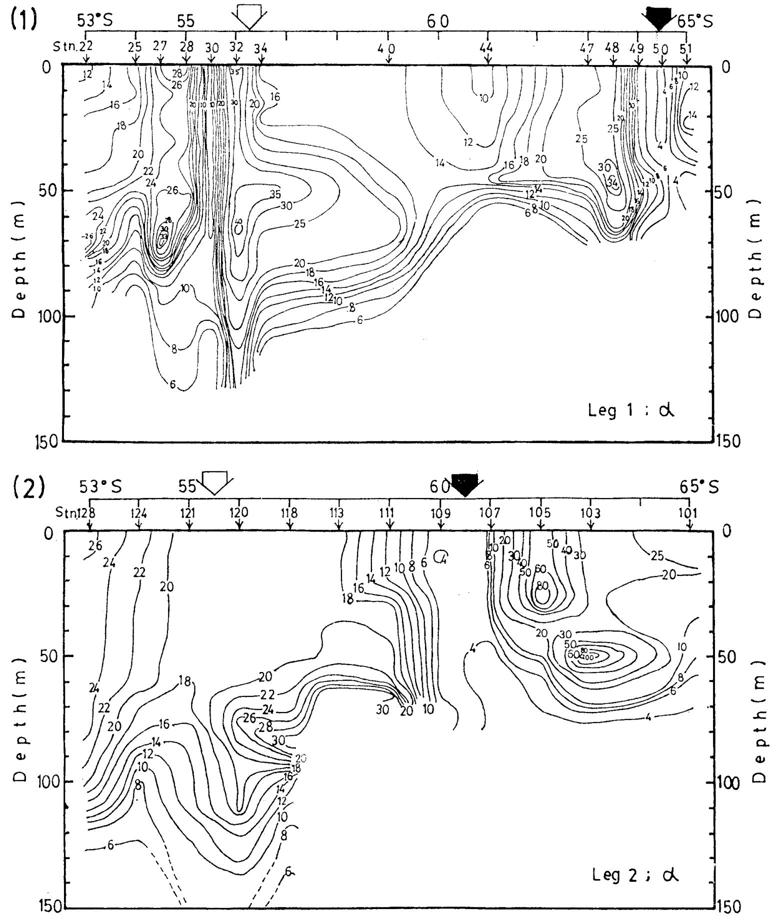

Fig. 6. Vertical profiles of beam attenuation coefficient in Leg 1 (upper figure) and Leg 2 (lower figure). Values are $\times 10^2$. The open arrows and the solid ones show the Antarctic Convergence Zone and the Antarctic Divergence Zone, respectively.

Table 1. The ranges and mean values of beam attenuation coefficient (m^{-1}) in five water zones. Mean value is the average for 0-10 m layer.

Leg	Depth (m)	Sub-Antarctic Zone Range	Sub-Antarctic Zone Mean	Antarctic Convergence Range	Antarctic Convergence Mean	Antarctic Zone north of A. D. Range	Antarctic Zone north of A. D. Mean	Antarctic Divergence Range	Antarctic Divergence Mean	Antarctic Zone south of A. D. Range	Antarctic Zone south of A. D. Mean
1	0- 50	0.06-0.28	0.18	0.13-0.38	0.27	0.10-0.34	0.19	0.04-0.15	0.06	0.04-0.14	0.10
	50-100	0.05-0.36	0.16	0.10-0.40	0.27	0.06-0.24	0.15	0.04-0.14	0.08	—	—
2	0- 50	0.21-0.26	0.21	0.18-0.19	0.18	0.11-0.20	0.17	0.04-0.05	0.04	0.08-1.00	0.33
	50-100	0.08-0.25	0.19	0.13-0.26	0.18	0.13-0.36	0.22	—	—	0.04-0.90	0.18

おり，ここが発散域と考えられる。従って，表層における南極発散域は下層と異なり Leg 1 では 64°30′S, Leg 2 では 60°30′S であると考えられる。

3-2　濁度の分布

海中の濁度(光束消散係数)の鉛直断面分布図を Fig. 6 (1) および (2) に示す。前者は Leg 1, 後者は Leg 2 の場合である。これらは前記の水温，塩分の測定と同時に行われたものである。図内の数値は 10^2 倍して表示されている。

本調査で得られた濁度の値を各水域別にまとめたものを Table 1 に示す。この表および Fig. 6 (2) から，亜南極表層水 (Stn. 128) の α 値は表層から水深 100 m 迄において 0.24～0.26 m^{-1} で，比較的大きく，同一測器，同一波長で測定した黒潮強流域の α 値 0.11～0.12 m^{-1} (MATSUIKE and MORINAGA, 1977) の約2倍である。次に，南極収斂線を含み，それより北側に分布する混合南極表層水では Leg 1, 2 を通して平均0.16～0.27 m^{-1} の範囲の値で，亜南極表層水のそれとほぼ等しい。これらに対し，南極海の主要水塊である南極表層水のうち，夏季水における濁度の値は 0.10～0.22 m^{-1} で (ただし Leg 2 の南極発散域の南側水域を除く)，前2者より値が小さく，清澄な海水といえる。更に，夏季水の真下に分布する冬季水は 0.04～0.08 m^{-1} の値で，サルガッソー海の値 0.07 m^{-1} (490 nm; SCOR, 1973) に匹敵する。

濁度(光束消散係数)は従来，測器の不統一(精度，使用フィルター)により，海域の相互比較が困難であった。この解決策として，著者は数年前から同一測器，同一フィルターを装着した高精度の Beam Transmisso Meter を用い，現場海域における濁度の把握を行ってきた。従って，この調査で明らかにした南極表層水夏季水の値 (0.10～0.22 m^{-1}) はベーリング海大陸棚水の値 0.35～0.80 m^{-1} (未発表)より小さく，日本海対馬暖流表層水の値 0.11～0.20 m^{-1} (未発表)に近似しているといえる。

Fig. 6 (1) でわかるように，南極収斂線の場合，その北側では南北方向に濁度勾配が激しく，かつ等値線が鉛直に連らなり，水塊の境界を顕著に示している。これは著者ら (MATSUIKE and MORINAGA, 1977) が沿岸水域と黒潮強流域との間のフロントで観測した濁度の分布と一致している。また，Fig. 6 (2) では表層から約 60 m 深まで南北方向に変化がみられず，0.18～0.20 m^{-1} の均一な値を示している。この分布は Fig. 6 (1) の場合と異なり，水塊の境界をはっきり示していない。しかし，水深 70～80 m 以深では等値線が垂れ下り，上層の分布と異なる。これは海水の下方向への動きを示しているといえる。

南極発散域の場合，Leg 1 (Fig. 6 (1)) では観測断面の右端付近に位置しているため，その南側では分布の様相が明確でない。しかし，その北側では等値線は約 70 m 深まで鉛直に連らなり，Leg 1 の収斂線と同様，濁度勾配が南北方向に激しい。また，発散域内の濁度は表層から 60 m 深まで 0.04～0.06 m^{-1} の非常に均一な値を示し，冬季水の値に近似している。さらに，Leg 2 (Fig. 6 (2)) において，南北両側には約 70 m 深まで等値線が鉛直に連らなり，濁度勾配が南北方向へと非常に激しく，かつ，その南側には 0.8～1.0 m^{-1} におよぶ高濁度層が形成されている。発散域内の濁度は Leg 1 と同様に同じ値を示している。このようなことは，冬季水とまったく同じ値の清澄な海

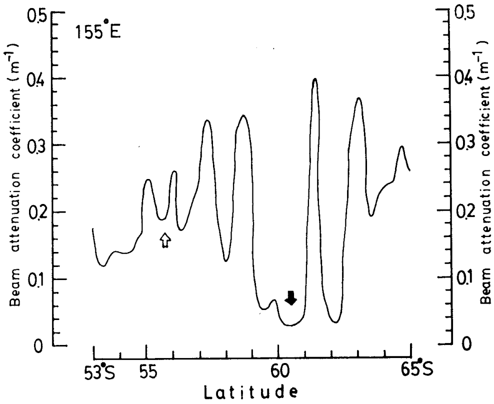

Fig. 7. Continuous record of turbidity of the surface water along 155°E. The open arrow and the solid one show the Antarctic Convergence Zone and the Antarctic Divergence Zone, respectively.

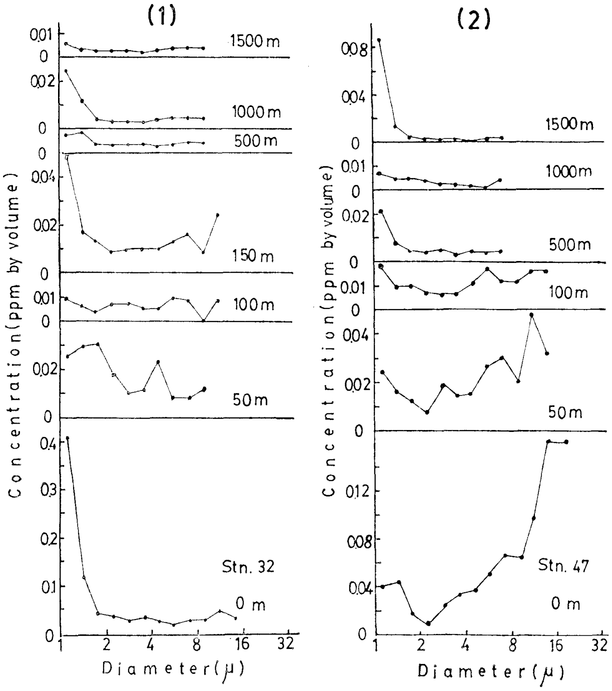

Fig. 8. Particle-size distributions of suspended matter in the surface, 50 m, 100 m, 150 m, 500 m, 1,000 m and 1,500 m depth water at Stn. 32 (56°S) and Stn. 47 (63°S) in Leg 1.

水が Leg 1 では約 30 マイル，Leg 2 では約 60 マイルの幅でそれぞれ表層へと上昇していることを示唆し，その位置は前述の表層水における塩分の連続記録から判断した発散域と一致している。これはさらに，155°E 線に沿って航走した際の濁度の表層連続記録（Fig. 7）から明白に裏付けられる。従って，南極収斂線や発散域における位置と様態は水温，塩分および σ_t から認識されることを明らかにしたが，濁度（光束消散係数）のような光学的手法の併用により，更に明確にしうるといえる。

南極収斂線や発散域の付近においては，濁度の大きな値が表層から水深 80〜90 m まで連って分布している（Fig. 6(1)）。このことは海中懸濁物の潮境への集中現象を示しているものと考えられる。このような海域における懸濁物の粒径分布を Fig. 8 に示す。両者には水深 100 m 以浅において顕著な相違がある。すなわち，収斂線（Stn. 32 表層）はほとんど粒径 2.0 μm 以下の非常に小さい粒子で占められ，平均粒径（$\bar{D}=\frac{\Sigma N_i D_i^3}{\Sigma N_i D_i^2}$；$N_i$ は i 番目の粒子数，D_i は i 番目の粒子の径）1.62 μm であるのに対し，発散域（Stn. 47 表層）では粒径 8.0 μm 以上の大きな粒子が多く，平均粒径（$\bar{D}$）5.0 μm である。水深 100 m 以深では，両者において粒径の相異はなく（例えば水深 500 m でおよそ 1.90 μm），深くなるに従って漸次減少する。さらに，両者を重量濃度（100 m 以浅における）からみると，収斂線の場合は 0.20〜0.30 mg/l，発散域の場合は 0.40〜50 mg/l で，後者の方が少し大きい。

3-3 水塊構造と濁度分布との関連性

155°E 線に沿う表層水の水温，塩分の連続記録を Fig. 9 に示す。これは Fig. 7 の濁度の連続記録と同時に測定されたものである。水温より塩分における変化の方が大きく，その最大は 61°S から 62°S に生じている。これらの傾向は 160°E 線における塩分の連続記録（Fig. 5）に類似している。濁度変化のピーク（Fig. 9 内に細い棒で表示）

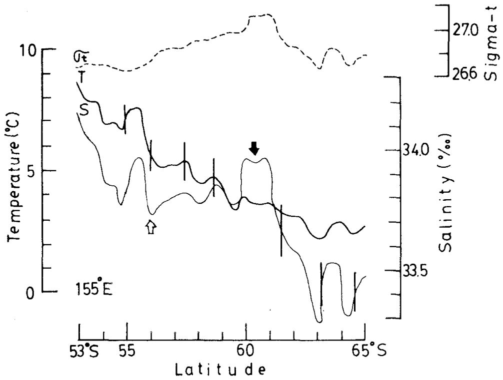

Fig. 9. Continuous records of temperature, salinity and σ_t of the surface water along 155°E. The open arrow and the solid one show the Antarctic Convergence Zone and the Antarctic Divergence Zone, respectively. The vertical bars indicate the positions of turbidity peaks and the range of turbidity based on Fig. 7.

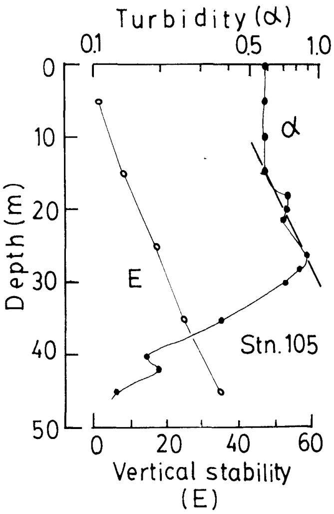

Fig. 10. Vertical distributions of the turbidity and the vertical stability of water mass at Stn. 105.

は水温，塩分の急変箇所に全て現われている。その対応は発散域より北側と南側とでは相違する。前者では主に水温，後者では塩分に該当している。また，ピークのうち，濁度の最大のものは塩分の変化の最も急な箇所と一致している。これらのことから，表層付近における懸濁物は密度勾配が南北方向に大きい所に集中し，特に発散域の南側付近で顕著といえる。

濁度の鉛直断面 (Fig. 6 (1) と (2)) からわかるように，高濁度層は潮境付近と南極表層水の水深約 40 m〜80 mの範囲に形成されている。潮境における収斂線の場合，Leg 1 では水深 50〜80 m の水温躍層付近に高濁度層が観察される。また，発散域 の場合，Leg 1 では水深 30〜50 m, Leg 2 では水深 20〜30 m の塩分勾配の急な所に高濁度層が形成されている。南極表層水の高濁度層は，発散域より北側では水温躍層の付近に，より南側では塩分躍層の付近にそれぞれみられる。従って，南極海における高濁度層は約 60°S を境に，その北方では水温，その南方では塩分の各躍層付近に形成されている。このことは，海水中を沈降する懸濁粒子が密度の急激な増大によって沈降速度が遅くなったり，渦動拡散係数の減少で，そこに集中あるいは滞留しやすい (JERLOV, 1958) ことを

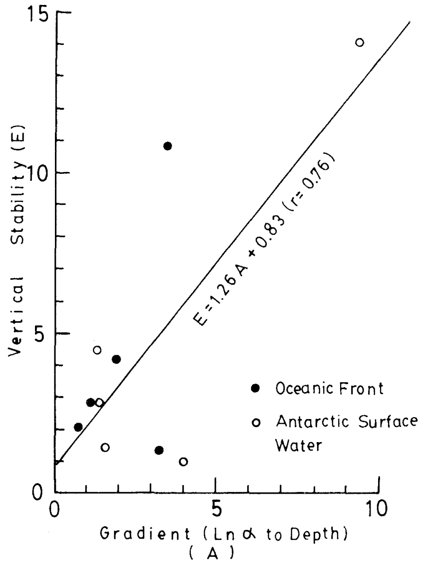

Fig. 11. Relation between the vertical stability of water mass and the gradient of turbidity in high turbidity layers. The vertical stability is $\frac{d\sigma_t}{dZ}\times 10^3$, and the gradient is $\frac{d\ln\alpha}{dZ}\times 10^2$.

示している。

Fig. 10 は密度躍層付近における濁度分布の指数関数的な増大の一例である。この現象は内湾の場合の三宅 (1982) の結果と一致する。深さに対

する濁度(対数表示)の勾配(Fig. 10 に示す直線の傾き)と水塊の鉛直安定度との間には Fig. 11 に示すような関係がある。発散域(Leg 2)付近の鉛直安定度は非常に大きく，濁度の勾配も急である。データ数は少ないが，両者の間には正の相関関係が認められる。このことから，高濁度層の形成機構には密度の鉛直勾配が関与しているといえる。しかし，この機構は濁りに起因する懸濁粒子が生体の場合には，複雑であると考えられる。(YAMAGUCHI and SHIBATA, 1981)。今後，資料の蓄積により，さらに水塊構造と濁度分布との関連性や潮境付近における懸濁粒子の動きについて究明していかねばならない。

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Turbidity Distributions near Oceanic Fronts in the Coastal Region of the East China Sea*

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Abstract: Characteristic features of the turbidity distribution in the coastal region of the East China Sea and the Yellow Sea were investigated on the basis of sectional observations across fronts and supplementary surface measurements on a cruise made in September 1981. One of the major sources of the high turbidity in the surveyed area was the outflow of the turbid Yangtze River water. The outflow of the Yangtze River, which was highly stratified, spread toward east, and its offshore boundary was formed by a distinct front near 123°E. Near the front the outflow had a thickness of about 5 m, and, across the frontal zone about 1 km wide, the salinity and the beam attenuation coefficient at the water surface changed, with strong negative correlation, from 23.8‰ to 29.8‰ and from $3.8\,m^{-1}$ to $1.7\,m^{-1}$, respectively. Significant changes were also found in the composition and the size distribution of suspended matters. Another major source was the upward diffusion of the bottom sediments by the tidal stirring. It was dominant in both the East China Sea and the Yellow Sea, but its influence on the turbidity distribution was different between the East China Sea and the Yellow Sea. In the East China Sea where the seasonal thermocline remained, the turbid layer was confined to depths below the seasonal thermocline, while in the coastal region of the Yellow Sea, where the seasonal thermocline had disappeared, the turbidity was very high ($>2.0\,m^{-1}$) up to the water surface.

1. Introduction

Recent development of optical methods has enabled us to measure in situ concentrations of suspended matters rapidly and continuously. The measurements by use of a transmissometer, especially those combined with temperature and salinity measurements enable us to compare distributions of suspended matters with other physical features, and can provide useful information for understanding the movement of suspended matters. Such measurements were made, for example, by DRAKE (1971) for investigating the intrusion of near-bottom turbid continental shelf water into offshore water, and by MATSUIKE and MORINAGA (1977) for detecting the turbid coastal water trapped within the Kuroshio Water.

In the present study we describe observational results of the turbidity, temperature and salinity distributions in the coastal regions of the East China Sea and the Yellow Sea, with emphasis on the offshore area of Yangtze River, where the high salinity East China Sea water was in contact with the low salinity Yellow Sea water near 32°N, and the outflow of Yangtze River covered surface thin layer west of about 123°E. The characteristics of water in this area varied both horizontally and vertically, forming distinct fronts of different types. So far very few studies have been done on these small-scale features.

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2. Methods of observations

The data were collected on the 24th cruise of Umitaka-Maru from Sept. 4 to Oct. 1 in 1981. Figure 1 shows the location of the observation stations and the main cruise tracks, on which surface measurements of the turbidity, temperature and salinity were made continuously

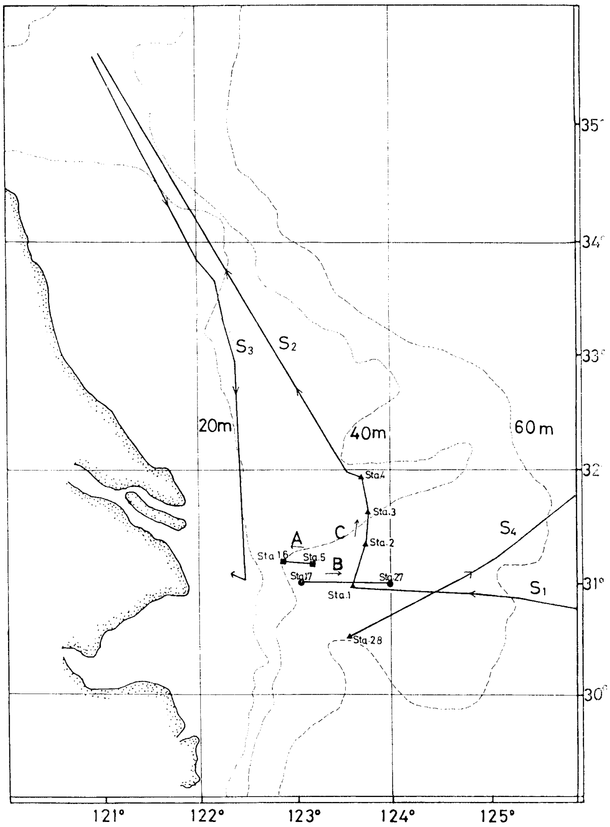

Fig. 1. Location of hydrographic stations and main cruise tracks along which surface measurements were made.

for water pumped up from a depth of about 4 m. The cruise S_1 was made from Sept. 10 to 11, S_2 from Sept. 12 to 13, S_3 from Sept. 17 to 18 and S_4 on Sept. 25. Sectional observations were made along A, B and C sections. The A-section consists of 12 stations (from Stn. 5 to Stn. 16) spaced at about 2.1 km intervals, B-section 11 stations (from Stn. 17 to Stn. 27) spaced at about 9.2 km intervals and C-section 5 stations (from Stn. 1 to Stn. 4 and Stn. 28) spaced in average at 42.6 km intervals. The A-section was observed in the period from 10 h to 15 h on Sept. 23 and B-section from 7 h to 14 h on Sept. 24. For C-section the observations from Stn. 1 to Stn. 4 were made on Sept. 11 and those at Stn. 28 on Sept. 25.

The turbidity was measured by using a transmissometer which measures transmittance of beam with centroidal wavelength 460 nm over path length of 50 cm (surface measurements), and also by using an XMS in-situ transmissometer (Martek Co., Ltd.; centroidal wavelength 486 nm) with a pass length of 1 m (sectional observation). The former was calibrated to fit the measurements by the latter. In the sectional observations the transmissometer, a temperature sensor and a salinity sensor were fixed with each other for the measurements being made at the same location. Concentrations of suspended matters were measured by the filtration of sampled waters by using 0.45 μm pore-size Millipore filters, and the size distributions by a Coulter Counter (Coulter Electronics Inc.). The beam attenuation coefficient $\alpha(m^{-1})$ versus the concentration of suspended matters SS(mg/l) was confirmed to fit a straight line, $\alpha = 0.63SS + 0.16$ (Fig. 2).

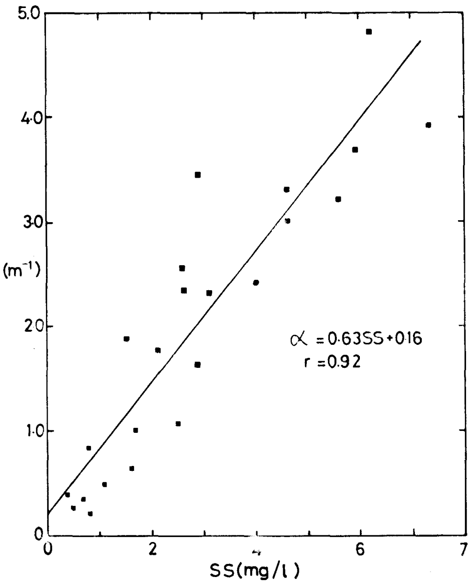

Fig. 2. Beam attenuation coefficient α (m^{-1}) versus concentration of suspended matters SS (mg/l).

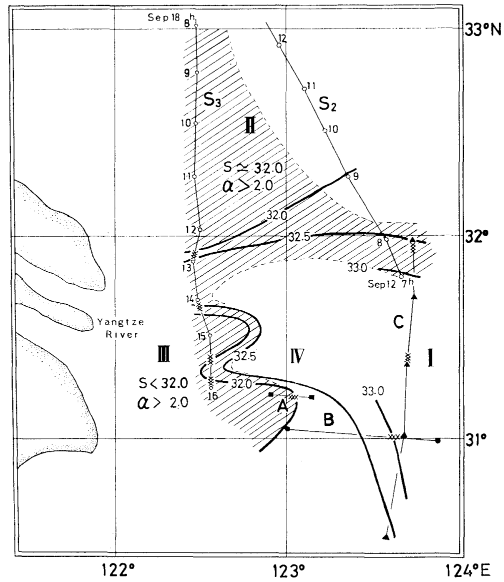

Fig. 3. Near-surface salinity and turbidity distributions. Shaded regions represent the areas where the beam attenuation coefficient α is larger than 2.0 m^{-1}, and the symbols xxx locations of salinity fronts.

3. Gross features of near-surface salinity and turbidity distributions

Gross features of near-surface salinity and turbidity were examined by the surface measurements. Figure 3 shows isohalines and the location of high turbidity regions where α is larger than 2 m^{-1} (hatched region). Some distinct fronts were identified by abrupt changes of S (spatial variations of temperature were rather small over the surveyed area). The locations of the observed fronts are indicated by xxx in the figure. In order to show small features, records of temperature T(°C), S and α along S_2 and S_3 in the region south of 33°N are presented in Figs. 4a and b, respectively. In Fig. 4b the record of α is lacked in some portions, which is due to the extremely high turbidity beyond the measurable range of the instrument used ($\alpha < 12\ m^{-1}$).

The near-surface water was found to be classified into several types in terms of salinity. Characteristic features in the distributions of water types and the near-surface turbidity are:

(a) The salinity is highest in the southeast of the studied area (Region I in Fig. 3) with the values ranging from 33.6 to 34.1‰. The water of similar salinity is found rather persistently in the coastal regions of the East China Sea (SU *et al.*, 1981; FUKASE, 1975; SAWARA and HANZAWA, 1979). Hereafter, we call the water with similar values of salinity as the East China Sea Water (ECSW). As shown in Section 4, ECSW is also found in Regions III and IV below the surface lower salinity water.

(b) The salinity is nearly uniform (S≃32.0‰) in the north of the studied area (Region II). Similar values of salinity were found also in the regions north of 33°N. Hereafter, this water is called as the Yellow Sea Coastal Water (YSCW).

(c) The salinity is lower than 32‰ in the Southwest of the studied area (Region III). The abrupt decrease in the values of salinity on approaching the mouth of the Yangtze River (Fig. 4b) indicates that the low salinity in this region is associated with the outflow of Yangtze River. This water is called hereafter as Yangtze River Diluted Water (YRDW) according to SU *et al.* (1981).

(d) The salinity ranges from 32.0 to 33.0‰ in the middle part of the studied area. The water

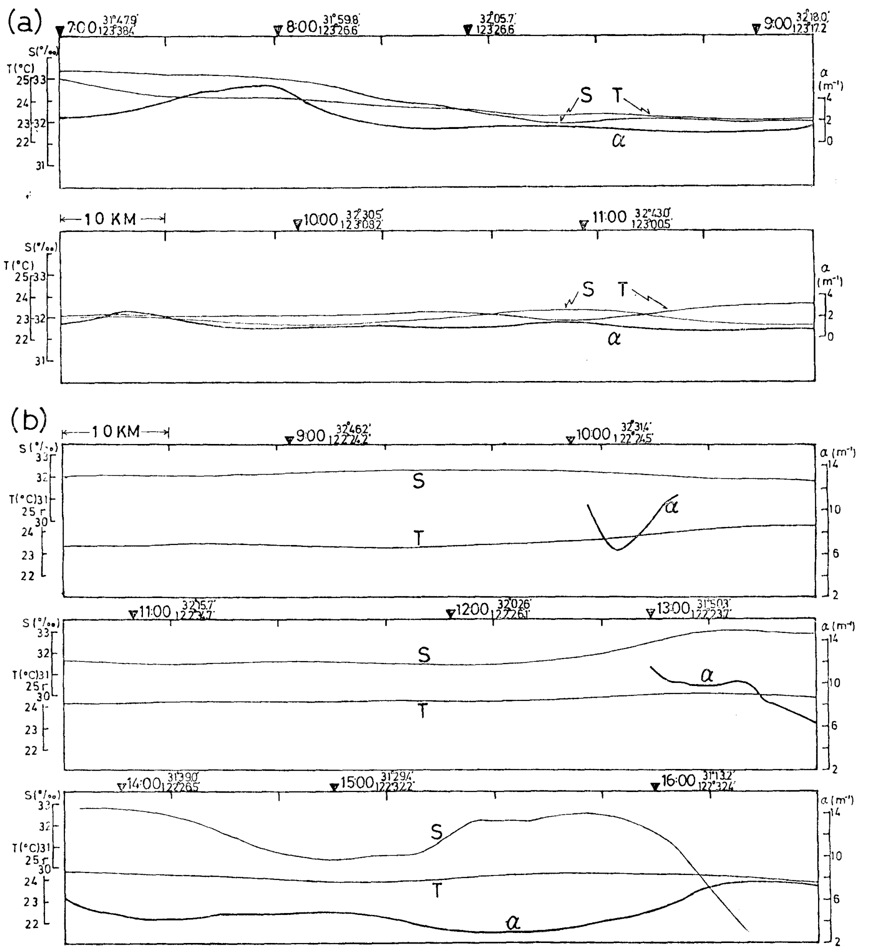

Fig. 4. Temperature T (°C), salinity S (‰) and beam attenuation coefficient α (m^{-1}) along S_2 (a) and S_3 (b). The record of α is lacked in some portions in (b) due to the high turbidity beyond the measurable range of the instrument used ($\alpha < 12\ m^{-1}$).

in this region is considered as the mixture of the above three water types. This water is called hereafter as Coastal Water off Yangtze River, or simply as Coastal Water (CW).

(e) The turbidity is particularly high in the coastal region of the Yellow Sea north of 31°50′N and also in the region of YRDW. In the coastal region of the Yellow Sea a turbid band was found to intrude into the offshore region along 32°N as shown by YAN *et al.* (1981) using satellite images.

The characteristics of water and also the circulation patterns in the East China Sea and the Yellow Sea significantly vary in time associated with the horizontal mixing processes and the air-sea interaction processes (SU *et al.*, 1981; MAO and GUAN, 1981). Therefore, the above-mentioned features may not be persistent, but may show only synoptic features in the observation period. However, the following two facts found in our observations seem to be worth noting. One is that in coastal regions of the Yellow Sea the front of the turbid water does not necessarily imply the front of a water type with characteristic values of temperature and salinity. As seen from Figs. 4a and b, the turbidity is much higher on S_3 than on S_2, indicating the presence of a distinct turbidity front between S_2 and S_3. However, the values of T and S are nearly same between S_2 and S_3, and when the ship crossed turbidity fronts on S_3, no particular changes of T and S were observed. According to LI and LI (1981), the Yellow River had discharged into the Yellow Sea near 34°N till 1885, and a great amount of silt and clay has been deposited in the shallow regions of the Yellow Sea. The density stratification is very weak or absent in the region shallower than about 20 m even in summer (GUO, 1981), presumably by the effect of the tidal stirring. The high turbidity in the shallow region of the

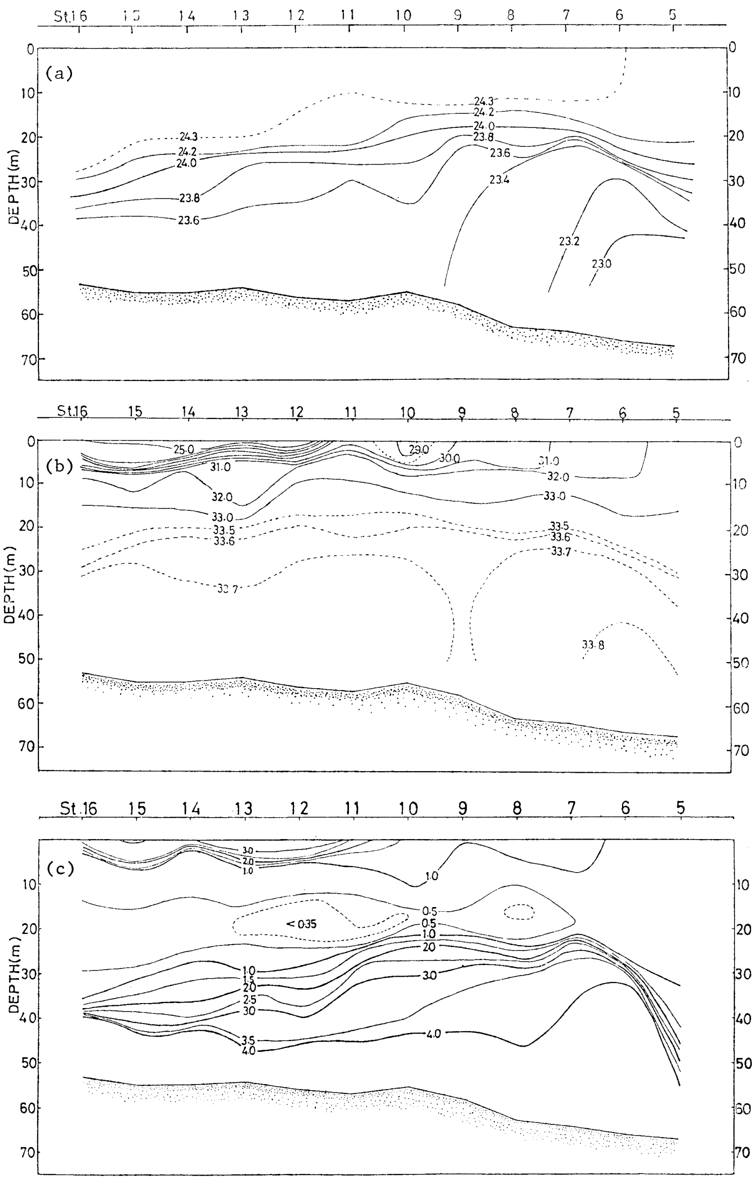

Fig. 5. Vertical sections along A-section; (a) temperature (°C), (b) salinity (‰) and (c) beam attenuation coefficient (m^{-1}).

Yellow Sea is predicted to be due to the bottom sediment dispersed up to the water surface by tidal stirring. The other fact is that the water of high salinity (S>33.0‰) extends as far as about 32°N, even near the coast where the water depth is less than 20 m. As seen from Fig. 4b, the values of S on S_3 increase from 31.5‰ near 32°03′N to 33.0‰ near 31°50′N, suggesting that the high salinity ECSW underlies YRDW occupying the surface layer, and is advected northward beyond the mouth of the Yangtze River; in the deeper regions of the East China Sea east of about 124°E, prevailing northward flow has been confirmed by INOUE (1975). This northward flow in ECSW may affect the dispersion of the fresh water and the terrigenous matters discharged by the Yangtze River and the movements of the suspended matters near the bottom.

4. Tubidity sections across fronts

Sectional observations were made along A-, B- and C-sections. As seen from Fig. 3, the A-sectoin transects a front between YRDW and CW, the B-section a front between CW and ECSW and the C-section fronts between ECSW and YSCW. In this section we describe the characteristic features found in the turbidity sections.

(1) A-section

This section was taken so as to transect perpendicularly the front on the basis of the surface measurements made prior to the sectional observations. The station intervals are about 2.1 km.

Figures 5a, b and c show the temperature, salinity and turbidity sections, respectively. In the salinity section a distinct front is identified between Stns. 12 and 11. The width of the frontal zone is about 1 km, and the salinity at the water surface changes from 23.8‰ to 29.8‰ across the front. On the onshore side of the front, the water with salinity lower than 30‰ occupies near-surface layer of a thickness of about 5 m, and, within the layer, the salinity increases abruptly with the depth, in contrast that the surface layer on the offshore side is well mixed. A seasonal thermocline is found at a depth of 20 to 30 m, and the high salinity ECSW (S≃33.7‰) lies below the seasonal thermocline. Isopleths of T and S are raised upward from Stn. 9 to Stn. 5, which may suggest the local occurrence of the upwelling.

Turbid water with $\alpha>1.0\,\mathrm{m}^{-1}$ is found near the water surface and also below the seasonal thermocline where ECSW occupies. The region of high turbidity near the water surface well corresponds to that occupied by YRDW; the region of $\alpha>1.0\,\mathrm{m}^{-1}$ corresponds to that of S<31.0‰. In the frontal zone surface values of α decrease offshore from $3.8\,\mathrm{m}^{-1}$ to $1.7\,\mathrm{m}^{-1}$. The surface values of α and S are inversely well correlated as shown in Fig. 6, suggesting that the high turbidity near the water surface is mainly due to the terrigenous matters discharged by the Yangtze River.

The thickness of the turbid water below the seasonal thermocline is about 30 m, and near Stns. 6 and 7 where isopleths of T and S are raised upward, it attains up to more than 40 m. In the turbid layer α abruptly increases on approaching the bottom, while T and S remain nearly constant, which indicates that the high turbidity near the bottom is not due to the advection, but is the local suspension of bottom sediments by the intense tidal stirring; a current measurement at 31°50′N, 124°00′E (NAGATA *et al.*, 1981) suggests that, in this region, the intensity of tidal current is more than 1 knot and the semidiurnal component dominates. In the seasonal thermocline values

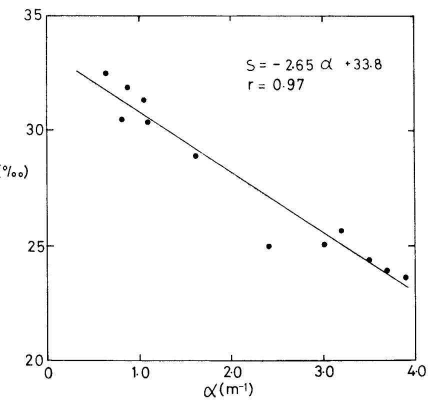

Fig. 6. Beam attenuation coefficient α (m^{-1}) versus salinity S (‰) at the water surface along A-section.

of α decrease abruptly upward, which may be attributed to the effect of stable stratification in the seasonal thermocline since the stable stratification has an effect to suppress the occurrence of the turbulence and the associated vertical diffusion of suspended matters.

The water of extremely low turbidity ($\alpha < 0.5\,m^{-1}$) with a thickness of 5 to 15 m is found near the top of the seasonal thermocline. This low turbidity layer seems to be maintained by some particular mechanism, since, as shown later, the turbid YRDW contains inorganic matters in a considerable proportion, which implies that suspended matters are transported from the turbid surface layer downward by settling. This low turbidity layer may be due to the combined effect of the suppression of the upward diffusion of suspended matters in the seasonal thermocline and the advection of ECSW below the turbid YRDW mentioned in Section 3, since the turbidity of ECSW is very low except in near-bottom layer, as will be shown in Section (3).

(2) B-section

The temperature, salinity and turbidity sections are shown in Figs. 7a, b and c, respectively. As seen from the salinity section, CW with salinity lower than 33.0‰ occupies surface layer on the onshore side of the front near Stn. 23. Surface measurements indicate that the width

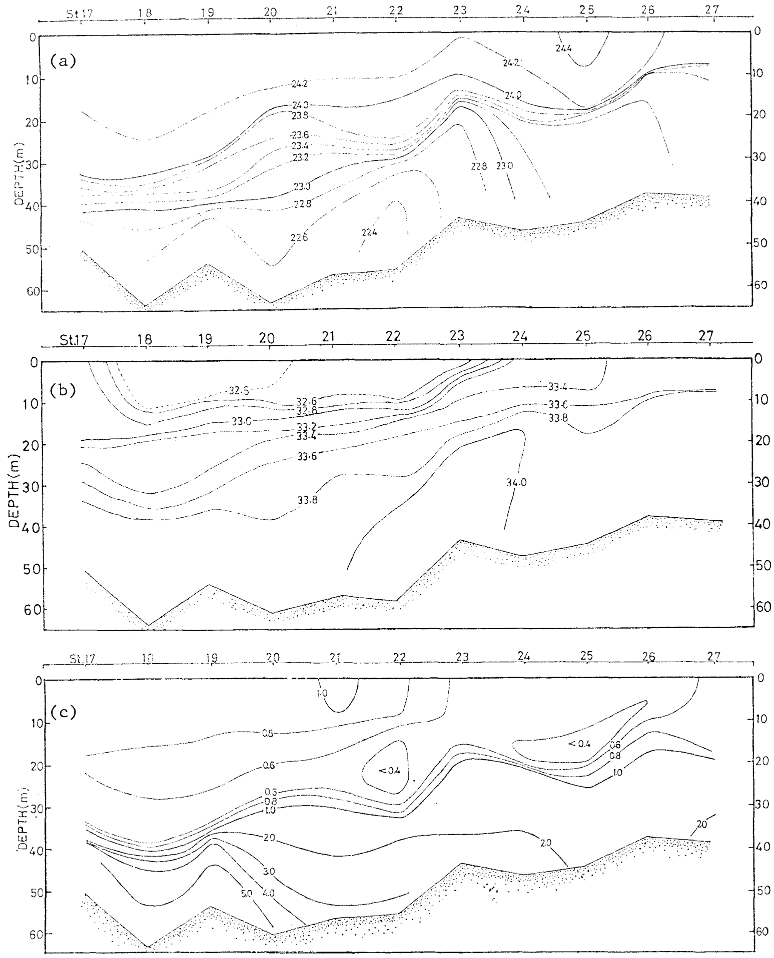

Fig. 7. Vertical sections along B-section; (a) temperature (°C), (b) salinity (‰) and (c) beam attenuation coefficient (m^{-1}).

of the frontal zone is about 6 km, and the salinity changes from 32.6‰ on the onshore side to 33.4‰ on the offshore side across the front. A seasonal thermocline is found at a depth of 20 to 40 m, and the high salinity ECSW (S>33.8‰) lies below the seasonal thermocline as in A-section.

The turbidity of CW is nearly constant ($\alpha \simeq 0.8\,\mathrm{m}^{-1}$) between Stns. 17 and 22, and decreases offshore from $0.8\,\mathrm{m}^{-1}$ at Stn. 22 to $0.5\,\mathrm{m}^{-1}$ at Stn. 23, indicating the presence of turbidity front. In contrast with YRDW, however, the location of the turbidity front is found significantly on the onshore side of the front identified in the salinity section. Near the salinity front the turbidity is uniform ($\alpha \simeq 0.5\,\mathrm{m}^{-1}$). The turbidity is also high ($\alpha > 1.0\,\mathrm{m}^{-1}$) below the seasonal thermocline. The turbidity distribution near the sea bed significantly varies along the section, which may reflect the spatial variations of the properties of bottom sediments and also the change of the intensity of tidal current in the observation period.

(3) C-section

The temperature, salinity and turbidity sections are shown in Figs. 8a, b and c, respectively. The distributions in the region between Stns. 28 and 1, obtained by measurements 14 days apart, are drawn by dashed lines. The isopleths between Stns. 28 and 2 are determined by interpolation. The high salinity ECSW (S>33.7‰) occupies the region south of Stn. 2 and the low salinity YSCW (S≃32.0‰) the region north of Stn. 4. Near Stn. 28 CW with salinity lower than 33.0‰ lies near the water surface. In the region north of Stn. 2 the temperature and salinity are vertically uniform presumably associated with the intense tidal mixing and also with the wind mixing. Two fronts, which intersect the bottom, are found near Stns. 2 and 4. Near Stn. 2 the temperature front is more distinct near the

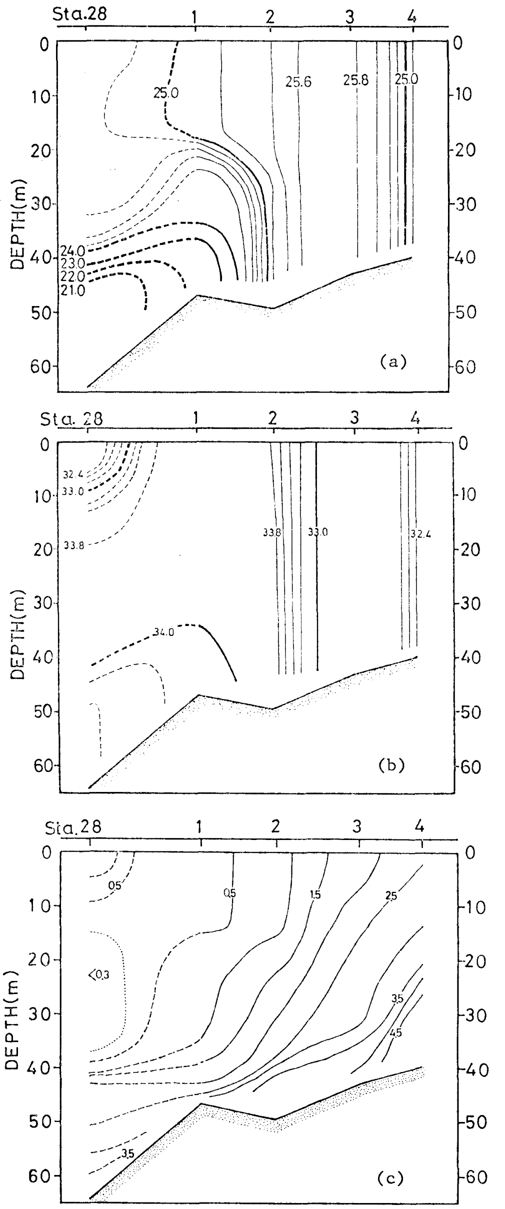

Fig. 8. Vertical sections along C-section; (a) temperature (°C), (b) salinity (‰) and (c) beam attenuation coefficient (m^{-1}).

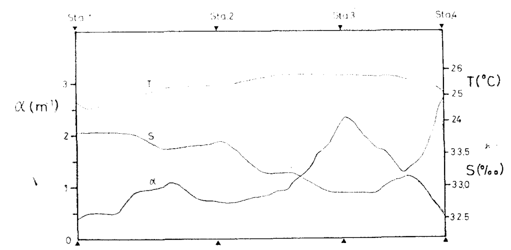

Fig. 9. Surface measurements of temperature T (°C), salinity S (‰) and beam attenuation coefficient α (m^{-1}) from Stn. 1 to Stn. 4.

bottom than the surface. The width of the front near Stn. 2 is about 20 km, and, across the front, the salinity and the temperature near the bottom change by 1.0°C and 0.6‰, respectively.

Except in the near-bottom layer, the turbidity of ECSW is very low ($0.2<\alpha<0.5\,m^{-1}$). The values of α are comparable with those in the low turbidity region found in A-section (Fig. 5c). The values of α become to increase northward near Stn. 2 where a front is formed and the seasonal thermocline disappears. At just north of Stn. 2, α exceeds $1.0\,m^{-1}$ at any depth from the water surface to the bottom. In this area α increases downward monotonously from the water surface to the bottom, while T and S are vertically uniform. This suggests that the high turbidity in this area is brought about by the upward diffusion of the bottom sediments, and it even affects the turbidity distribution near the water surface.

The surface measurements between Stns. 1 and 4 (Fig. 9) show some features smaller than the station intervals. The near-surface values of α and S show small scale variations with negative correlation, which may reflect the complicated advection processes in the frontal zone between ECSW and YSCW. In Section 3 the presence of a turbid band intruding along 32°N toward east was shown (Fig. 3). The turbid band may result not only from the local suspension of bottom sediments by the intense tidal stirring but also from the advection of turbid, less saline water from the near coast as noted by YAN *et al.* (1981).

5. Properties of suspended matters

The water sampling was made at the surface along A-section and along C-section at some depths. The concentration of total suspended matters SS, the concentration of inorganic matters IOM (=SS - COM) and the particle size were examined.

Figure 10 shows SS, COM and IOM at the water surface along A-section, indicating that not only SS but also the composition of suspended matters significantly varies across the front lying between Stns. 11 and 12. On the onshore side of the front (Stns. 12 - 16) IOM/COM is nearly 1 but is about 0.5 on the offshore side (Stns. 5 - 11). The particle size distributions also significantly vary across the front. As seen from Fig. 11, the frequency of particle size larger than 5 μm decreases from 35 to 40% on the onshore side to 10 to 15% on the offshore side.

The measurements along C-section are summarized in Table 1. At Stn. 28, where the measurements were made at various depths, SS is large in the near-surface CW and also in a near-bottom layer, and very small in the intermediate layer occupied by clean ECSW (Fig.

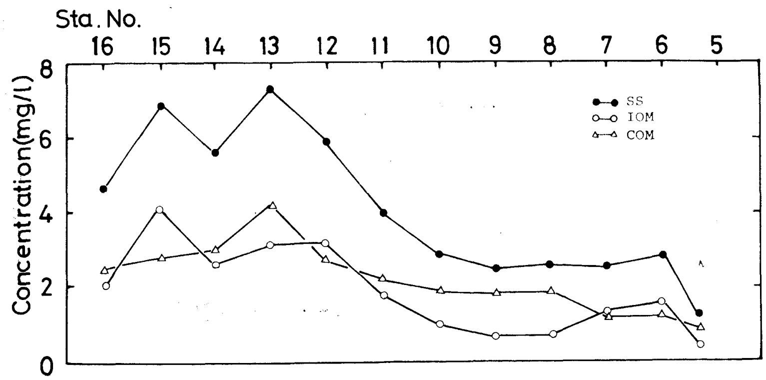

Fig. 10. Distributions of suspended matters at the water surface along A-section. SS, COM and IOM (=SS−COM) indicate the concentration of total suspended matters, the concentration of combustible organic matters and the concentration of inorganic matters, respectively.

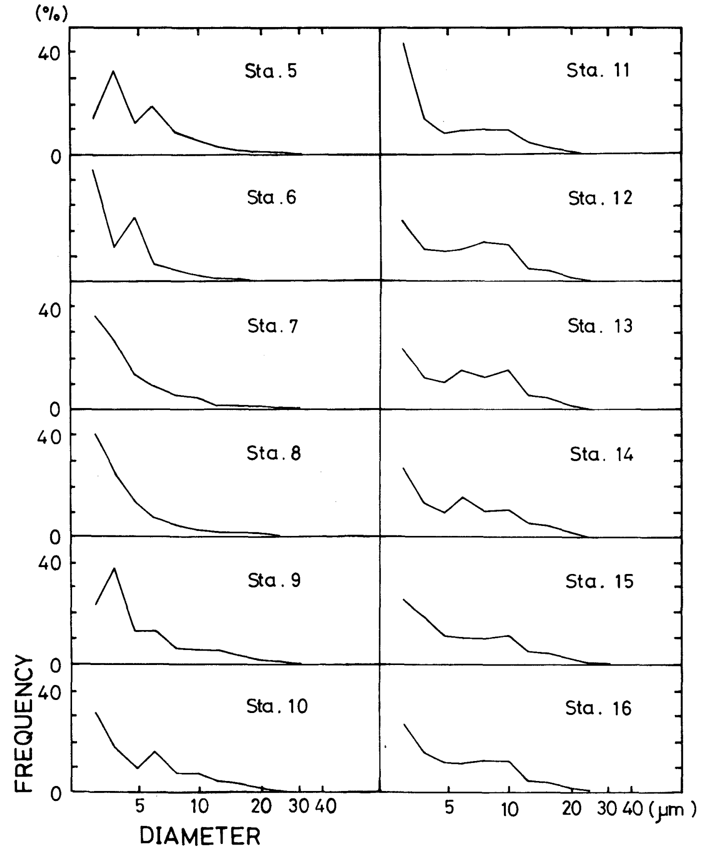

Fig. 11. Size distributions of suspended matters at the water surface along A-section.

Table 1. The concentration of suspended matters SS(mg/l), the concentration of inorganic matters IOM (mg/l) and mean size $\bar{d}$ (μm) for C-section.

Stn. no.	Depth (m)	SS (mg/l)	IOM (mg/l)	$\bar{d}$ (μm)
28	0	1.4	0.6	11.17
	5	1.7	0.7	9.98
	10	1.1	0.5	9.36
	19	0.5	0.1	5.62
	28	0.8	0.1	5.25
	38	0.4	0.1	5.24
	47	2.6	2.1	4.22
	57	4.6	3.6	5.08
1	0	0.7	0.2	8.55
2	0	0.9	0.2	5.71
3	0	2.1	1.1	4.89
4	0	3.1	1.7	4.23

8c). The present results indicate that these variation in SS are caused mainly by the variations of IOM. In particular, in the near-bottom layer, SS is very large and is composed almost of IOM (Table 1). The mean diameter $\bar{d}$ is about 10 μm in CW and nearly constant (about 5 μm) below a depth of 20 m. The surface values of SS become to increase northward near Stn. 2. The increase of IOM, in particular, between Stns. 2 and 3 is quite abrupt. The values of $\bar{d}$ decrease northward, and at Stns. 3 and 4 they were about 5 μm through the whole depth.

6. Summary

The characteristic features of the turbidity distribution in the coastal regions of the East China Sea and the Yellow Sea were described, with special attention to the relation between

the turbidity distribution and the water type distribution. In the coastal regions of the East China Sea and the Yellow Sea there are two major sources of the turbidity; discharge of the turbid Yangtze River, and bottom sediments suspended and diffused by the tidal stirring.

The outflow of the Yangtze River (YRDW) spread toward east, and a distinct front was formed near 123°E. Near the front the YRDW about 5 m thick was highly stratified. Across offshore the frontal zone about 1 km wide, the salinity and the turbidity varied from 23.8‰ to 29.8‰ and from $3.8\,m^{-1}$ to $1.7\,m^{-1}$, respectively, preserving the strong negative correlation, and the ratio of the concentration of inorganic matters to that of organic matters from 1.0 to 0.5. This front seems to define the offshore boundary of the region where the prominent source of the turbidity is the terrigenous matters discharged by the Yangtze River, because no distinct negative correlation was found in water with salinity of about 32.6‰ (CW) occupying just offshore side of YRDW, though the turbidity ($\simeq 0.8\,m^{-1}$) was considerably higher than that of the more saline water (ECSW) occupying the offshore side of the front of CW.

The suspension and diffusion of bottom sediments by the tidal stirring was dominant in both the East China Sea and the Yellow Sea, but its influence on the turbidity distribution was different between the East China Sea and the Yellow Sea associated with the difference in the vertical density structures. In the East China Sea, the upward diffusion of bottom sediments was strongly suppressed in the seasonal thermocline, and the turbid water was confined below the seasonal thermocline. In the coastal region of the Yellow Sea, on the other hand, the temperature and salinity were vertically uniform, and the bottom sediments were considered to be diffused up to the water surface. The effect of tidal stirring was very intense in the onshore region shallower than about 25 m from about 32°N to 34°N. In this area distinct color fronts were found, but across them the salinity and temperature showed no particular variations, which indicates that in the coastal region of the Yellow Sea the turbidity front does not necessarily coincide with the salinity or the temperature front.

Acknowledgements

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東海沿岸域のフロント付近における濁度分布

松生　洽，奥田邦明，上原研吾

要旨: 東海及び黄海沿岸域における濁度分布の特徴を，フロントを横切る断面観測，及びそれを補う広域にわたる表層連続観測に基づいて述べる。観測は1981年9月，揚子江河口沖海域において集中的に行われた。調査海域における高濁度の主な原因は，濁った揚子江河川水の流出と，潮流による海底堆積物の上方への拡散であった。揚子江河川水は東に分散し，123°E 付近に顕著なフロントを形成していた。フロント付近において，約 5 m の厚さの河川水域は強く成層し，塩分と濁度分布は強い負の相関を示した。約 1 km の幅のフロント域を横切って，塩分，濁度の値及びその分布だけでなく，懸濁物質の性質も顕著な変化を示した。海底堆積物の上方への拡散は，特に黄海沿岸域において顕著であった。季節躍層の存在している東海沿岸域では，海底堆積物の上方への拡散は季節躍層付近までに限定されていたのに対し，季節躍層の消滅している黄海沿岸域では，海底堆積物の拡散は水面にまで及び，水面から海底に到る全層で高濁度を示した。

La mer 21: 145–150, 1983
Société franco-japonaise d'océanographie, Tokyo

Relative Yields of Marine Algae Grown in Heavily Nutrient-enriched Seawater*

Serge Y. MAESTRINI** and Eliane GONZALEZ-RODRIGUEZ***

Résumé: Valeurs relatives de la biomasse produite par des algues marines cultivées dans de l'eau de mer fortement enrichie en nutriments. Six algues marines ont été cultivées dans de l'eau de mer, enrichie soit avec des produits de laboratoire soit avec des produits industriels. Avec les produits de laboratoire, la biomasse maximale est obtenue avec environ 1.700 μg-at. l^{-1} d'azote, les autres éléments étant présents à des concentrations équilibrées, alors qu'avec les composés non raffinés de qualité industrielle cette même biomasse est obtenue dans une gamme allant de 250 à 1.000 μg-at.l^{-1} d'azote et des valeurs 10 fois moindres de phosphore. Dans l'ensemble, les enrichissements les moins concentrés conduisent aux meilleurs rendements et au minimum de gaspillage en nutriments. Tous aspects confondus, l'usage de 500 μg-at.l^{-1} d'azote et 50 μg-at.l^{-1} de phosphore est le meilleur compromis pour la production massive d'algues unicellulaires marines.

Abstract: Six marine algae have been grown at different concentrations of nutrients, either provided by laboratory-grade or industrial-grade compounds. The absolute maximum biomass was obtained at approximately 1,700 μg-at.l^{-1} nitrogen and other nutrients at balanced levels with laboratory-grade compounds, and within 250–1,000 μg-at.l^{-1} nitrogen and 1/10 phosphorus with industrial-grade compounds. On the whole, the lowest concentration led to the best use of nutrients and minimum waste. Authors assess that the use of concentrations of 500 μg-at.l^{-1} nitrogen and 50 μg-at.l^{-1} phosphorus industrial-grade compounds is an acceptable compromise for controlled mass cultures.

1. Introduction

The mass production of algae has been hitherto most frequently devised with the prerequisite of getting a high value of the ratio biomass production/volume of culture vessel (*e.g.* pertaining to marine strains: UKELES, 1965, 1973; CANZONIER and BRUNETTI, 1975; DROOP, 1975; GUILLARD, 1975; FLASSH, 1978; HELM *et al.*, 1979; SPECTOROVA *et al.*, 1981/1982; TROTTA, 1981). Otherwise, since the culture equipments have been experimentally operated or have supported a limited high-cost shellfish production, little attention has been paid to the financial cost of inorganic compounds used to enrich the water. However, the possible and hoped development of aquaculture, either at a high-rate and industrial size or at low-rate and rural size (see *e.g.* SOEDER, 1980; ARRIGNON, 1982), will critically require (i) the availability of low-cost algal nutrients and (ii) the need of knowledge of concentrations which lead to the lowest nutrient losses.

Some attempts to provide low-cost nutrients have been based on human or bioindustrial waste recycling (RYTHER *et al.*, 1972; DE PAUW and DE LEENHEER, 1979) or artificial upwelling of deep nutrient-rich water (ROELS *et al.*, 1971; MOREIRA DA SILVA, 1971; NEVE *et al.*, 1976). Waste nutrients which are in fact a byproduct of water reclamation are cheap, but they are not free from contamination. On the contrary, deep waters are clean and could be a suitable source for aquafarming, were it not that convenient sites are quite rare. Thus, that brings

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us back to the use of inorganic compounds for enrichment of seawater.

The use of industrial-grade compounds for preparing algal-culture media is not at all a novelty, indeed (LOOSANOFF and ENGLE, 1942; VOSKRESENSKY and YURINA, 1965; UKELES, 1980; SPECTOROVA *et al.*, 1981/1982; WITT *et al.*, 1981). On the contrary, little attention if any has been paid, so far, to the efficiency of biomass production versus nutrient enrichment. In other words, losses of nutrients resulting from luxury uptake and/or subsequent excretion, or unbalanced respective concentrations have been neglected; see however BOYD and MUSIG (1981).

The researches reported below were based upon the aim of pointing out the best concentration for nutrient enrichment of sea water.

2. Materials and methods

Six algal species routinely maintained in axenic conditions were used: one Bacillariophyta: *Phaeodactylum tricornutum* BOHLIN; one Chlorophyta: *Chlamydomonas palla* BUTCHER; one Cryptophyta: *Rhodomonas lens* PASCHER and RUTTNER; one Eustigmatophyta: *Monallantus salina* BOURRELLY; and two Haptophyta: *Isochrysis galbana* PARKE and *Pavlova pinguis* GREEN.

The cultures were made in test tubes, 22× 220 mm, containing 20 ml medium. They were incubated at 18°C constant temperature and illuminated with fluorescent tubes especially devised for plant culturing, with 14 h illumination and 10 h darkness and ≃6,000 lux. The growth was followed by daily measurement of optical density at 600 nm. All cultures were made in duplicates.

Two sets of nutrient enrichments were made: (i) The Conway medium (WALNE, 1966), at 0.5, 1, 1.5, 2 and 3 fold concentrations; which resulted in 585, 1,170, 1,750, 2,340 and 3,500 μg-at. l^{-1} NO_3-N, respectively, and other nutrients at balanced levels. (ii) A mixture of industrial-grade compounds: Ammonium nitrate COFAM^R 33.5 %, Superphosphate COFAM^R 18 % and Iron-sequestrene Fredilom^R 138 (EDDHA-Fe) 6 %; this mixture was used at different concentrations in order to obtain respectively 250, 500, 750, 1,000 and 1,500 μg-at.l^{-1} nitrogen, and phosphorus and iron at balanced levels. The nitrogen/phosphorus ratio always had a value of 10, in order to obtain cells showing a status of nutrient satiety (HEALEY, 1975, 1978).

Because optical density is questionable for absolute biomass estimation, the yield coefficient (unit optical density per unit nitrogen) has been

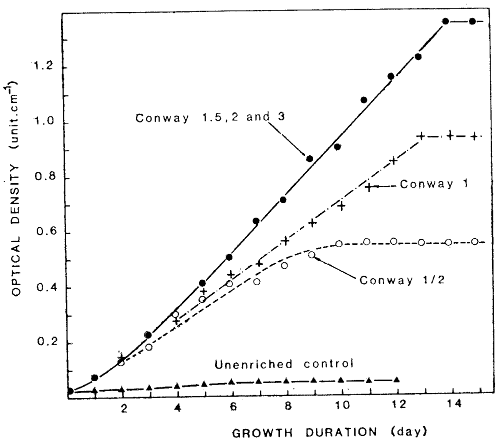

Fig. 1. Cell density, as optical density, versus growth duration of the diatom *Phaeodactylum tricornutum* grown at varied concentrations of Conway enriching mixtures and unenriched control.

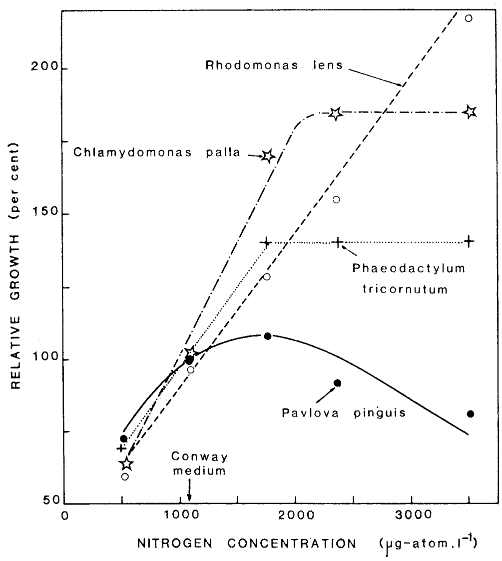

Fig. 2. Relative growth, as percent of growth in Conway medium, of four marine algae grown at different nutrient concentrations depicted by the nitrogen concentration.

computed as relative yield versus the one obtained with regular Conway medium or a similar nutrient concentration.

3. Results

All the cultures behaved smoothly. The lag phase was short, if any. Figure 1 depicts a typical set of experimental data.

The highest nutrient concentration did not necessarily induce the highest algal biomass, except for *Rhodomonas lens* (Fig. 2). With *Pavlova pinguis*, the maximum biomass was obtained for N=1,750 μg-at.l^{-1} and other nutrients at balanced levels; then the biomass decreased. For three other algae, *Isochrysis galbana*, *Monallantus salina* and *Phaeodactylum tricornutum*, the maximum biomass was also shown at the same value, but there was not a decrease; the biomass remained at a plateau. The Chlorophyta *Chlamydomonas palla* pertained to an intermediate case between *Rhodomonas lens* and the group of the former three algae.

Plotting the relative yield coefficient values against the nutrient concentrations clearly demonstrated that the more concentrated the nutrients the lesser the biomass produced per unit number of nutrient provided (Fig. 3). The Haptophyta *Pavlova pinguis*, whose biomass has decreased with highest nutrient concentrations, shows the most drastic decrease of the yield index values. On the contrary, the curve belonging to *Rhodomonas lens* has the slightest slope. Curves of other algae range between these two extremes.

The respective behavior of the same test algae was notably different when grown at increasing concentrations of N+P+Fe-sequestrene provided with industrial-grade compounds. *Chlamydomonas palla* showed a maximum biomass for a nitrogen concentration ranging from 750 to 1,000 μg-at.l^{-1}; at higher concentrations the biomass decreased dramatically (Fig. 4). For *Rhodomonas lens* the biomass increase was quite proportional to the nutrient-concentration increase. Contrariwise, the respective maximum biomass of *Isochrysis galbana*, *Monallantus salina* and *Pavlova pinguis* was maximum with the lowest nutrient concentration (250 μg-at.l^{-1} nitrogen) and decreased sharply at the double value, and then decreased slowly. With *Phaeodactylum tricornutum*, the biomass increased up to the 500 μg-at.l^{-1} nitrogen concentration and then also slowly decreased.

The respective curves of relative yield index versus nutrient concentration better depict the waste of nutrients at higher concentrations

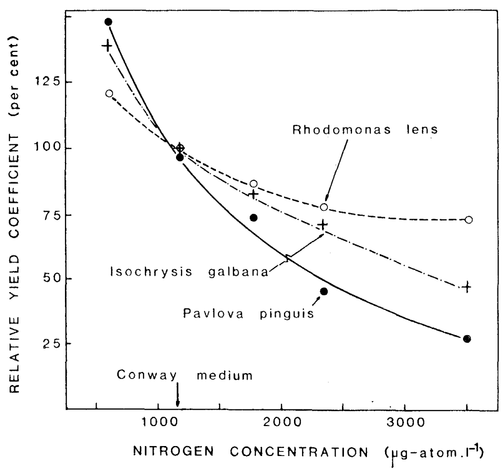

Fig. 3. Relative yield coefficient, as percent of the one obtained with the regular Conway medium, of three marine algae grown at increasing nutrient concentrations depicted by the nitrogen concentration.

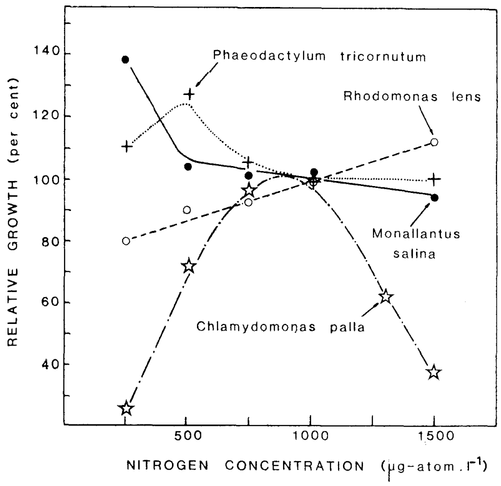

Fig. 4. Relative growth, as percent of growth in Conway-like concentration, of four marine algae grown at different nutrient concentrations depicted by the nitrogen concentration.

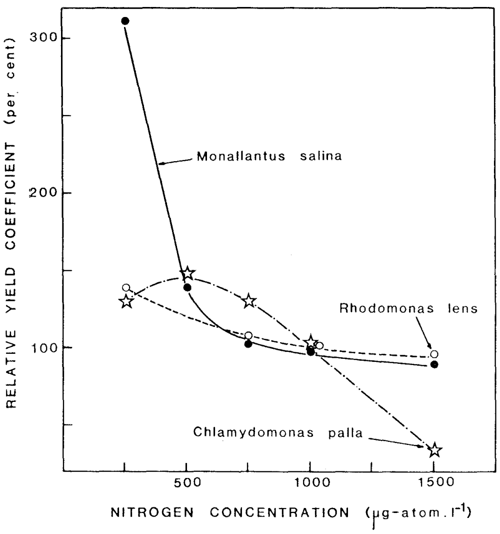

Fig. 5. Relative yield coefficient, as percent to the one obtained with Conway-like concentration, of three marine algae grown at increasing nutrient concentrations depicted by the nitrogen concentration.

(Fig. 5). As a matter of fact, with *Monallantus salina* and the two other companion species, the production of biomass is drastically more efficient at the lowest nutrient concentrations; the decrease of the yield is quite fast, indeed, down to half the value with 500 μg-at.l^{-1} nitrogen and 3 fold less with the maximum concentration involved. With *Rhodomonas lens* the shape of the curve depicts a slow and continuous rate of decrease of the yield index value. *Chlamydomonas palla* showed an increase from 250 to 500 μg-at.l^{-1} nitrogen, then a sharp decrease, down to 35 % of the one obtained with a Conway-like concentration (=1,170 μg-at.l^{-1} nitrogen).

4. Discussion

For all the tested species, the maximum yield could be enhanced by increasing 1.5 fold the nutrient concentration of the Conway medium (WALNE, 1966) prepared with laboratory-grade compounds; only one alga, *Rhodomonas lens*, allows an increase up to 3 fold the regular concentration. That is, however, far lower than the concentration used by SPECTOROVA *et al.* (1981/1982): 18 mg-at.l^{-1} NO_3-N and other nutrients at balanced levels, for the high-density culture of the marine flagellate *Dunaliella tertiolecta*. Unfortunately, the parameter these authors used, namely dry weight, and the one we used do not allow a comparison of results and to assess whether the use of such huge quantities of nutrients led to a subsequent increase of biomass. However CHU (1943), who grew an array of six algal species including Chlorophyta and diatoms at increasing nitrogen concentrations up to 6.1 mg-at.l^{-1}, brought data which demonstrated that the biomass of all species, but one, was maximum within a range of 494–757 μg-at.l^{-1} NO_3-N, and the exceptional species at 1,221 μg-at.l^{-1}; all extra added nitrogen was wasted. WITSCH and HARDER (1961) had an evidence that increasing three fold the initial nitrogen concentration of the medium where they grew *Chlorella pyrenoidosa* only slightly increased the final standing crop (cell density and dry weight). That is not surprising, indeed, since they used huge quantities of nutrients: 5.5 mg-at.l^{-1} NO_3-N, whereas BERLAND *et al.* (1973) later demonstrated that the biomass yielded is no longer proportional to nutrient concentration when the latter is very high. Thus, with the diatom *Skeletonema costatum* non-linearity is observed with concentration above 40 μg-at.l^{-1} nitrogen.

The mixture N+P+Fe-sequestrene prepared with industrial-grade compounds is not at all convenient, as far as maximum biomass is concerned. As a matter of fact, *Rhodomonas lens* was the only alga showing a continuously increased biomass at increasing concentrations of nutrients. *Chlamydomonas palla* showed an increased biomass up to the Conway-like concentration (*i.e.* 1,000 μg-at.l^{-1} nitrogen) and then a decrease. For the four other species, the respective maximum biomass pertained to lower concentrations: 500 μg-at.l^{-1} nitrogen for *Phaeodactylum tricornutum*, and 250 μg-at.l^{-1} nitrogen for *Isochrysis galbana*, *Monallantus salina* and *Pavlova pinguis* (Fig. 4). Published data in this field are rare, and thus any comparison is difficult. However, WITT *et al.* (1981) stated that "excessively high nutrient concentrations such as 12 mg N/l and 2.4 mg P/l did not lead to growth inhibition"; yet these concentrations are not really high, since 12 mg.l^{-1} nitrogen = 857 μg-at.l^{-1}, and 2.4 mg.l^{-1} phosphorus = 80 μg-at.l^{-1}. The origin of this unexpected inhibition of crop production is probably due to an excess of inorganic micronutrients which act at low concentrations (BERLAND *et al.*, 1976) and which are brought by unpurified compounds; unfortunately no information was obtainable from the manufacturer and no analysis could be done to confirm this hypothesis.

For either laboratory-grade or industrial-grade compounds the respective algal biomass produced per unit atom of nutrient added (=yield coefficient) decreases at increasing concentrations of nutrients. However, there are some species differences: the decrease is continuously slight for *Rhodomonas lens* (Figs. 3 and 5), continuously sharp for *Pavlova pinguis* (Fig. 3), or sharp from the lowest concentration to intermediate concentrations and then slight for *Monallantus salina* (Fig. 5).

Thus, on the whole, the lowest concentrations lead to the best use of nutrients by algae; the waste is minimum. However, the absolute maximum biomass is obtained with an approximate concentration of *e.g.* 1,700 μg-at.l^{-1} nitrogen and other nutrients at balanced levels according to WALNE (1966) with laboratory-grade compounds, and within 250–1,000 μg-at.l^{-1} nitrogen with industrial-grade compounds. The final choice is therefore a matter of compromise.

Since (i) the industrial-grade compounds are much cheaper than chemically refined items and thus are solely convenient for large-scale enrichment, (ii) the yield index is maximum or slightly decreased for 500 μg-at.l^{-1} nitrogen, except for only one species, (iii) the absolute maximum biomass is maximum or slightly decreased at this same value, and (iv) other results have brought the evidence that Fe-sequestrene is frequently useless (GONZALEZ-RODRIGUEZ, 1982), we think using concentrations of 500 μg-at.l^{-1} nitrogen and 50 μg-at.l^{-1} phosphorus is an acceptable compromise for controlled mass culturing of marine algae.

Further researches will be needed to investigate the cell status of algae grown in such a medium.

Acknowledgements

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高度に栄養塩添加した海水中で培養した海産微細藻の収量

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要旨: 6種の海産微細藻を，研究用試薬または工業用試薬を用いて調整した種々の栄養塩濃度の培地で培養した結果，最大収量は，研究用試薬を用いた場合には約 1,700 μg-at.N・l^{-1}（他の栄養塩は完全調整）で，工業用試薬を用いた場合には 250-1,000 μg-at.N・l^{-1} と 1/10 P 濃度で得られた。全体として，栄養塩は最も低い濃度で最もよく利用され，無駄が最も少なかった。制御された大量培養のためには，工業用試薬では 500 μg-at.N・l^{-1} および 50 μg-at.P・l^{-1} の濃度を採用するのが妥当と考えられる。

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Vertical Distribution of Euphausiids in Sagami Bay, Central Japan*

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Abstract: The vertical distribution of adult and juvenile euphausiids in Sagami Bay, Central Japan, was studied. Species belonging to the genus *Euphausia* such as *E. nana*, *E. similis*, *E. recurva* and *E. tenera* were dominant in Sagami Bay, and the maximum abundance was observed between depths of 300 and 350 m during the day, and between 10 and 50 m during the night. Distribution depths of *E. similis* and *Nematoscelis gracilis* became deeper with increase in body size; at night *E. similis* of 5 to 10 mm long was found between 30 and 75 m depths but one of 15 to 20 mm long was found between 100 and 200 m. The depth of maximum abundance for each *Euphausia* species was constant throughout the night. "Midnight sinking" and "dawn rise" were not observed in the present study. Vertical segregation of species within the same genus was clear for *Euphausia* and *Stylocheiron*; *E. similis* and the *E. gibba* group (*E. pseudogibba* and *E. hemigibba*) were distributed deeper than other *Euphausia* species such as *E. tenera*, *E. nana* and *E. recurva* at night. The vertical distribution of *Stylocheiron* species became deeper all day in the following order: *S. carinatum*→*S. suhmii* →*S. affine*→*S. longicorne*→*S. elongatum*.

1. Introduction

Euphausiids are divided into three groups, epipelagic, mesopelagic and bathypelagic species according to their vertical ranges (BRINTON 1962). Several reports indicate that larger individuals of a species are distributed at greater depths than smaller individuals (EINARSSON 1945, PONOMAREVA 1959, MAUCHLINE 1960, WIBORG 1971, ANTEZANA 1978). Some species demonstrate diurnal vertical migration while other species are non-migrant. Residence time of migrant species in the epipelagic zone at night varies with species, some occurring in the epipelagic zone throughout the night while some occurring at night before midnight and others occurring after midnight (ROGER 1971, ANTEZANA 1978). There is a clear tendency for vertical segregation among species within one genus (such as *Stylocheiron*) which do not exhibit diurnal vertical migration (BAKER 1970, BRINTON 1979).

It is thought that the factors influencing the vertical distribution and migration of euphausiids are light intensity, water temperature, dissolved oxygen content and the vertical distribution of food (LEWIS 1954, BODEN and KAMPA 1965, BRINTON 1967, 1979, YOUNGBLUTH 1975, 1976).

This study reports on the vertical distribution of euphausiids including (1) changes in the depth of occurrence according to size, (2) diurnal vertical migration and (3) vertical segregation of species within the same genus, in Sagami Bay where seasonal variation in water temperature is large.

We would like to thank the captains and crews of the R. V. Tansei Maru and the R. V. Hakuho Maru of the Ocean Research Institute, University of Tokyo, for their kind assistance in the collection of material.

2. Materials and methods

The samples were obtained in Sagami Bay during five cruises of the R. V. Tansei Maru

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and the R. V. Hakuho Maru of the Ocean Research Institute, University of Tokyo (Table 1, Fig. 1). An MTD net with a mouth diameter of 0.56 m and a mesh size of 0.33 mm (MOTODA 1971) was towed horizontally for about 30 minutes. Samplings were generally operated between the surface and 400 m depth. Depth of the net was estimated from records of Time-Depth meter (Yanagi Instrument Co., Ltd.) installed on the triangular frame or from the wire angle during towing. A flowmeter (Rigosha & Co., Ltd.) was installed in the mouth of each net to estimate the volume of water filtered. Filtered volume ranged from 100 to 800 m^3.

Table 1. Data on MTD net collections in Sagami Bay.

Cruise	Section	Date	Time
KT-77-13	S-4	Sept. 15-16, 1977	22:28-01:10
KT-78-15	S-2	Sept. 10, 1978	10:32-11:04
	S-2	Sept. 04, 1978	22:35-23:20
	S-4-1	Sept. 07, 1978	12:34-15:10
	S-4-2	Sept. 07, 1978	19:00-19:36
	S-4-3	Sept. 07, 1978	21:18-21:56
	S-4-4	Sept. 07-08, 1978	23:37-00:18
	S-4-5	Sept. 08, 1978	02:11-02:47
	S-4-6	Sept. 08, 1978	04:14-04:49
	S-4-7	Sept. 08, 1978	05:25-05:59
KH-78-5	S-1	Dec. 11-12, 1978	22:02-00:10
	S-3-1	Dec. 16, 1978	12:35-13:05
	S-3-2	Dec. 16, 1978	15:38-16:08
	S-3-3	Dec. 16, 1978	17:26-17:56
	S-3-4	Dec. 16, 1978	19:28-19:58
	S-3-5	Dec. 16, 1978	21:30-22:13
	S-3-6	Dec. 17, 1978	00:04-00:38
	S-3-7	Dec. 17, 1978	02:37-03:09
	S-3-8	Dec. 17, 1978	04:31-05:04
	S-3-9	Dec. 17, 1978	06:26-07:00
	S-3-10	Dec. 17, 1978	10:13-10:43
KT-79-11	S-2	July 16, 1979	03:40-04:10
KT-80-4	S-2	Mar. 15, 1980	11:32-13:08
	S-2	Mar. 15, 1980	21:15-22:55

The samples were preserved in 5-10% buffered formalin sea water immediately after collection. Juveniles and adults were sorted and identified. Biomass of each species (expressed as wet weight) was measured with a precision balance (Mettler P-120 type).

Temperature was measured with a mechanical BT or digital BT.

3. Results

1) Hydrography

Vertical profiles of water temperature in July 1979, September 1978, December 1978 and March 1980 are shown in Fig. 2. Surface temperature varied considerably within a year, between 25°C in September and 14°C in March. A seasonal thermocline clearly existed between 20 and 60 m in July and September, but disappeared in December and March. No seasonal

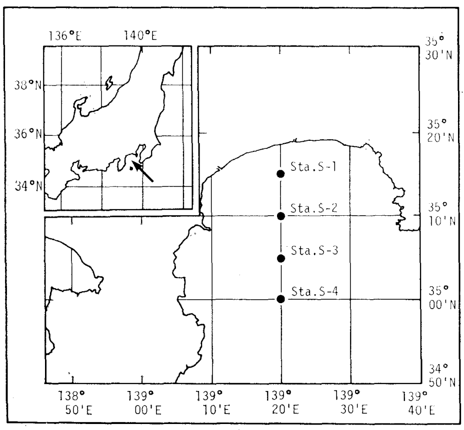

Fig. 1. MTD net sampling stations in Sagami Bay from 1977 to 1980.

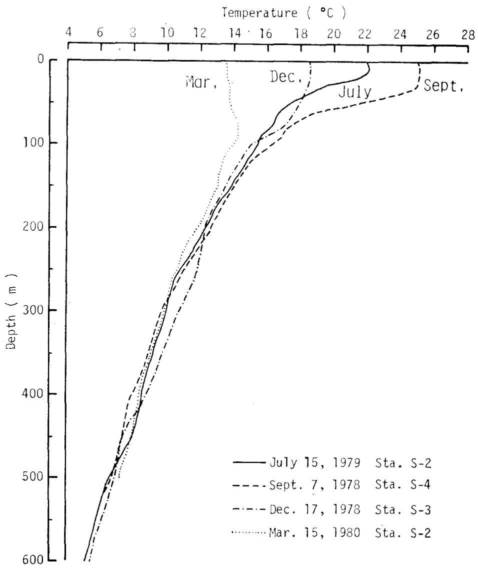

Fig. 2. Vertical profiles of water temperature in Sagami Bay.

change in the temperature of the waters deeper than 150 m was evident.

2) *Vertical distribution of euphausiids*

In the daytime, euphausiids were most abundant between 300 and 350 m depths in September 1978, December 1978 and March 1980. (In July 1979, no samples were collected in the daytime.) During the night they were most abundant at 10 m in July and September and at around 50 m in December and March (Fig. 3).

Fig. 4 shows the vertical distribution of euphausiid biomass expressed as wet weight. Biomass of euphausiids was greatest between 300 and 400 m in the daytime, whereas at night it

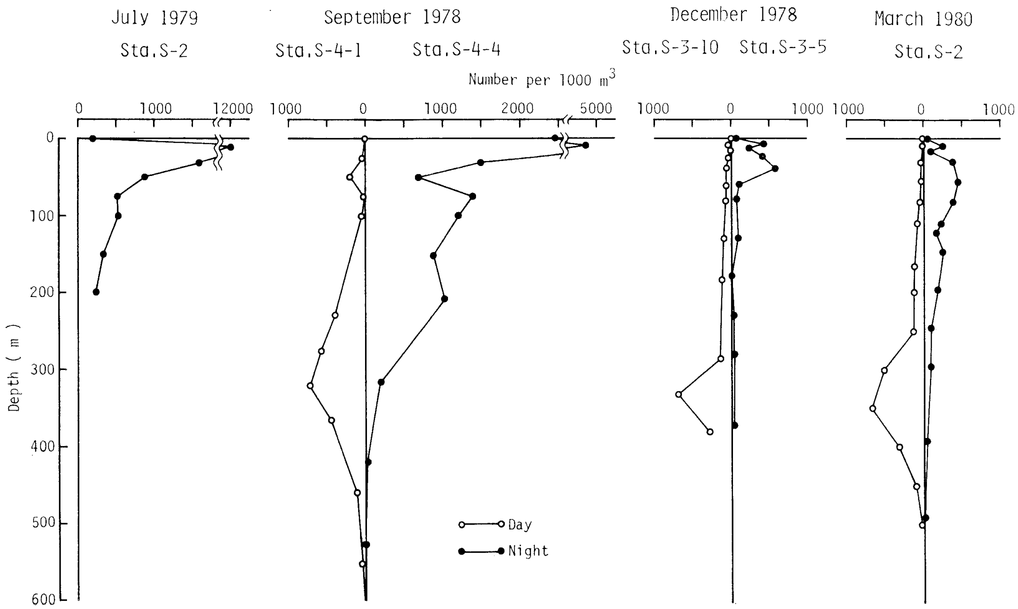

Fig. 3. Vertical distribution of euphausiid numbers in Sagami Bay.

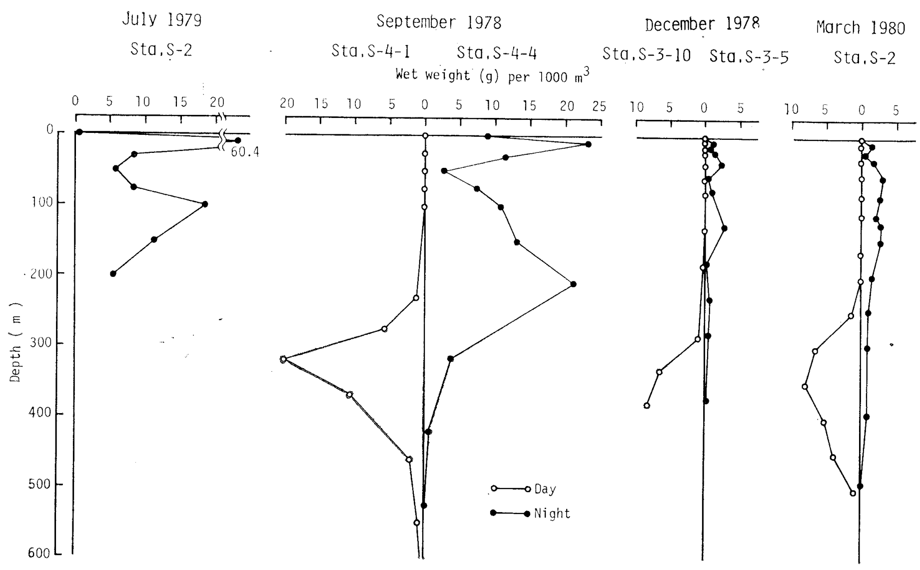

Fig. 4. Vertical distribution of euphausiid biomass (wet weight) in Sagami Bay.

showed a bimodal distribution in July and September. The depths of maximum abundance were observed at 10 m and 100 m in July and at 10 m and 200 m in September. About 95 % of euphausiid biomass at the shallower maximum consisted of *Euphausia nana* and *E. recurva* and 87 % of the biomass in the deeper maximum consisted of *E. similis*.

Euphausia species formed 66.7 % of the total euphausiids in the four sample series and were followed by *Nematoscelis* species occupying 14.5 %.

Biomass of euphausiids in the winter season (December and March) was far less than that in the summer season of July and September. On average, *Euphausia* species formed 68.7 % of total euphausiid biomass in these four samples and *Nematoscelis* species 25.8 %.

3) *Vertical distribution of each euphausiid species*

In this study, 33 species belonging to 8 genera were collected from Sagami Bay (Table 2). Seasonal occurrence varied with species.

Euphausia recurva occurred mainly in September and December. Juveniles and adults of this species were most abundant at a depth of about 300 m in the daytime and at 10 m at night in September and between 30 and 40 m in December at night.

Euphausia nana was a dominant species in Sagami Bay and occurred all year round (Fig. 5). In the daytime, juveniles were mainly distributed between 200 and 300 m and adults at about 300 m. At night, most juveniles and adulst were distributed between 0 and 30 m, but in September 1978 adults were widely distributed between 0 and 200 m without any clear maximum concentration.

Euphausia similis was found all year round in Sagami Bay (Fig. 6). In the daytime, juveniles occurred between 300 and 350 m and adults were distributed below 350 m depth. At night, there were maximum concentrations of juveniles at a depth of 40 m in December, 50 m in March, 100 m in July and 200 m in September. Thus, the depth of maximum abundance of this species largely changed in accordance with season with a tendency that the vertical distribution was shallower in winter than in summer. In the South Pacific Ocean, SHEARD (1953) described *E. similis* as being distributed between 25 and 50 m during the night while GRIFFITHS (1979) stated that this species was distributed between 200 and 400 m at night. The vertical range of occurrence of *E. similis* in the present study is intermediate between the ranges in SHEARD's and GRIFFITHS' studies.

Euphausia tenera occurred in Sagami Bay the whole year round (Fig. 7). In the daytime, juveniles and adults were distributed between 200 and 400 m, while at night they came up to

Table 2. A list of euphausiid species collected in Sagami Bay.

Euphausiaceae
Euphausiidae
Thysanopoda monacantha ORTMANN, 1893
Thysanopoda tricuspidata MILNE-EDWARDS, 1837
Thysanopoda aequalis HANSEN, 1905
Thysanopoda obtusifrons G. O. SARS, 1883
Thysanopoda orientalis HANSEN, 1910
Pseudeuphausia latifrons (G. O. SARS, 1883)
Euphausia mutica HANSEN, 1905
Euphausia diomedeae ORTMANN, 1894
Euphausia recurva HANSEN, 1905
Euphausia pacifica HANSEN, 1911
Euphausia nana BRINTON, 1962
Euphausia similis G. O. SARS, 1883
Euphausia tenera HANSEN, 1905
Euphausia gibboides ORTMANN, 1893
Euphausia sanzoi TORELLI, 1934
Euphausia pseudogibba ORTMANN, 1893
Euphausia hemigibba HANSEN, 1910
Tessarabrachion oculatum HANSEN, 1911
Thysanoessa gregaria G. O. SARS, 1883
Nematoscelis difficilis HANSEN, 1911
Nematoscelis tenella G. O. SARS, 1883
Nematoscelis gracilis HANSEN, 1910
Nematoscelis microps G. O. SARS, 1883
Nematobrachion flexipes (ORTMANN, 1893)
Nematobrachion boopis (CALMANN, 1905)
Stylocheiron carinatum G. O. SARS, 1883
Stylocheiron microphthalma HANSEN, 1910
Stylocheiron suhmii G. O. SARS, 1883
Stylocheiron affine HANSEN, 1910
Stylocheiron elongatum G. O. SARS, 1883
Stylocheiron longicorne G. O. SARS, 1883
Stylocheiron abbreviatum G. O. SARS, 1883
Stylocheiron maximum HANSEN, 1908

10 m in July, December and March and to 30 m in September. BRINTON (1979) reported that *E. tenera* was mainly distributed between 200 and 350 m in the eastern tropical Pacific in the daytime. This agrees with our results. YOUNGBLUTH (1975) showed that juveniles and adults of *E. tenera* were distributed between 350 and 650 m, a level somewhat deeper than our results, during the day in the central waters of the eastern South Pacific. YOUNGBLUTH (1976) also showed that the depth of occurrence of *E. pacifica* in coastal waters off California was shallower than in ocean waters. He speculated that in coastal regions in which a high standing

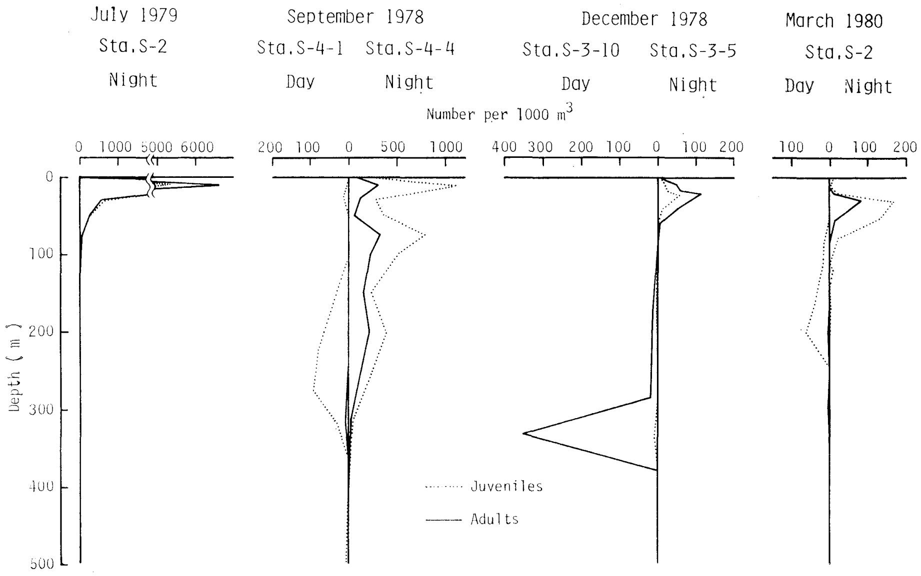

Fig. 5. Vertical distribution of *Euphausia nana* (numbers) in Sagami Bay.

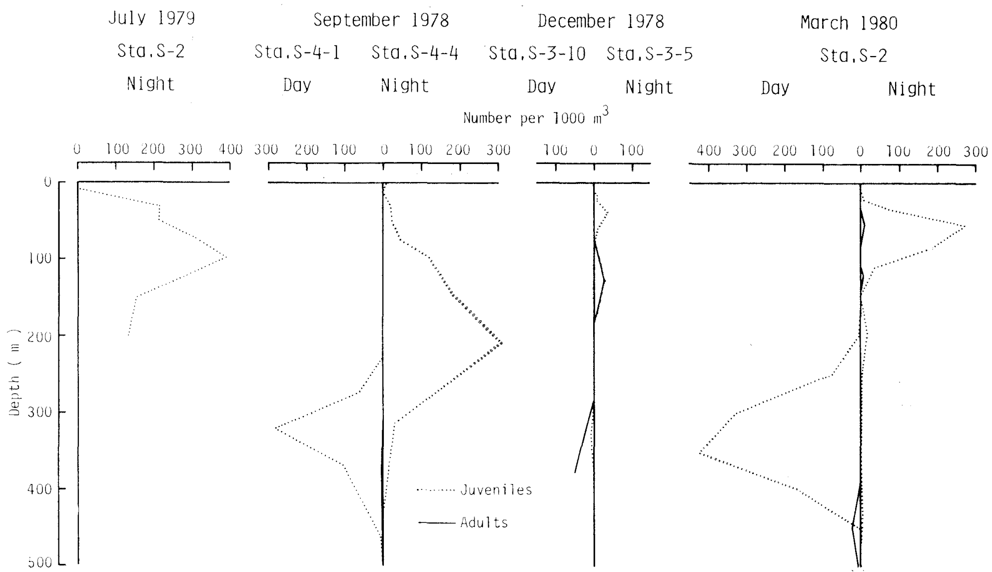

Fig. 6. Vertical distribution of *Euphausia similis* (numbers) in Sagami Bay.

crop of phytoplankton occurs, light penetration is lower and *E. pacifica* comes up into shallower depths as a result. The daytime distributions of *E. tenera* in Sagami Bay and the eastern tropical Pacific, where phytoplankton standing crop is high, were shallower than in the central waters of the eastern South Pacific where the standing crop is lower. Thus, the result of this study supports YOUNGBLUTH's hypothesis.

Nematoscelis gracilis occurred in Sagami Bay the whole year round (Fig. 8). In the daytime, small juveniles occurred in the upper 100 m and large juveniles between 100 and 400 m, while adults were distributed between 300 and 400 m. At night, juveniles occurred in the upper 100 m layer. Adults occurred between 100 and 200 m in September and December and between 100 and 400 m in March. BRINTON (1979) found that in the daytime some juveniles of *N. gracilis* were present in the upper 100 m and others

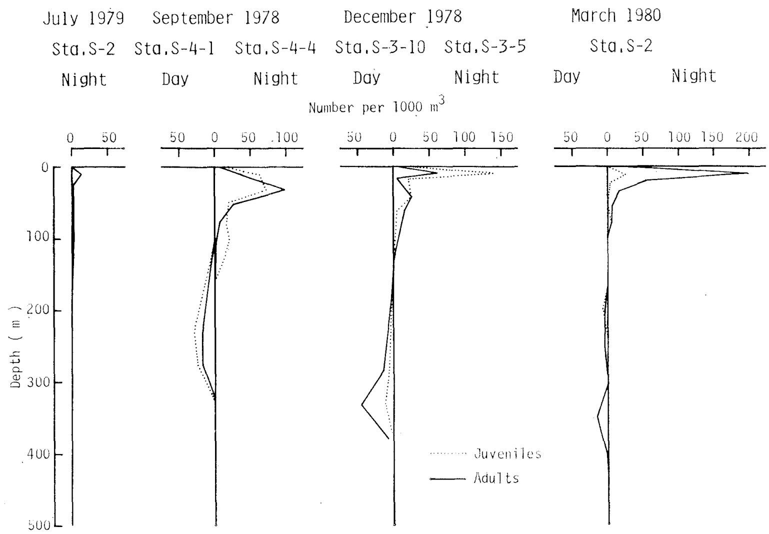

Fig. 7. Vertical distribution of *Euphausia tenera* (numbers) in Sagami Bay.

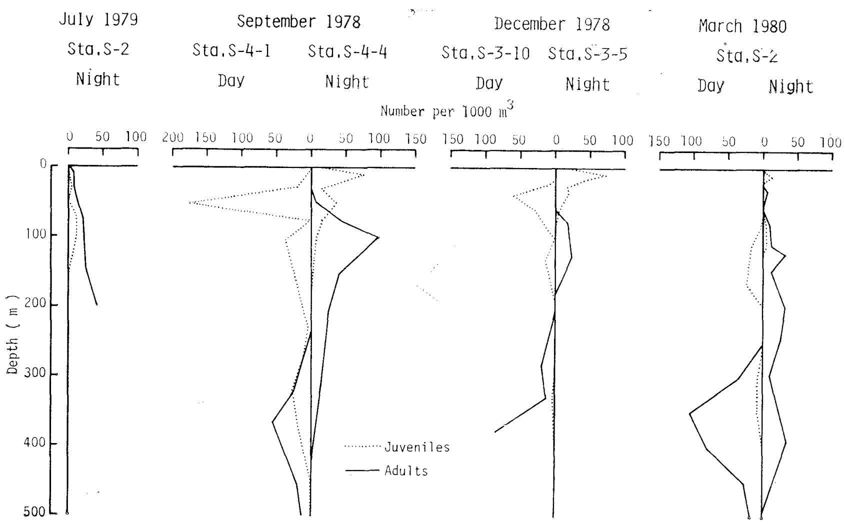

Fig. 8. Vertical distribution of *Nematoscelis gracilis* (numbers) in Sagami Bay.

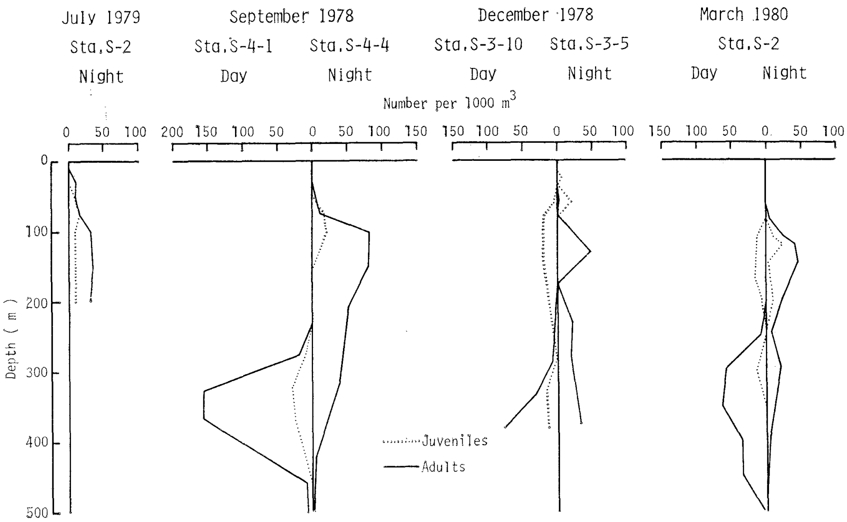

Fig. 9. Vertical distribution of *Nematoscelis microps* (numbers) in Sagami Bay.

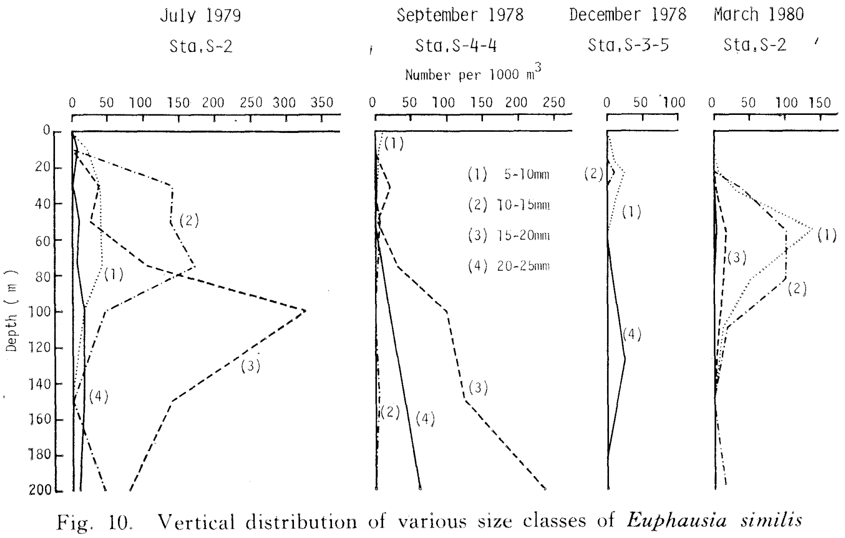

Fig. 10. Vertical distribution of various size classes of *Euphausia similis* in Sagami Bay at night. Size indicates total length.

between 200 and 400 m.

Nematoscelis microps appeared in Sagami Bay all year round (Fig. 9). In the daytime, juveniles were found between 100 and 400 m and adults were found mainly between 300 and 400 m. At night, juveniles were distributed in the upper 200 m, and adults in the shallower layers between 100 and 200 m, with some individuals remaining between 200 and 400 m.

4) *Relation between size of euphausiids and vertical distribution*

Fig. 10 shows the vertical distributions of *E. similis* at night according to size in each season of the year. Most of smaller individuals (5-10 mm) were found between 30 and 75 m and those of 10-15 mm were also distributed between 30 and 80 m. Those of 15-20 mm and 20-25 mm were found in the deeper layers between 100 and 200 m. In general, distribution depths of *E. similis* at night became deeper with increase in size. Similarly almost all juveniles of *Nematoscelis gracilis* moved into the upper 50 m during the night, while adults remained at depths greater than 100 m as shown in Fig. 8. The tendency that larger individuals of *N. gracilis* remain in deeper layers than smaller ones was very clear. In contrast, the vertical distribution of juveniles of three species of the genus *Euphausia* (*E. recurva*, *E. nana* and *E. tenera*) was the same as that of adults.

5) *Diurnal vertical migration of euphausiids*

We carried out an intensive sampling (10 sampling periods distributed over 24 hours) in December 1978 to examine the diurnal vertical migration of euphausiid species. The results for *Euphausia tenera* are shown in Fig. 11. Both juveniles and adullts of *E. tenera* were found between 250 and 350 m in the daytime. They began to ascend to the surface half an hour before sunset (16:31) and reached the upper 50 m an hour after sunset. The speed of ascent was more than 1 m/min, and then they stayed in the surface layer (above 50 m) till 03:00 hr. The depth of the 50 % level of distribution ranged from 18 to 34 m (Table 3) and the depth of maximum abundance was between 8 and 20 m. By sunrise (06:44) they were descending and the depth of 50 % level

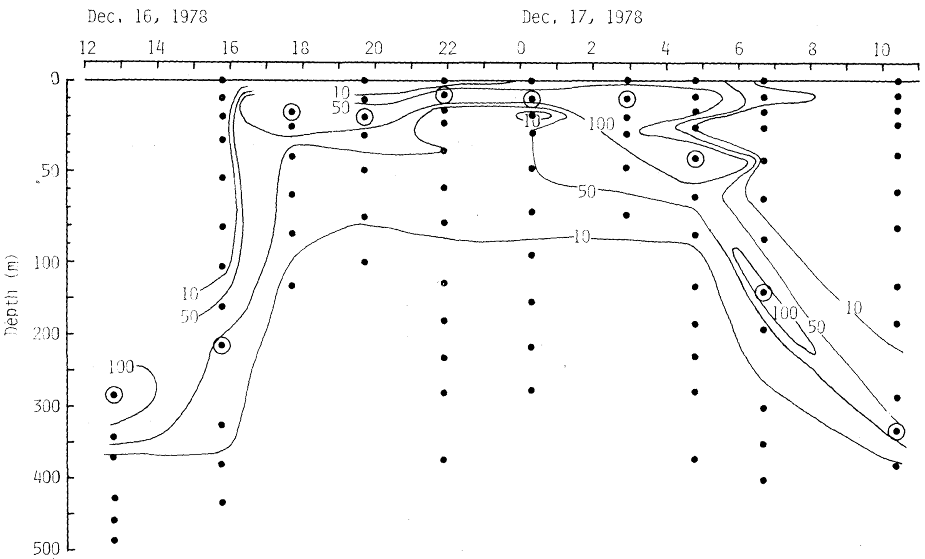

Fig. 11. Diurnal variation of vertical distribution of juveniles and adults of *Euphausia tenera* (No./1000 m^3) at Stn. S-3 in Sagami Bay. Closed circle: sampling depth. Open circle: depth of maximum abundance of *E. tenera*. Sunrise: 06:44. Sunset: 16:31.

Table 3. Diurnal variation of vertical distribution of juvenile (Ju.) and adult (Ad.) euphausiids at Stn. S-3 on December 16-17, 1978. Values are depth (m) for the 50 % level of populations obtained from a plot of cumulative percent against depth.

Sampling time	12:35 -13:05	15:38 -16:08	17:26 -17:56	19:28 -19:58	21:30 -22:13	00:04 -00:38	02:37 -03:09	04:31 -05:04	06:26 -07:00	10:13 -10:43
Euphausia mutica Ju. +Ad.	317	186	30	24	37	34	32	47	154	300
Euphausia recurva Ju. +Ad.	329	185	27	31	38	37	40	49	184	329
Euphausia nana Ju. +Ad.	335	282	23	27	25	34	29	51	160	328
Euphausia similis Ju.	335	367	39	47	40	47	49	62	200	315
Euphausia tenera Ju. +Ad.	317	217	18	27	27	34	23	49	149	315
Nematoscelis gracilis Ju.	329	123	35	24	16	14	14	56	112	68

of distribution laid at about 160 m. By three hours after sunrise, they were again in the 250 to 350 m layer. The descending speed was more than 1 m/min. The pattern of diurnal migration of other euphausiid species such as *E.* nana, *E. mutica* and *E. recurva* was similar with *E. tenera*. *E. nana*, *E. mutica* and *E. recurva* also occurred between 250 and 350 m during the day and began to ascend by half an hour before sunset and to descend before sunrise. The distribution depths of these three species from 17:30 to 03:00 hr were consistent according to species. The depths of the 50% level during the night were 23 to 34 m for *E. nana*, 24 to 37 m for *E. mutica* and 27 to 40 m for *E. recurva* (Table 3).

Fig. 12 shows the diurnal vertical migration of *Euphausia similis*. Juveniles of this species occurred between 300 and 350 m during the day. They came up to the surface and remained there from an hour after sunset to two hours before sunrise and then descended at sunrise to a depth of about 200 m. The depth of the 50% level at night was from 39 to 49 m. Juveniles of *Nematoscelis gracilis* occurred in the surface layer between 21:30 and 03:00 hr, with the 50% level around 15 m (Table 3).

6) *Vertical segregation of species within the same genus*

Species of *Euphausia* were vertically segregated according to species during the night at Stn. S-3 in December 1978. The depth of maximum abundance of *E. tenera* was between 10 and 20 m, *E. nana* between 20 and 30 m, *E. mutica* and *E. recurva* between 30 and 40 m, the *E. gibba* group (*E. pseudogibba* and *E. hemigibba*) between 30 and 50 m and *E. similis* between 40 and 50 m (Fig. 13). In March 1980, the depth of maximum abundance was 11 m for *E. tenera*, 33 m for *E. nana* and 55 m for *E. similis*. Thus, vertical distribution of *Euphausia* species during the night became deeper in the following order: *E. tenera*→*E. nana*→*E. mutica*, *E. recurva*→*E. gibba* group, *E. similis*. In September 1977 and 1978, however, the vertical segregation of *Euphausia* species at night was not clear, *E. tenera*, *E. nana*, *E. mutica* and *E. recurva* occurring at similar depths (Fig. 13). In summary, *E. tenera*, *E. nana*, *E. mutica* and *E. recurva* were separately distributed when a seasonal thermocline was absent, while they were not clearly separated when a marked seasonal thermocline was present in winter.

Fig. 14 shows the vertical distribution of

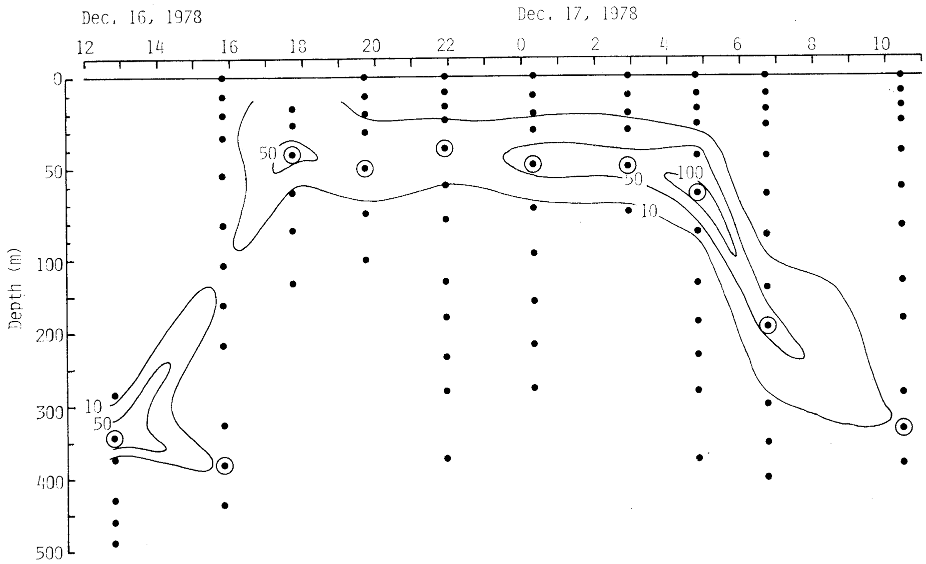

Fig. 12. Diurnal variation of vertical distribution of juveniles of *Euphausia similis* (No./1000 m^3) at Stn. S-3 in Sagami Bay. Closed circle: sampling depth. Open circle: depth of maximum abundance of *E. similis*. Sunrise: 06:44. Sunset: 16:31.

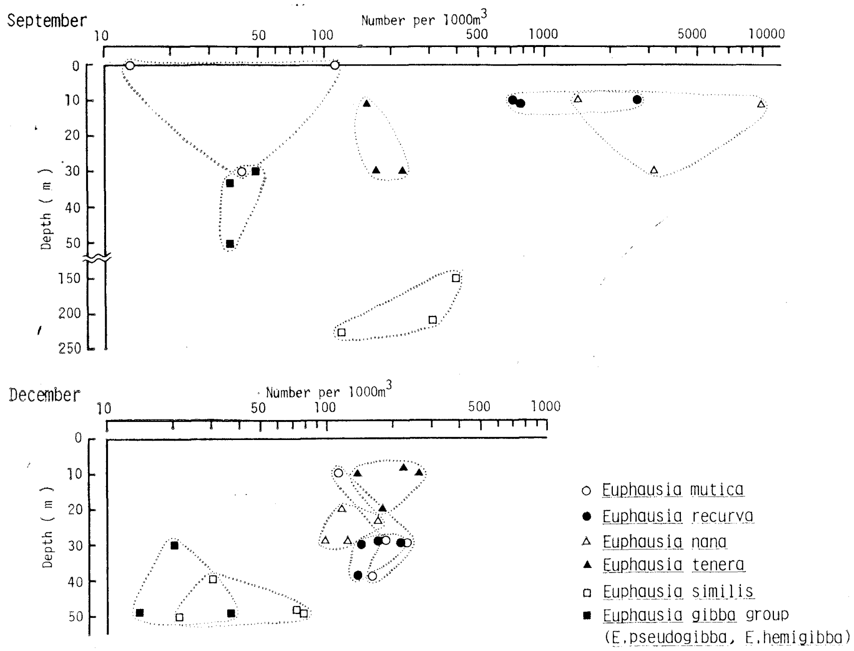

Fig. 13. Depth of maximum number of *Euphausia* species at night in Sagami Bay. Upper: Stns. S-4 (KT-77-13), S-2 and S-4-4 (KT-78-15). Lower: Stns. S-3-4, S-3-5, S-3-6 and S-3-7 (KH-78-5).

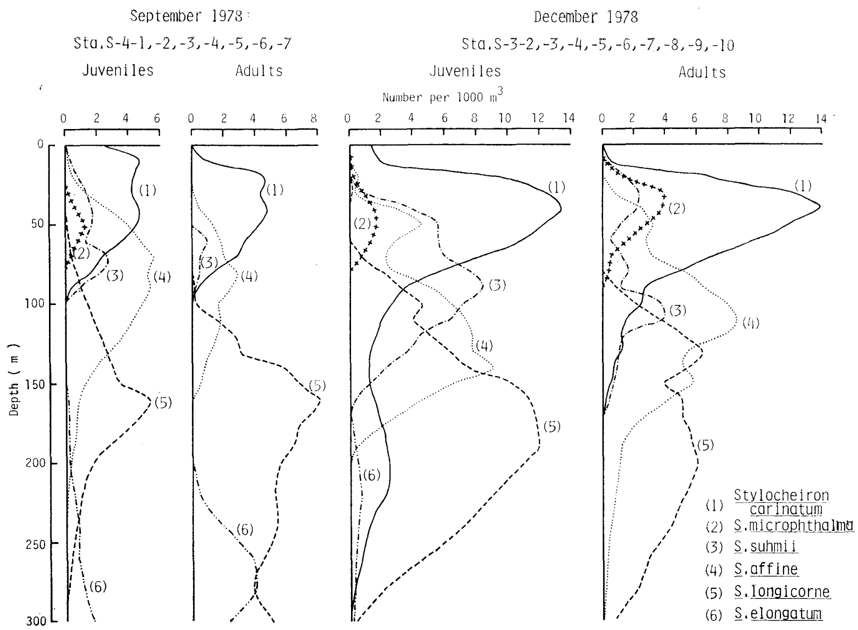

Fig. 14. Vertical distribution of individual numbers of six *Stylocheiron* species in Sagami Bay.

Stylocheiron species. Individual numbers of *Stylocheiron* species were few in Sagami Bay and there were, at most, only about 100 inds/1000 m^3. In order to examine their vertical distributions, seven series of data (Stn. S-4-1 to Stn. S-4-7) in September 1978 and nine series (Stn. S-3-2 to Stn. S-3-10) in December 1978 were summed to calculate average distributional profiles. Adults of *Stylocheiron carinatum* in September 1978 were abundant between 20 and 40 m, *S. affine* at 80 m, *S. longicorne* at 160 m and *S. elongatum* between 260 and 280 m. Juveniles occurred at the same depths as adults. In December 1978, juveniles and adults of *Stylocheiron carinatum* were most abundant at 40 m, *S. suhmii* between 90 and 110 m, *S. affine* between 110 and 140 m and *S. longicorne* at 190 m. *S. microphthalma* were few in individual number, below 4 inds/1000 m^3, and occurred above 100 m in September and December. Thus, vertical depths of occurrence for *Stylocheiron* species differed according to species and became deeper in the order *S. carinatum*→*S. suhmii*→*S. affine*→*S. longicorne*→*S. elongatum*.

4. Discussion

In this study, a tendency that larger individuals distribute in deeper layers than smaller ones was found on *Euphausia similis* and *Nematoscelis gracilis*. This tendency has been also found on *Meganyctiphanes norvegica* in the North Atlantic by EINARSSON (1945) and MAUCHLINE (1960). ROGER (1971) also reported a similar result for nine tropical species of euphausiids. MAUCHLINE (1960) concluded that temperature and salinity had no effects on this tendency.

Our results indicate that each species of *Euphausia* and *Nematoscelis* occurred at constant depth throughout the night. But ESTERLY (1914) found that the individual number of *Euphausia pacifica* and *Nyctiphanes simplex* occurring at the surface during the night was variable. KANAEVA and PAVLOV (1976) also reported similar findings. CUSHING (1951) pointed out that the phenomena of "midnight sinking" and "dawn rise" were found in ESTERLY's (1914) data. ROGER (1971) indicated that there are three types in behavior of euphausiid species migrating in the epipelagic zone at night, i.e. first type occurring throughout the night, second type occurring during the night after the midnight and third type occurring during the night before the midnight. ANTEZANA (1978) reported that several species such as *Euphausia eximia* occurred in the 0 to 40 m layer throughout the night, while *E. tenera* was found in the 0 to 40 m layer during the night before midnight and in the 40 to 80 m layer during night after midnight. In this study, six euphausiid species, *E. tenera*, *E. nana*, *E. mutica*, *E. recurva*, *E. similis* and *N. gracilis* did not show clear "midnight sinking" and "dawn rise".

We found that the vertical segregation of *Euphausia* species at night was clear in winter, but not in summer. The *E. gibba* group was consistently distributed deeper than *E. tenera*, *E. nana*, *E. mutica* and *E. recurva* throughout the year in Sagami Bay. In the eastern Pacific, however, BRINTON (1967) reported that *E. hemigibba* was abundant in the 0 to 20 m layer in which *E. recurva* and *E. brevis* were also abundant. The above results suggest that the vertical range of occurrence of *Euphausia* species varies with season and region. YOUNGBLUTH (1975) suggested that an important factor affecting the vertical distribution of euphausiids is the vertical distribution of their food. *Euphausia* species in Sagami Bay are considered to be omnivorous and to feed primarily on microplankton including tintinnids, foraminiferans, copepods, dinoflagellates and diatoms (PONOMAREVA *et al*. 1962, NEMOTO 1967, WEIGMANN 1970, PONOMAREVA 1976). However, we do not know the detailed vertical distribution of euphausiid food in Sagami Bay and therefore can not compare it with the distribution of euphausiids.

There was also vertical segregation among *Stylocheiron* species in Sagami Bay. BAKER (1970) reported that non-migrants such as species of *Stylocheiron* showed a tendency to segregate vertically according to species within the same genus and the distribution depth became deeper in the order *S. suhmii*→*S. affine*→*S. longicorne*→*S. elongatum* in the North Atlantic Ocean. BRINTON (1979) noted that the habitats of *Stylocheiron* species became deeper in the order

S. carinatum→*S. affine*→*S. maximum* and *S. longicorne* in the eastern tropical Pacific. The vertical distribution of *Stylocheiron* species in Sagami Bay is in agreement with the results of BAKER (1970) and BRINTON (1979).

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相模湾におけるおきあみの鉛直分布

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要旨: 相模湾におけるおきあみの鉛直分布について研究した。*Euphausia* 属おきあみの大部分は，昼間 300-350 m，夜間 10-50 m 層に分布した。*Euphausia* 属の種は，夜間をとおして，ほぼ同じ層に分布し，真夜中に沈降したり，明け方に上昇する動きは認められなかった。また，夜間，*Euphausia similis* および *Nematoscelis gracilis* では体長の大きい個体ほど，深い層に分布する傾向が認められた。*Euphausia* 属のおきあみは，種間で夜間の分布深度が異った。*E. gibba* グループの種および *E. similis* は，他の種より分布層が深い。*Stylocheiron* 属のおきあみも種間で分布層が異なり，*S. carinatum*→*S. suhmii*→*S. affine*→*S. longicorne*→*S. elongatum* の順に分布層が深い。

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Photosynthesis and Productivity of the Cultivated *Monostroma latissimum* Population*

Miyuki MAEGAWA** and Yusho ARUGA***

Abstract: Photosynthesis and productivity of the cultivated *Monostroma latissimum* population were studied outdoors by using a large assimilation chamber which continuously monitored the oxygen concentration in water. Standing stock, solar radiation and photosynthetic rate were measured during 25 days in November-December. Increment in standing stock, daily gross production (P_g), net production (P_n), respiration, P_n/P_g ratio and energy efficiency of P_g and P_n were compared during the measurement period.

1. Introduction

The primary production in offshore areas of the sea is mainly carried out by phytoplankton, whereas in coastal areas the seaweeds play an important role as primary producers. Estimation of the primary productivity of seaweeds has generally been based on the measurements of photosynthesis and respiratory rates. Thus, a considerable amount of knowledge on photosynthesis and respiration of seaweeds has been accumulated from an ecological point of view (DOTY 1971, YOKOHAMA 1973, MAEGAWA and ARUGA 1974, KING and SCHRAMM 1976, BUESA 1977). Population photosynthetic activity is especially important for estimating and/or analyzing production of a seaweed population. There are, however, relatively few studies of the population photosynthesis of aquatic plants in relation to their environmental factors (ODUM 1956, EDWARD and OWENS 1962, IKUSIMA 1966, 1967, SATOMI *et al.* 1966, MAEGAWA 1980). The causal appreciation of the primary productivity in coastal ecosystem seems impossible without appropriate information on the photosynthetic characteristics of seaweed populations.

In a previous paper (MAEGAWA 1980) the method of measuring population photosynthesis and respiratory rates of cultivated *Monostroma* population was reported in relation to various weather conditions. Under natural conditions the solar radiation seems to be one of the most important factors in determining population photosynthesis. In the present study, a further investigation of the population photosynthesis of cultivated *Monostroma latissimum* was carried out continuously for 25 days in the earlier stage of the cultivation season, and the relationship between the photosynthetic production and the increment of standing stock was investigated.

2. Material and Methods

The material used in the present study was a green alga *Monostroma latissimum* (KÜTZING) WITTROCK, which is mostly cultivated in Japan with a method similar to that of red algae *Porphyra* (MIURA 1975). The study was carried out in Fisheries Research Laboratory, Mie University, located on Zagashima Island in Ago Bay, Mie Prefecture (34°16′N, 136°48′E). A cultivation net for the study was seeded artificially on September 9, 1979, and reared in a cultivation ground in Ago Bay, where the seawater has been influenced only little with river water but was eutrophicated by sewage. The net for *Monostroma* cultivation was made of synthetic fibers, and was about 18 m long and 1.2 m wide. On November 1, 1979, the cultivation net with young *M. latissimum* fronds

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was cut into ten parts with a size of about 77 cm by 60 cm each, and they were spread in frames for measuring photosynthesis, respiration, standing stock and loss. Then, they were set in floating baskets (100×80×30 cm) covered with small mesh nets (4×4 mm) to keep the fronds detached from the cultivation net by wave action. The *M. latissimum* population thus prepared was cultivated with a floating facility at a depth of 10 cm.

The population photosynthesis and respiration were measured with a large assimilation chamber (MAEGAWA 1980), which continuously monitored the oxygen concentration in water (Fig. 1). In the present study a flow meter was employed for measuring the volume of fresh seawater flown into the assimilation chamber, and the volume was regulated at a constant level of 3 l/min. The measurements were carried out from November 7 to December 1, 1979.

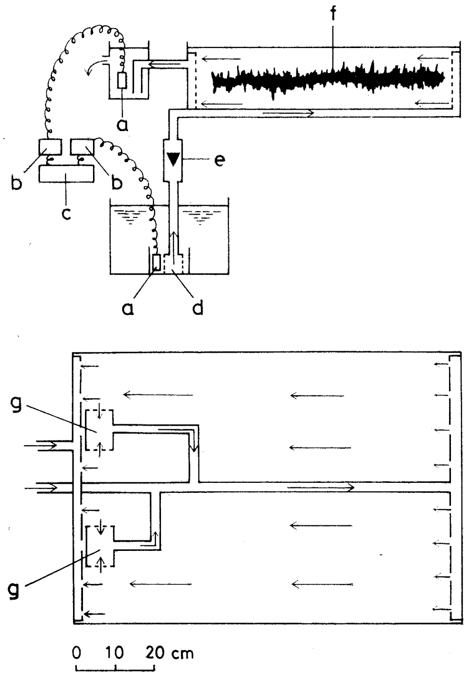

Fig. 1. Diagrams showing principal components of the apparatus (upper) and the assimilation chamber (lower) for measuring population photosynthesis of *Monostroma*. a, O_2 electrode; b, analyzer unit; c, recorder; d, water pump for drawing; e, flow meter; f, *Monostroma* population; g, water pump for stirring.

The standing stock and detached fronds were measured every five days. Fronds detached by wave action were picked up from floating baskets. For the measurement of standing stock, ten pieces of net yarn (10–15 cm long) were cut out of the net, rinsed quickly with freshwater, dried overnight at 80°C, and picked out from the net yarn to obtain the dry weight.

Solar radiation was measured with a Robitch type actinometer (Tokyo Keiki Co.) set up close to the assimilation chamber, which responded to the irradiance of whole spectrum.

3. Results

Figure 2 shows the changes in water temperature measured at 9:00 a.m. in the assimilation chamber. The water temperature lowered from about 21°C on November 7 to about 16°C on November 23, the level being maintained until December 1.

The photosynthetic and respiratory rates (gO_2/m^2 net area/hr) were calculated from the difference in oxygen concentration between inflow and outflow seawater, the volume of inflow seawater and the diffusion rate of oxygen from water surface (cf. MAEGAWA 1980). Photosynthesis and respiration were computed every 30 min. from the continuous records. The obtained diurnal changes of photosynthesis and respiration were illustrated in Fig. 3 together with the diurnal changes in solar radiation (kcal/m^2/hr) averaged every 30 min. Changes in the photosynthetic rate showed a trend similar to those in solar radiation. On fine or cloudy-fine days (November 7, 8, 11, 12 and 13) in

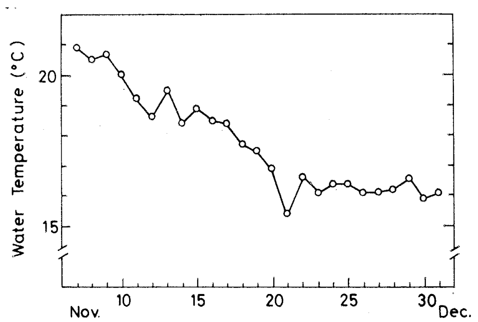

Fig. 2. Changes of water temperature measured daily at 9:00 a.m. in the assimilation chamber, November 7 to December 1, 1979.

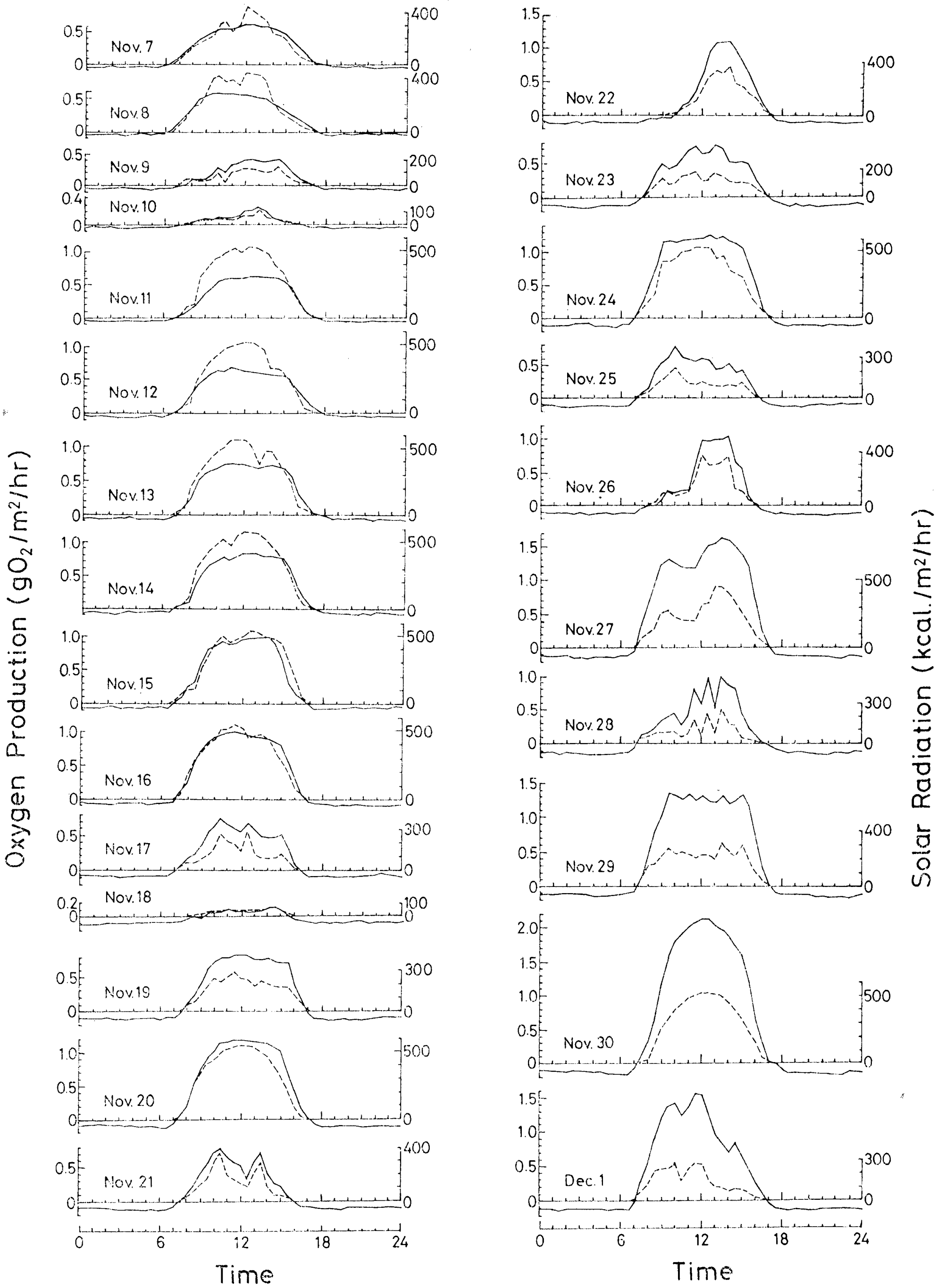

Fig. 8. Diurnal changes of oxygen production (solid lines) by the *Monostroma latissimum* population and solar radiation (dotted lines). November 7 to December 1, 1979.

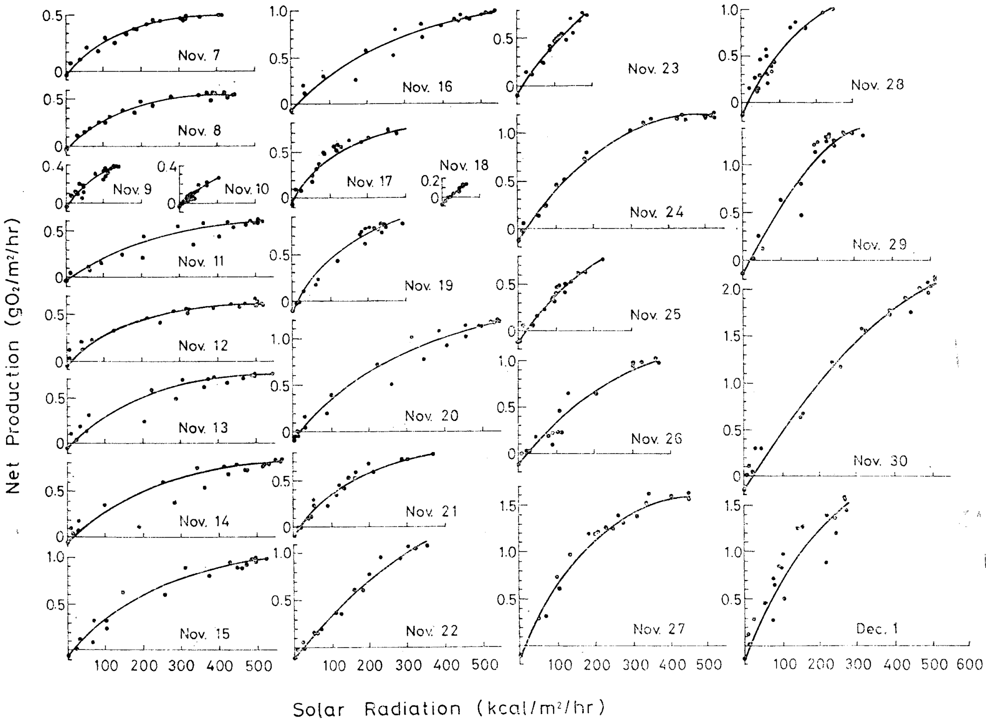

Fig. 4. Relationships between the net production of *Monostroma latissimum* population and the solar radiation. November 7 to December 1, 1979.

the earlier period of measurement, the diurnal changes in photosynthetic rate were not associated with those in solar radiation in the range over 300 $kcal/m^2/hr$ (30 $cal/cm^2/hr$). On rainy days (November 10 and 18) the photosynthetic rate was depressed by low solar radiation. On a fine day (November 30) a maximum photosynthetic activity of 2.12 $gO_2/m^2/hr$ was reached at 515 $kcal/m^2/hr$ at noon. Respiratory rate, which was kept almost at a constant level throughout the night, was 0.04 $gO_2/m^2/hr$ in the earlier period of measurement and gradually increased to 0.13 $gO_2/m^2/hr$ in the later period.

Figure 4 shows relationships between the solar radiation and the photosynthetic rates obtained at an interval of 30 min. throughout the day, corresponding to net photosynthesis-light curves. As for the respiratory rate, the values averaged throughout the night was employed. As expected from the diurnal changes in Fig. 3, the photosynthetic rates varied rather smoothly with solar radiation. On November 7, 8, 11, 12, 13 and 24 (fine and cloudy-fine days) the light-saturation of photosynthesis was observed (Fig. 4). On the other days, no light-saturation was observed up to the highest solar radiation of 500 $kcal/m^2/hr$ on fine days.

Table 1 shows the summary of the present investigation. Standing stock of *Monostroma latissimum* population was 21.31 g(d. w.)/m^2 at the start of measurement, and increased to 107.3 g(d. w.)/m^2 at the end. Loss of fronds from the cultivation net (estimated as detached fronds) by wave action was a little (0.03–1.45 g(d. w.)/m^2/5 days) compared with the standing stock. Daily solar radiation varied from 300 $kcal/m^2/day$ on a rainy day to 3590 $kcal/m^2/day$ on a fine day. The photosynthetic productivity varied with light condition and standing stock. The maximum photosynthetic productivity of 14.9 $gO_2/m^2/day$ for gross production or 11.8 $gO_2/m^2/day$ for net production was reached under a solar radiation of 3120 $kcal/m^2/day$ on November 30 at the later period of measurement. The respiratory rate was low, about 1 $gO_2/m^2/day$, at the beginning of measurement, and it increased to about 3 $gO_2/m^2/day$ at the later period. The gross and net production and the respiration expressed in gO_2 were converted to those in dry weight as 1 gO_2 is equivalent to 0.84 g dry matter (IKUSIMA 1965). The maximum daily gross and net production during the measurement period were 12.5 and 9.9 g (d. w.)/m^2/day, respectively, on November 30. The P_n/P_g ratio ranged from 0.08 to 0.82 except for the negative value on November 18 when the solar radiation was the lowest. It was higher on fine days and lower on cloudy or rainy days, but was almost the same (0.73–0.79) on fine days when the solar radiation was over 3000 kcal/m^2/day. The energy efficiency was calculated for gross and net production, assuming that the photosynthetic O_2 production of 1 g is equivalent to 3.5 kcal (RYTHER 1956). It varied from 0.5 to 2.5% for gross production and from 0.1 to 1.8% for net production, except for the negative value on November 18.

Figure 5 shows the daily gross production and net photosynthetic activity on fine days in relation to the standing stock of *Monostroma latissimum* population. The net photosynthetic activities in this figure approximately correspond to the light-saturated net photosynthetic rates, and increased linearly with increase in standing stock. The daily gross production also increased linearly with increase in standing stock. As shown in Fig. 6, however, the photosynthetic activity on a dry weight basis decreased with

Table 1. Changes in standing stock, frond loss, solar radiation, gross production (P_g), net production (P_n), respiration (R), P_n/P_g ratio and energy efficiency of the cultivated *Monostroma latissimum* population from November 7 to December 1, 1979.

Date		Standing Stock **	Loss **	Solar Radiation ***	P_g *	P_g **	P_n *	P_n **	R *	R **	P_n/P_g	Efficiency (%) P_g	Efficiency (%) P_n
Nov.	7	21.31±3.43		2190	4.9	4.1	3.9	3.3	1.0	0.8	0.80	0.8	0.6
	8			2560	4.6	3.9	3.8	3.2	0.9	0.7	0.82	0.6	0.5
	9			710	2.8	2.3	1.6	1.3	1.1	1.0	0.58	1.4	0.8
	10			350	1.3	1.1	0.1	0.1	1.2	1.0	0.08	1.3	0.1
	11	32.54±2.07	0.03	3280	4.8	4.0	3.5	3.0	1.2	1.0	0.74	0.5	0.4
	12			3160	5.5	4.6	4.2	3.5	1.3	1.1	0.76	0.6	0.5
	13			3410	6.3	5.3	4.8	4.1	1.5	1.2	0.77	0.6	0.5
	14			3590	6.4	5.4	4.9	4.1	1.5	1.3	0.76	0.6	0.5
	15			3190	7.3	6.2	5.8	4.8	1.6	1.3	0.79	0.8	0.6
	16	51.09±3.31	0.10	3310	7.4	6.2	5.6	4.7	1.8	1.6	0.75	0.8	0.6
	17			1060	5.0	4.2	2.8	2.3	2.2	1.9	0.55	1.7	0.9
	18			300	1.3	1.1	−1.7	−1.0	2.5	2.1	−0.89	1.5	−1.4
	19			1680	6.4	5.4	3.9	3.3	2.5	2.1	0.61	1.3	0.8
	20			3420	9.0	7.6	6.9	5.8	2.2	1.8	0.76	0.9	0.7
	21	61.89±8.02	0.23	1240	4.6	3.9	2.1	1.8	2.5	2.1	0.46	1.3	0.6
	22			1260	5.1	4.3	2.6	2.2	2.5	2.2	0.51	1.4	0.7
	23			1030	5.7	4.8	2.8	2.3	2.9	2.5	0.49	1.9	0.4
	24			3240	10.3	8.7	7.5	6.3	2.8	2.4	0.73	1.1	0.8
	25			950	4.8	4.0	1.9	1.6	2.9	2.4	0.40	1.8	0.7
	26	78.25±6.89	0.93	1330	5.0	4.2	2.1	1.8	2.9	2.4	0.44	1.3	0.6
	27			2280	12.2	10.3	9.2	7.7	3.0	2.5	0.75	1.9	1.4
	28			880	6.0	5.0	2.7	2.3	3.3	2.8	0.45	2.4	1.1
	29			1930	11.2	9.4	8.3	7.0	2.9	2.4	0.74	2.0	1.5
	30			3120	14.9	12.5	11.8	9.9	3.1	2.6	0.79	1.7	1.3
Dec.	1	107.28±5.72	1.45	1390	10.0	8.4	7.0	5.9	3.0	2.5	0.70	2.5	1.8

* gO_2/m^2 ** g(d.w.)/m^2 ***kcal/m^2/day

increase in standing stock. The respiratory rate on a dry weight basis was almost the same; only a slight decrease was observed with increase in standing stock.

Figure 7 shows the relationships between the energy efficiency of gross production and the standing stock. The energy efficiency was higher on rainy and cloudy days than on fine days. It was low at an early stage of the growth and increased almost linearly with the growth, i. e. with increase in standing stock. The relationships were almost linear within the range of standing stock concerned in the present study.

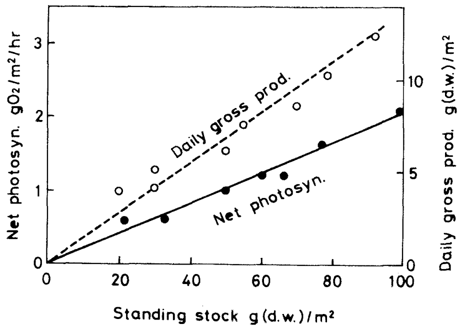

Fig. 5. Relationships of the light-saturated net photosynthesis and the daily gross production of *Monostroma latissimum* population to the standing stock.

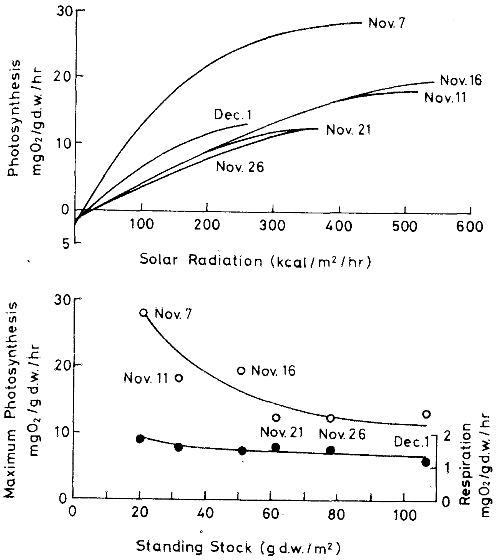

Fig. 6. (Upper) Photosynthesis-light curves of the *Monostroma latissimum* population. (Lower) Relationships of the maximum population photosynthesis and population respiration to the standing stock of the *M. latissimum* population.

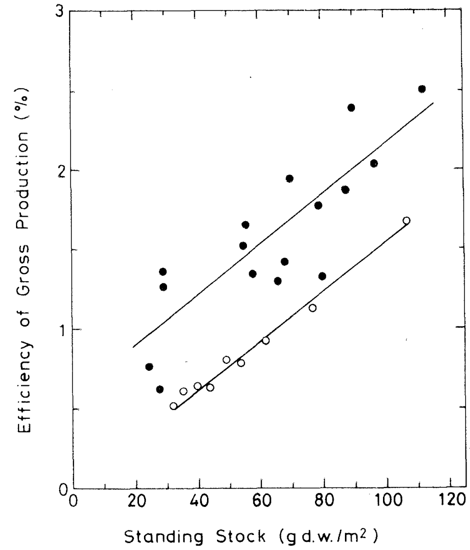

Fig. 7. Relationships between the energy efficiency of gross production and the standing stock of the *Monostroma latissimum* populatton. Solid circles, cloudy and rainy days; open circles, fine days.

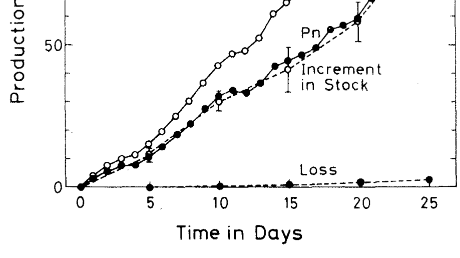

Fig. 8. Changes in the cumulated gross production (Pg, —∘—), cumulated net production (Pn, —•—), increment in stock (···∘···) and frond loss (···•···) of the cultivated *Monostroma latissimum* population from November 7 to December 1, 1979.

In Fig. 8 the cumulated net production was compared with the increment of standing stock plus loss of fronds. The cumulated gross production was also shown. The cumulated gross and net production during 25 days were 136.7 and 91.3 g(d.w.)/m^2, respectively, while the increment in standing stock plus frond loss amounted to 88.7 g(d.w.)/m^2. As can clearly be seen in the figure, the net production agreed quite well with the increment in standing stock.

4. Discussion

The estimation of primary productivity of seaweeds in coastal ecosystem seems impossible without appropriate information on the photosynthetic characteristics of seaweed populations. In general, photosynthetic activity of seaweeds has been measured with a single frond or only a part of frond under stationary conditions. In such measurements errors caused by the containment of frond sample in a bottle cannot be negligible, and the resolution is limited by the incubation period. In the present study, we intended to estimate the primary production of cultivated *Monostroma* population by using a large scale assimilation chamber which continuously measures diurnal changes in photosynthesis and respiration under natural conditions.

Diurnal patterns with a midday or afternoon depression of photosynthesis have been reported in phytoplankton populations (HARRIS and LOTT 1973, JASSBY 1978, MARRA 1978), freshwater macrophytes (GOULDER 1970, HOUGH 1974, McCRACKEN *et al.* 1975) and seaweeds (RAMUS and ROSENBERG 1980). However, the result of EDWARDS and OWENS (1962) obtained from diurnal oxygen changes in a natural river showed no obvious depression of photosynthesis. SMITH (1981) also reported no depression of diurnal photosynthetic pattern in *Codium carolinianum* and *Lodophora variegata* calculated from an *in situ* study. The photosynthetic rate of cultivated *Monostroma latissimum* measured with a single frond showed no depression at light intensities as high as 100 klux during the cultivation season (MAEGAWA and ARUGA 1974). In the present measurements with cultivated *M. latissimum* population, no midday or afternoon depression of photosynthesis was observed even on fine days (Fig. 3). This is also clear from the curves illustrated in Fig. 4. It seems that such an intertidal alga as *Monostroma latissimum* is most tolerant to high light intensity.

It was reported that the maximum standing stock of cultivated *Monostroma* population could reach 450–600 g(d.w.)/m^2 (MAEDA and OHNO 1972, MAEGAWA and ARUGA 1974). In the present study, the standing stock of *M. latissimum* used for the measurements was 21.3–107.3 g(d.w.)/m^2 (Table 1). These values were observed in an earlier stage of the cultivation season with higher relative growth rate (MAEGAWA and ARUGA 1974).

The half-hourly photosynthesis vs. solar radiation plots (Fig. 4) show that the net photosynthetic rate on an area basis increases with solar radiation and also with growth. On fine days, the net photosynthetic rate and the daily gross production on an area basis increased linearly with increase in standing stock (Fig. 5). When plotted on a dry weight basis, however, the light-saturated rates of photosynthesis decreased with increase in standing stock (Fig. 6). The decrease in the photosynthetic rate seems to be related with age of a frond (cf. MAEGAWA and ARUGA 1974), and the effect of self-shading seems to be quite small at this younger stage of cultivated *Monostoroma* population.

The relationship between the energy efficiency of gross production and the standing stock (Fig. 7) is almost linear within the range of standing stock investigated. The energy efficiency of gross production reached 1.7% in the population with a standing stock of 107 g(d.w.)/m^2 on November 30 (fine day), when the efficiency of net production was 1.3% (Table 1). In a previous paper (MAEGAWA 1980), it was reported that the efficiency on a fine day was 1.6% for gross production and 1.2% for net production in the cultivated *M. latissimum* population with a standing stock of 180 g(d.w.)/m^2. The energy efficiency of cultivated *M. latissimum* populations, particularly that of net production, is high as compared with that of terrestrial plant communities (cf. RYTHER 1956). It seems that the maximum energy efficiency on a fine day of gross and net production of cultivated *M. latissimum* populations is at least 1.7% and 1.3%, respectively, under field conditions.

There are many studies of photosynthetic productivity of seaweeds, and the importance of a close relationship between photosynthetic productivity and increment in standing stock has been recognized. However, only a few investigations have been undertaken to obtain appropriate information on the photosynthetic production of seaweed populations (SATOMI *et al.* 1967, MAEGAWA 1980). In the present study the cumulated net production agreed quite well with the increment in stock plus frond loss as can clearly be seen in Fig. 8. This would also indicate that the present measurements of photosynthesis and respiration of the *Monostroma latissimum* population were carried out quite reasonably.

5. Summary

Diurnal changes in the population photosynthesis of cultivated *Monostroma latissimum* were investigated in relation to various weather conditions and growth. The gross and net production and their energy efficiency were estimated, and the production was compared with the increment in standing stock.

(1) Population photosynthesis and respiration were measured outdoors by using a large assimilation chamber which continuously monitored the oxygen concentration in water. Measurement was carried out continuously for 25 days in November-December 1979 at the earlier stage of cultivation season.

(2) Standing stock of *M. latissimum* population was 21.3 g(d. w.)/m^2 at the start of measurement and increased to 107.3 g(d. w.)/m^2 at the end. Solar radiation ranged from 300 to 3590 kcal/m^2/day according to the weather condition during the period of measurements.

(3) Diurnal changes in photosynthetic rate showed a trend similar to those in solar radiation. No midday or afternoon depression was observed in the population photosynthesis even on fine days.

(4) Daily gross and net photosynthetic production of 14.9 and 11.8 gO_2/m^2/day, respectively, were reached under a solar radiation of 3120 kcal/m^2/day in the later period of measurements. Respiration rate was 0.04 gO_2/m^2/hr in the earlier period of measurements and gradually increased to 0.13 gO_2/m^2/hr in the later period.

(5) Energy efficiency ranged from 0.5 to 2.5% for gross production and from 0.1 to 1.8% for net production except for the negative values obtained on a day of the lowest solar radiation. The P_n/P_g ratio ranged from 0.08 to 0.82, being higher on fine days and lower on cloudy or rainy days.

(6) The cumulated net production agreed quite well with the increment in standing stock during the measurement period. This would indicate that the present measurements of population photosynthesis and respiration were carried out quite reasonably.

Acknowledgement

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養殖ヒロハノヒトエグサの光合成と物質生産

前 川 行 幸, 有 賀 祐 勝

要旨: 養殖ヒロハノヒトエグサ個体群の光合成の日変化と物質生産について，特に天候と生長との関係を中心に研究した。個体群光合成の測定は大型同化循環水槽を用い，1979年11月から12月にかけて25日間連続して行った。現存量は測定期間中 21.3 g(d.w.)/m^2 から 107.3 g(d.w.)/m^2 に増加した。また太陽放射は 300〜3,590 kcal/m^2/day の間で天候により変化し，日中の光合成速度の変化は太陽放射の変化とよく一致した。11 月 30 日には太陽放射は 3,120 kcal/m^2/day で，総光合成量は 14.9 gO_2/m^2/day，純光合成量は 11.8 gO_2/m^2/day の最大値を示した。測定期間中の積算された純生産量の変化は現存量の変化とよく一致し，本測定は自然条件に非常に近い状態で実施されたものと考えられる。

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Société franco-japonaise d'océanographie, Tokyo

The Failure of Instruments Moored in the Deep Sea*

Keisuke TAIRA**, Shoji KITAGAWA** and Toshihiko TERAMOTO**

Abstract: Four examples of the failure of deep sea instruments are described in order to improve the mooring technique and the instruments: (1) The collapse due to water leakage. During the mooring the water leaked into a pressure chamber without exhausting the air. When it ascended at a high speed for recovery, the inflation of the trapped air broke the chamber. We suffered the collapse of three Aanderaa current meters, two OAR radio transmitters, and one TSK current meter. (2) The collapse due to failure of the depth capability. Two Aanderaa current meters designed for 6,000 m depth were collapsed while they were moored at 5,750 m layer. (3) The breaking of glass spheres. Three glass spheres were collapsed due to creeping of an elastic tape between the coupled semispheres. (4) The malfunction of an acoustic release. Water leakage caused the malfunction of an acoustic release which had been moored in the Oshima-West Channel. The acoustic release was found off Katsuura (Chiba) after drifting 28 days and the current meter was recovered off Hisanohama (Fukushima) after drifting about 230 days.

1. Introduction

Since 1976, we have been engaged in deep sea mooring of current meters in order to obtain long time series at selected stations in the Kuroshio south of Honshu (TAIRA and TERAMOTO, 1981) and in the deep seas east of the Izu-Ogasawara Trench (TAIRA, TERAMOTO and HORIBE, in preparation). The length of the time series exceeds 1200 days to date at several stations. Maximum depth of measurement is nearly 6000 m. The mooring observations require both the knowledge on the capability of instruments and mooring gears and the technique of operations (e.g., TAIRA, IMAWAKI and TERAMOTO, 1976). Any failure of the mooring should be investigated thoroughly in order to improve the instruments and the mooring technique.

In this paper, we describe several case studies on the failure of the instruments, which we have suffered during our mooring observations. A short description of the instruments and the operational procedure is present in the section 2. The collapse of pressure chambers caused by the inflation of the trapped air is described in the section 3. The failure of depth capability is described in the section 4. The breaking of glass spheres is described in the section 5. The malfunction of an acoustic release and the resultant drift of the mooring line are described in the section 6.

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2. Description of the mooring instruments

Figure 1 shows schematically a typical mooring line of our current measurements. A radio transmitter (Ocean Applied Research Inc., Model ST-202, depth capability of 7000 m) was attached to a buoy assembly (signal buoy). The signal buoy, which was designed by the crew of the R/V Hakuhomaru, was composed of the iron frame and three glass spheres for floatation. We used glass spheres of 17 inch diameter manufactured by the Benthos Inc. and of 16 inch diameter manufactured by the Ocean Research Equipment Inc. The hard hats containing the glass spheres were linked to iron chain with U clamps (Fig. 2). A ring was adopted to connect the chain to mooring rope. We used the Kevler rope (Phillistrand, 6.25 mm daimeter) and the Nylon Doubler rope (Teikoku Sangyo Co., 12 mm diameter). We standardized the length of the mooring rope: 50 m, 100 m, 200 m and 400 m. A mooring anchor (weight)

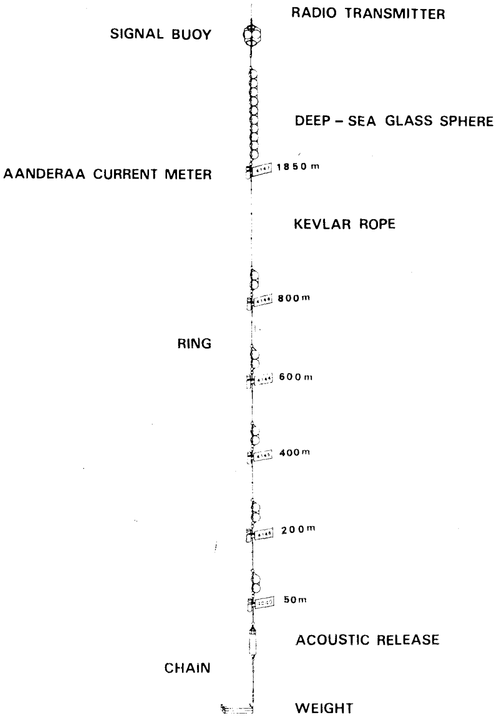

Fig. 1. A schematic diagram of the mooring line for current measurements.

was composed of steel bars for railroad. The bars were 2 m long (100 kg/2 m) and fastened together by iron bolts.

We used Aanderaa current meters (Aanderaa Instruments, Model RCM-5, depth capability of 6000 m). An acoustic release (Sea-Link, Model 255, depth capability of 6100 m) was used for recovery. We also used acoustic releases manufactured by the Nichiyu Giken Kogyo (Model M for 2000 m depth and Model L for 6000 m depth) for the moorings in the Kuroshio. Lithium batteries were used for a receiver of the acoustic release, and their life time was about one year.

We launched the mooring line in a procedure of the "buoy first, anchor last" (BERTEAUX and WALDEN, 1969). The mooring rope was reeled on a winch drum in an order from the lower to the upper portions of the mooring line. On launching, the rope was unwound at a speed of 1 m/s while the ship was steaming at about 4 knots towards the mooring station. Glass spheres, current meters and the acoustic release were linked to the rope on the poop deck.

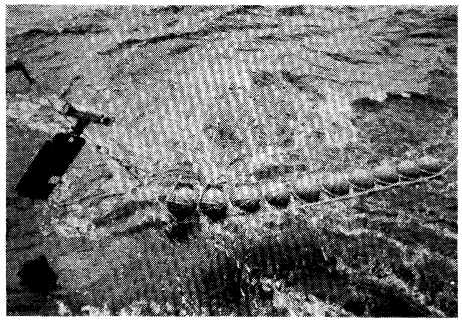

Fig. 2. Launching of a current meter from the R/V Hakuhomaru.

The mooring weight was hauled down when the ship passed about one-third of the total length of the mooring away from the station.

For recovering the mooring, an acoustic command signal was sent to the release from a hydrophone hauled from the ship side. The receivable range was about 15000 m. The ascending speed of the mooring was 1–2 m/s (TAIRA, IMAWAKI and TERAMOTO, 1976). Ship positions determined by the Navigation Satellite System or by the LORAN-C were usually so accurate that the buoys came out in sight range.

3. An explosive collapse due to water leakage

From December 1977 to February 1978, current measurements at 5000 m layer were carried out at five stations in the east of the Izu-Ogasawara Trench (IMAWAKI, TAIRA and TERAMOTO, in preparation). One of the moorings was not recovered. Three of the current meters were equipped with pressure sensors. A bottom plate was lost from a current meter (Fig. 3). Two current meters from other stations were also collapsed: one was blowing out the air after it had been retrieved on the deck, and the other had a bottom plate obliquely sliding out. The collapse was evidently caused by the inflation of the trapped air. We found that each recorder of the collapsed current meter was stopped 20–30 hours after the deployment. If we assume that flood to the level of battery terminals caused the recorder to stop, it would take 80–120 hours for the air trapped in the chamber to balance with the ambient pressure. On recovery, the chamber came out to the sea surface within one and half hour from the 5000 m depth. The air and water trapped in the chamber could not be exhausted so quickly that the pressure difference was equilibrated. The chambers were collapsed easily by the inflation of the trapped air because they were designed to persist externally exerting pressure. The current meter without the pressure sensor was not collapsed. We received a letter after the cruise from the Aanderaa Instrument for the warning of water leakage from the pressure sensors due to misapplication of an adhesive material (see also, HENDRY and REINIGER, 1978).

We suffered explosive collapse of the end caps of two radio transmitters. We found that electric erosion of the antenna terminals had caused water leakage into the cases. The erosion might be accelerated by the transmission of radio waves in the water which was to be turned off by the pressure switches.

In September 1975, a recording unit of a current meter (Tsurumi Seiki Co., MTCM-5) was lost after it had been moored at 300 m depth in Tosa Bay. The housing of the recorder was composed of two plastic tubes, one attached to the upper end-plate and the other attached to the bottom end-plate. The latter one was lost together with the recording unit. We could not find any scratches which the crash due to high pressure had to make on the other tube. This brought us a conclusion that the loss might be caused by an explosive force. We assume that the loss was caused by the explosive collapse.

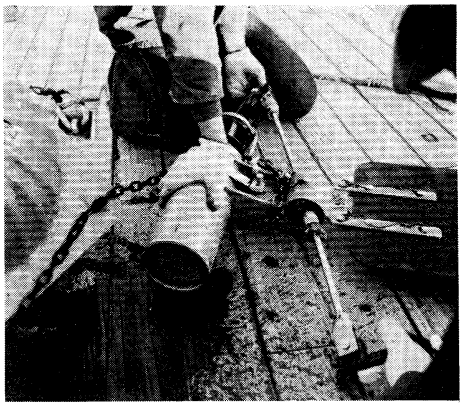

Fig. 3. The current meter recovered without the bottom plate.

4. The collapse due to failure of the depth capability

Two Aanderaa current meters, one recovered in July 1979 and the other in June 1980, were collapsed as shown in Fig. 4. Both had been moored at 5750 m depth. The central portion of the chamber was flattened and the magnetic tape was destroyed. In each case, another current meter was recovered without collapse from 5800 m depth. The capability depth of the current meters was not always large enough for 6000 m. We asked the Aanderaa Instruments to improve the capability. They began to deliver current meters of a special model which had been tested at 10500 psia (equivalent to 7370 m water depth) in December 1981.

5. Breaking of the glass sphere

The glass sphere manufactured by the Benthos Inc. is composed of two semispheres coupled

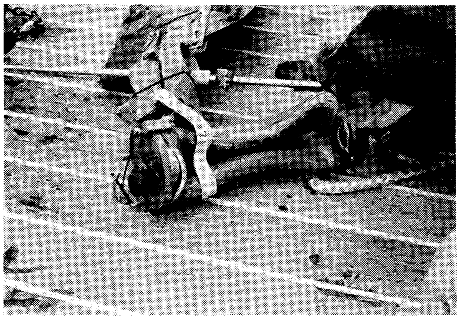

Fig. 4. The current meter collapsed by the high pressure at 5,750 m depth.

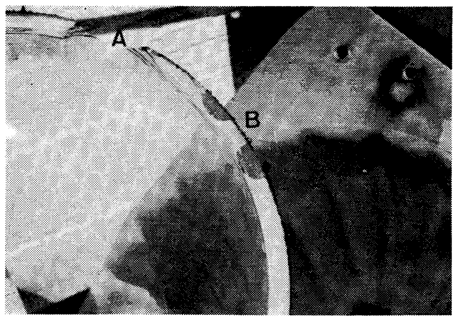

Fig. 5. Breaking of a glass sphere: (A) Flakes of glass were lost from the edge. (B) The elastic tape creeping on the mating face.

together in a vacuum chamber. When we recovered a mooring line, we found that one of the glass spheres was broken as shown in Fig. 5. Flakes of glass were lost from the edge of the semisphere and creeping of the elastic tape between the semispheres was observed. The hard hat containing the glass sphere was not injured. The breaking was different from the failure of depth capability, which we had suffered once in the course of a wire test. The crash made the glass sphere into fine powder.

We suffered the breaking of glass spheres three times. Each of the moorings was deployed in the summer season. The glass spheres were stored on the ship deck long time before the deployment. The heat and the ship's vibration might result in the creeping of the elastic tape. The tape became soft at high temperature and hard at low temperature. The creeping tape would work as a solid wedge in the cold sea water to break the glass sphere during the descent to deep water.

6. Malfunction of an acoustic release and the resultant drift of the mooring

Since February 1977, we have kept a mooring of a single current meter in the Oshima-

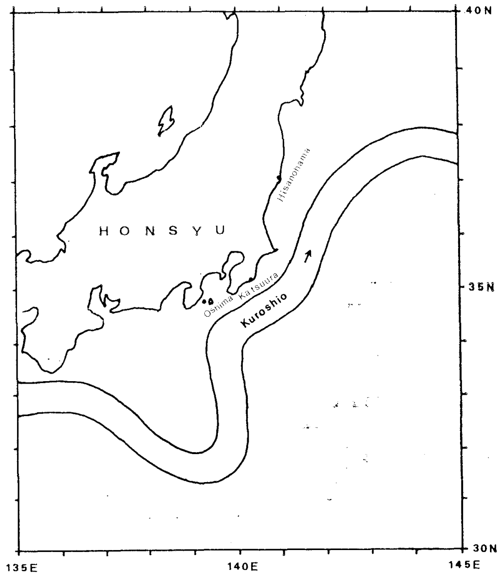

Fig. 6. The drift of a mooring line from the Oshima-West Channel (marked by the dot) to Katsuura where the acoustic release was found, and to Hisanohama where the current meter was found. A mean path of the Kuroshio was adopted from the *State of the adjacent seas of Nippon*, April-June 1980, Hydrographic Department, Maritime Safety Agency.

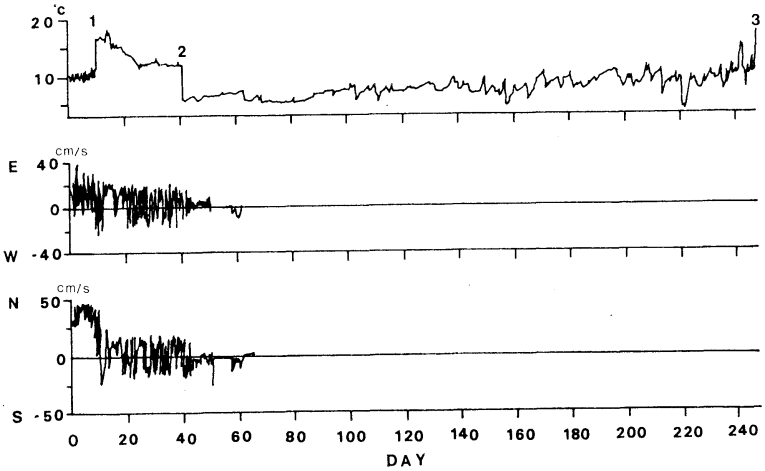

Fig. 7. Records of the current meter drifting from the Oshima-West Channel to Hisanohama (see Fig. 6): Upper panel; temperature (The start on 13 March 1980, Time mark 1 on 20 March, Time mark 2 on 24 April and Time mark 3 on 12 November). Middle panel; the eastward component of velocity. Bottom panel; the northward component of velocity.

West Channel by replacing every 2–10 months (TAIRA and TERAMOTO, 1981). A mooring line was deployed on 13 March 1980 at a station (34°45′N, 139°15′E, 500 m deep). An Aanderaa current meter was tethered with 200 m long rope and an acoustic release (Nichiyu Giken Kogyo, Model M) to a mooring anchor. On 16 April 1980, the acoustic release was found drifting together with two glass spheres off Katsuura, Chiba (Fig. 6). The release had accidentally actuated to disconnect the mooring anchor. Examination at the factory revealed that the sea water leaked through an O-ring face had made a short circuit to fire the squib. A standard model of the release works with a three-month life time battery. However, the release was sent back to the factory to be installed with a lithium battery of twelve-month life time. An acid solvent was used for cleaning of the case. Washing away was not complete and the erosion by the acid solvent caused the water leakage during the mooing.

On 9 November 1980, the current meter and the glass spheres were recovered from a fishing net fixed off Hisanohama, Fukushima (Fig. 6). The rotor of speed sensor was lost from the current meter. We used five glass spheres made by the Ocean Research Equipment. The hard hat for the glass sphere was composed of two pieces fastened together with three iron eyelets. Four of the glass spheres were lost from the hard hats because the eyelets were eroded. The eyelets of one hard hats were tied with rope. We make it a rule to refasten the hard hats with extra bolts of stainless steel.

Figure 7 shows the record of the current meter from 13 March to 12 November 1980. The current meter had been moored at 300 m layer until 02 h on 20 March (time mark 1 in the upper panel), when the temperature increased rapidly from 10.5°C to 17.0°C. The current meter might be floating on the sea surface until 16 h on 6 May (time mark 2), when the temperature decreased rapidly. Revolution of the rotor was recorded until 16 h on 6 May (Fig. 7, middle and bottom panels). The recorded temperature was changing largely. The current meter might be hanging from one glass sphere and drifting northward on the sea bottom.

The fisherman fixed the net off Hisanohama to catch the fish migrating from south. The drift of the current meter from the Oshima-West Channel showed that the Kuroshio water was flowing northward along the eastern coast of Honshu.

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深海に係留された機器の損傷

平　啓介，北川庄司，寺本俊彦

要旨：係留観測には使用する機器や用具の性能と強度についての十分な知識が必須であり，機器の損傷の原因を解明し，性能の向上と取り扱い法の改善をはかることが重要である。ここでは，わたくし達が1976年以来経験した係留中の機器の損傷を次の4事例について記述した。(1)回収時に耐圧容器が破壊する浸水事故。係留中に浸水し高圧空気がとじこめられることがある。回収時に外圧が減じ，内部の空気が膨張し耐圧容器が破壊する。(2)耐圧容器の性能不良による損傷。(3)深海浮力用ガラス球の破壊。半球を吸着したガラス球は，外気温が高いと粘着テープが接合面に付着し，使用時にこわれることがある。(4)音響切離装置の浸水による誤動作。係留中に浮上し流失した係留系が漁業者によって回収され，事故の原因が解明された。

La mer 21: 179, 1983
Société franco-japonaise d'océanographie, Tokyo

第2回 JECSS (Japan and East China Seas Study) 研究集会について*

高 野 健 三**

第2回 JECSS 研究集会は，海洋科学技術センター，日本 IBM-TSC (Tokyo Scientific Center), アメリカ地球物理連合，日仏海洋学会，日本海洋学会をスポンサーとして，1983年4月22日から27日まで筑波大学で開かれた。コンビーナは，第1回 JECSS 研究集会（1981年6月1日～4日）と同じく市榮誉（Texas A&M Univ.）と私であった。日本から27名，中国から6名，韓国から7名，米国から6名，計46名が参加した。韓国，米国，日本の参加予定者に取消しがあって当初の予定人数を10名あまり下廻った。ちなみに，前回の参加者は41名（日本から27名，中国から1名，韓国から6名，米国から7名）で，講演数は24だった。

今回は，38の講演が，Hydrography and descriptive oceanography (general features of the Japan and East China Seas), Hydrography and descriptive oceanography (special topics), Currents, Theory and modeling, Sediment transport, Remote sensing について行われたあと，Plenary session, Design of drifter experiment, Design of moored current meter experiment, Design of cooperative programs of remote sensing, Design of cooperative programs of modeling となって5日間の会を閉じた。日曜日（4月24日）には益子，日光，光徳牧場へ遠足に行った。

この集会の Proceedings は Elsevier Sci. Publ. から今年度じゅうに出版されるはずである（第1回のは本学会から今年1月に刊行されている)。

参加者の大半は第1回集会にも参加している。そういう参加者の評によると前回にもまして今回は成功だったそうである。コンビーナの市榮さん，スポンサーであるとともに集会の運営にも当った海洋科学技術センターと日本 IBM，それに参加者全員の努力のおかげである。

つぎの第3回の集会も日本で1985年に開くこと，JECSS News Letter を1年に4回発行して研究者間の情報交換に役立てること，発行は日本のどこかで担当すること，などがきまった。会のあと，5月に入って，編集・発行はとりあえず海洋科学技術センターと日本 IBM が引きうけてくれることになり，すでに第1号は刊行されている。編集者は海洋科学技術センターの宗山敬さんである。

第3回研究集会は筑波地区のどこかで，海洋科学技術センターの手で開かれる予定である。また筑波地区が候補になっているのは，1985年3月～9月に筑波で科学博が開かれるからである。第1回研究集会の直前の変ないきさつから私がコンビーナになってしまい，細々とした，みみっちい研究集会が2回も続いてしまったが，第3回は面目を一新して堂々とした会になるものと，国内・国外からすでに大きな期待が寄せられている。

東シナ海の堆積を中心として，中国とアメリカの研究者による共同研究はすでに発足している。JECSSは共同研究の実施までにはまだ至らないけれども，今回の成果などをふまえて各国の研究者が共同して調査・研究を進める日は遠くないだろう。第2回集会はただ学問の水準だけではなく，国際協調という意味でもよい集会だったと思う。参加者の一人，韓国の BAE さんもこの会の雰囲気に感心して，「海峡封鎖よりも平和・互恵の海を」という小文を書いて日本の新聞に投稿したそうである（新聞のコピーが送られてこないので採用にならなかったのかも知れないが)。

* 1983年6月27日受理
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日仏海洋学会賞受賞記念講演

海岸付近における波の防災科学的研究*

中　村　重　久**

Recherches scientifiques sur les vagues côtières pour la prévention des désastres*

Shigehisa NAKAMURA**

このたび日仏海洋学会賞を授与され，大変光栄なことと思っております。ただ，ここで標題の包含する問題は多岐にわたり，しかも現在なお研究がすすめられており，あるいは，今後将来に残された問題もあるというのが実状です。このような問題は，単に一個人の力で解決できるものではありません。しかし，一方，個人々々がそれぞれの与えられた場で天与の力を注ぎ，問題解明の方向に向かうよう努めることが必要なことも明らかであります。

わが国の人間活動は，とくに海岸付近に集中しており，しかもそこでは，津波や高潮などによる災害が顕著であります。その場合，海岸付近の構築物や財産のみならず人命の損失を無視ることはできません。このような災害の防止軽減に関連して，災害の実態を調べ，災害の要因の力学的機構を明らかにし，その予測を可能なものとし，その対策を経済的かつ効果的なものにする必要があると考えられます。

このような問題について力学的モデルを作って検討するというやり方は，これまでにも多くの例があります。実在の海岸付近の現象は複雑であるけれども，単純化したモデルを導入することによって，その現象を正しく把握し，その力学的機構が明らかにできると考えられる。“沿岸付近の潮流と渦度”，“河口付近の津波・うねり”の研究は，そのごく初歩的なものであった。その後，物理的現象の類似性を応用して，わが国では最初の“湾水振動の音波モデル”を研究した。津波や高潮の実験や観測の結果の力学的説明のために，“半無限海に面した直線状海岸でのエッジ波”，“円弧状海岸でのエッジ波”の力学的モデルについて漸近的微分方程式の手法などを応用して，エッジ波の沖向き波高分布で波数からみた共振条件を明らかにしようとした。とくに，“楕円弧状海岸”については，岸沿いに伝わる線型長周期波に周期解のほかに非周期解があらわれることを示し，周期解のみがあらわれる条件は，楕円弧海岸が円弧状に近い場合，波の周期が慣性周期に近い場合，水深が無限に深いとみなされる場合であることを明らかにした。

力学的モデルとしての数値モデルによる実験は水理実験と相補的な関係にあることから，海岸付近の津波や高潮の問題に有限差分法の応用をし，その力学的機構の解明に努めた。

大阪湾などのような湾に接近して台風が通過する場合，湾口を節とした副振動があらわれることは，これまでにも，ジェーン台風や伊勢湾台風などの例について指摘されていた。1979年9月30日夜半に室戸岬から大阪湾東部へと経路をとった

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* 1983年5月26日，日仏会館(東京)にて講演
Résumé de la conférence faite le 26 Mai 1983 après la remise du Prix de la Société franco-japonaise d'océanographie

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Observatoire Marin de Shirahama, Institut des Recherches de Prévention des Désastres, Université de Kyoto

7916号台風により，大阪湾内では高潮がみられ，それにつづいて顕著な副振動があらわれた。この副振動が，中村・LOOMIS (1980) がもとめた大阪湾の固有振動モードの組合せによってうまく説明できるかどうかは興味ある問題であった。大阪湾の固有振動に関連した研究には，たとえば，高谷 (1930)，日高 (1931–1938)，和達 (1938)，市衛 (1949) などがある。その後，大阪湾の潮汐や高潮が有限差分法によって数値的に解析されたが，そこでは，大阪湾の固有振動との関連にまで論及されていなかったようである。そこで，まず，LOOMIS (1970) の方法を応用し，任意形状の海岸線をもち，任意水深の港湾における線型浅水波動方程式に対する固有値問題を解く方法を考え，大阪湾の固有周期をもとめた。計算の結果，第1モード（周期 4.49 hr）は湾口に節があり，湾奥が腹となっていた。第2モード（周期 1.87 hr）は湾口のほかに湾中央部にもひとつの節がみとめられるたて振動で，湾奥は腹となっていた。第3モードは周期 1.38 hr で湾口のほかに湾軸沿いの節がひとつみとめられ，これは明石海峡とその対岸とを腹とするよこ振動である。さらに高次のモードも計算では得られるが，実際現象としては顕著ではないとみられる。かりにあらわれたとしても，高次のモードは急速に減衰してしまうであろう。

台風 7916 号による高潮の記録は，大阪湾沿岸では，洲本，深日，淡輪，阪南，岸和田，堺，大阪，尼崎，神戸の各検潮所で得られている。これをみると，台風通過にともない，たとえば大阪では高潮のピークがあらわれた後約1時間のうちに 1.75 m の水位低下がみられ，その後には顕著な減衰振動がつづいた。

ところで，中村・LOOMIS (1980) の与えた大阪湾の固有振動のモードそれぞれについて，たとえば大阪の振幅，位相および減衰係数が与えられれば，そのほかの検潮所の振幅，位相および減衰係数もそれにしたがって定まる。したがって，それと力学的機構が同じ現象については，固有振動のモードによって大阪の水位変動が説明できた場合には，同時にその他の検潮所の水位変動も説明できるはずである。台風7916号による高潮の記録も大阪湾内について，このようにして説明できたと考えている。

台風によって大阪湾内にひきおこされた高潮のもつポテンシアル・エネルギーは，(1) 外海から侵入する高潮，(2) 湾内における気圧低下による吸いあげ，(3) 風による吹きよせといったものの作用によって供給されたもので，台風通過後，高潮のピークがあらわれた後，一部は湾水振動の形成に使われ，それも海底摩擦などによって減衰することになるものと考えられる。大まかな計算によれば，大阪湾に台風7916号が供給したエネルギーは 2.74×10^{7} N・m（$=2.74\times10^{14}$ erg）そのうち，主な3つの固有振動モード形成には 1.94×10^{7} N・m（$=1.94\times10^{14}$ erg）だけ使われ，その残りは，固有振動の高次のモード形成に費やされ，また，その一部は海底摩擦など粘性によるエネルギー損失となり，その他の一部は大阪湾口を通して外へ向かう流れとして失なわれるものと考えられる。このとき，大阪湾の湾口断面平均流速の最大値は 5.16 m/s と計算された。

数値モデルは，波源の条件の不明な津波の検証にも有効であると考えられる。たとえば，1883年8月27日のクラカトア火山の大噴火によって生じた津波については，記述的史料のみがよりどころである。当時の津波の再現が可能となれば，次の津波の時に適切な対処をする手がかりが得られることになる。たまたま，寺田寅彦著“海の物理学”(1923) を見る機会があって，そこにクラカトア爆発時の波についての記述があった。その波の理論的到達時刻の実際との相異も津波の予測に関連して興味のある問題であるが，これも数値モデルの利用によって明らかにできる問題であると考えられる。このクラカトアの津波について波源の条件が不明のため，スンダ海峡のクラカトア火山に対応する水域での水面の鉛直変位高とその持続時間をパラメータとしてえらび，いろいろの値に対するパラメータの組合せに対する有限差分法による数値計算の結果を史料と対比した。このようにして，史料の概略を説明するに足るパラメータの組合せを，“考えられうる等価波源条件”と考えた。ごく限られた史料と手法にもとづくかぎり，精度

はよいとはいえないが，計算結果より波源域の全ポテンシアル・エネルギーは 1.355×10^{13} N•m ($=1.355\times10^{20}$ erg)，一方，スマトラのスンダ海峡 Telukubetung 沿岸の波高から，スンダ海峡内の水位変動のエネルギーは 7.33×10^{12} N•m ($=7.33\times10^{19}$ erg) とみられる。したがって，スンダ海峡からインド洋へ出た津波エネルギーは 6.22×10^{12} N•m ($=6.22\times10^{19}$ erg) となり，波源域のエネルギーの約 46％ が外海へ，約 54％ が海峡にという割合になる。Telukubetung で第1波の峯高は，すでに後続波の峯高とほぼ同じであり，波高もあまり変化していないことからみて，このエネルギー分配過程は，津波発生後 1-2 時間という比較的短時間の間にみられたものと考えられる。

このように，津波や高潮について数値モデルなどによる研究がすすめられる一方で，特定の場所について，いつ頃，どの程度の規模の津波や高潮が来襲するかを予測する必要性を何らかの方法で満さなくてはならない。この問題は，とくに海岸域が高度に利用されている場合に切実である。

津波の来襲頻度に対するポアソン分布のあてはめの例は WIEGEL (1970) をはじめとして，RASCON and VILLAREAL (1975) など，1970年代に入って多数の応用例がみられるようになってきた。GUMBELL (1953) によれば，サンプルサイズに比べてごく少数を対象とした場合の distribution of exceedance は極値から上位の部分について一般にポアソン過程が近似できるといわれている。この点で，ポアソン過程を津波の高さの予測に応用するのもあながち的外れではないと考えられる。ところで，フィリピンの津波危険度評価やインドネシアの津波の発生頻度解析などの例からみて，変形ポアソン分布とでも称すべき分布を考えると解析がやりやすい。このためには，地域的特性をあらわす補助的パラメータを導入すればよい。ただ，この変形ポアソン分布は確率論的に導びかれたわけではなく，発見的に導入されたものである。しかし，この実用上の便利さは，他の分布の適用よりすぐれていて簡単である。また，この手法を波浪に適用することによって，与えられた期間に対する“最大波高の超過確率”をもとめることができ，海岸付近の波の災害防止に対処するにあたってひとつの目安を与えることができる。

このような観点にたてば，津波や高潮による被害額の期待値とその対策に要する投資額予想値との和を極小とするような対策を講ずることも可能と考えられ，経済的対策の基礎を与えることにもなるであろうと考えている。

学　会　記　事

1. 昭和58年５月10日，日仏会館会議室において，日中海洋水産科学技術交流協会との共催で，中華人民共和国山東海洋学院温保華教授の「中国の海洋計測機器について」の講演会が行われた。

2. 昭和58年５月11日，日仏会館会議室において，日仏関連学会連絡会が開かれ，日仏会館増築計画，日仏交換教授計画，第４回日仏学術シンポジウムなどについて話合いが行われた。本学会から佐々木会長と有賀常任幹事が出席した。

3. 昭和58年５月18日，日仏会館ホールにおいて，日仏会館および日仏工業技術会と共催で，フランスのコメックス社（海洋開発）アンリ・ドゥローズ社長の「海底における作業――人間と機械――」(映画も上映）についての講演会が行われた。

4. 昭和58年５月23日，東京水産大学において評議員会が開かれた。

1) 会務報告および編集報告が行われた。

2) 学会賞受賞候補者として中村重久氏が推薦され，受賞者として決定された経過が報告された。

3) 昭和57年度の収支決算報告および監査報告が行われ，昭和58年度の収支予算案が審議された。

4) 昭和58年度学会賞受賞候補者推薦委員の選出について協議し，下記の通り決定された。
阿部友三郎，有賀祐勝，石野　誠，井上　実，岡見登，鎌谷明善，斎藤泰一，中村重久，根本敬久，松生　洽，丸茂隆三，村野正昭，森田良美

5) 学会誌 La mer の論文印刷費のうち，学会負担分は論文１篇につき印刷ページ７ページ以内とし，これを超える分については著者負担とすることが決められた。なお，これと関連して文部省に出版助成金を申請することを検討し，あわせて今後財源の確保に努めることとした。

6) 分科会活動の状況について報告がなされた。

5. 昭和58年５月26日，日仏会館会議室において第24回総会が開かれた。

1) 昭和57年度の会務報告および会計報告が行われ，別表の収支計算が承認された。

2) 編集委員長から学会誌 La mer 第20巻の編集経過報告が行われた。第20巻は総ページ数266ページで，その内訳は原著論文23篇(和文６，英文17)，総説１篇(英文)，寄稿４篇(和文１，英文３)，記念講演１篇(和文)，その他追悼記事と学会記事などである。

3) 学会賞受賞者として中村重久氏が決定に至る経過が報告された。

昭和57年度収支決算

収　入

事　　項	決算額(円)
前年度繰越金	37, 117
正会員会費	1, 852, 000
賛助会員会費	860, 000
学会誌売上金	223, 100
広　告　料	348, 500
著者負担印刷費	262, 000
雑　収　入	52, 812
計	3, 635, 529

支　出

事　　項	決算額(円)
学会誌等印刷費	2, 494, 600
送料・通信費	277, 620
編　集　費	72, 110
事　務　費	591, 270
交　通　費	149, 150
会　議　費	33, 810
次年度繰越金	16, 969
計	3, 635, 529

昭和58年度収支予算

収　入

事　　項	予算額(円)
前年度繰越金	16, 969
正会員会費	1, 836, 000
賛助会員会費	860, 000
学会誌売上金	250, 000
広　告　料	480, 000
著者負担印刷費	100, 000

雑　収　入	5,000
計	3,547,969

支　出

事　項	予算額(円)
学会誌等印刷費	2,400,000
送料・通信費	280,000
編　集　費	60,000
事　務　費	600,000
交　通　費	150,000
会　議　費	30,000
予　備　費	27,969
計	3,547,969

4) 昭和58年度予算案について審議の結果，別表の通り承認された。

5) 昭和58年度学会賞受賞候補者推薦委員が紹介された（前出の評議委員会の項参照)。

6) 分科会活動の状況が報告された。

6. 総会終了後，学会賞授与が行われた。

昭和58年度学会賞受賞者: 中村重久氏（京都大学防災研究所）

受賞課題: 海岸付近における波の防災科学的研究（別項「推薦理由書」参照)。

会長から中村氏に賞状，メダル，および賞金が授与され，続いて受賞記念講演が行われた。

7. 受賞記念講演終了後，懇親会が開かれ，盛会であった。

8. 昭和58年5月26日，日仏会館会議室において，昭和58年度学術研究発表会が次の通り行われた。

午前の部

1. 富山湾の寄り回り波に関する調査報告
…………………………矢内秋生(目白学園短大)，
小林　貴(桐蔭工業高専)

2. 波浪流に関する基礎的研究一その1
……………………糸洌長敬，五明美智男(東水大)

3. 波浪流に関する基礎的研究一その2
……………………糸洌長敬，五明美智男(東水大)

4. SMAC による流体運動の可視化について
……加納　敬(東水大)，奈良　肇(日本電子計算)

5. 赤泥の海洋プランクトンに及ぼす影響調査
第1報　植物プランクトン (*Skeletonema costatum*) を用いた実験結果
………………辻田時美，鈴木繁美(三洋水路測量)

6. 赤泥の海洋プランクトンに及ぼす影響調査
第2報　動物プランクトン（橈脚類3種）
を用いた実験結果
………………辻田時美，鈴木繁美(三洋水路測量)

7. 東京湾におけるクロロフィル*a*による蛍光の測定
……………岸野元彰，杉原滋彦，岡見　登(理研)

8. 夏季相模湾におけるクロロフィル蛍光の微細鉛直分布………………辻　義人(海洋科技センター)，
山脇亮司(筑波大・環境)，
佐々木　建(海洋科技センター)

9. 日本周辺における漂着流石油塊の原油別分類と含有微量元素の濃縮…………吉村広三，原川保之，
柴　多喜男，石井　操(海上保安庁)

10. 東海大学海洋科学博物館において沈殿しているマンガン酸化物について……………竹松　伸(理研)

午後の部

11. 三陸沿岸のイサザ集群 (*Euphausia pacifica*) の潜水観察(予報)………谷口　旭(東北大・農)，
花村幸生(沿岸調査開発)，遠藤宜成(東北大・農)

12. *Caulobacter* 細菌群の動態を支配する中栄養型淡水環境要因
…………江面　浩，関　文威(筑波大・生物科学)

13. 新池におけるバクテリオプランクトン現存量の限定要因……………姜　憲(筑波大・生物科学)

14. 水界の富栄養化における栄養型の境界特性
…………………………関　文威(筑波大・生物科学)

15. 鹿島灘沖合漸深海帯のベントス群集と深度区分
……………………………堀越増興(東大・海洋研)

16. 若狭湾沖合における漸深海帯ベントスの群集組成，深度区分から見た日本海の特性
……………………………堀越増興(東大・海洋研)

17. 新潟地方における漂泳漂着動物とその組織学的観察一続報…………………本間義治(新潟大・理)

18. 英虞湾における環境区分とプランクトン特性
………………安達六郎，和田聖一(三重大・水産)

学会賞受賞記念講演
海岸付近における波の防災科学的研究
……………………………中村重久(京大・防災研)

9. 昭和58年5月26日，日仏会館会議室において編集委員会が開かれ，La mer 第21巻第3号の編集を行った。

10. 新入会員（正会員）

氏　名	所　属	紹介者
橋口　和久	県立加茂丘高等学校	阿部友三郎

辻　義人	海洋科学技術センター	高野　健三
S. Y. Maestrini	G.R.S.-L'Houmeau, 17137 Nieul-sur-Mer, France	有賀　祐勝

11. 退会者

（正会員）塩見文作，吉田三郎，溝口　裕

12. 逝　去

増田辰良

13. 会員の住所・所属の変更

氏　名	新住所または新所属
増沢譲太郎	〒248 鎌倉市腰越 5-3-19-305
倉田　亮	〒520 大津市打出浜 1-10 滋賀県琵琶湖研究所
日本テトラポッド㈱	〒160 東京都新宿区西新宿 2-7-1 新宿第一生命ビル17Ｆ
井上　喜洋	〒104 東京都中央区勝どき 5-5-1 東海区水産工業研究所
寺崎　誠	〒164 東京都中野区南台 1-15-1 東京大学海洋研究所プランクトン部門
佐野　昭	〒100 東京都千代田区大手町 1-3-4 気象庁海洋気象部

14. 交換および寄贈図書

1)	滋賀大学教育学部湖沼実習施設論文集	No. 21
2)	航　海	第75，76号
3)	海洋産業研究資料	Vol. 32. Nos. 1～3
4)	JODC ニュース	No. 26
5)	研究実用化報告	Vol. 32. Nos. 4～6
6)	船と港のはくぶつかん	No. 20
7)	Bulletin of the National Science Museum	Vol. 9. No. 1
8)	神奈川県立博物館研究報告 自然科学	第 14 号
9)	東北区水産研究所研究報告	第 45 号
10)	鯨研通信	第349号
11)	Preliminary Report of the Hakuho Maru Cruise KH-80-2 and KH-82-1	
12)	なつしま	No. 64
13)	早稲田大学理工学部紀要	第 46 号
14)	広島日仏協会報	No. 85
15)	海洋時報	第 29 号
16)	東海大学紀要	第 16 号
17)	東海大学海洋学部業績集	第12集56～57年度
18)	水産工学研究所報告	第 4 号
19)	水産工学研究所技報，水産土木	第 4 号
20)	農業土木試験場場報	No. 38
21)	鯨と日本人	
22)	鯨資源の調査と管理	
23)	広島県水産試験場研究報告	第 13 号
24)	ガザミの増殖研究	
25)	JODC カタログ	Nos. 2，3
26)	実用塩分と国際海水状態方程式	増刊号第14
27)	理化学研究所第５回科学講演会記録	
28)	中部太平洋マンガン団塊分布図	21
29)	釜石沖海底地質図	22
30)	日本周辺海底地質図	23
31)	科学通報	Vol. 28. Nos. 3～5
32)	海洋水产研究	1～4
33)	Revue des Travaux de l'institut des pêches maritimes	Tome 45 Fasc 4
34)	L'Institut Océanographique	Tome 58 N° 2
35)	Science et Pêche	N° 330
36)	Boletim do INIP	N° 7
37)	Pesca Artesanal Nacostaalgarvia	1982

日仏海洋学会賞受賞候補者推薦理由書

氏　名：中　村　重　久（京都大学防災研究所）

題　名：海岸付近における波の防災科学的研究

推薦理由：わが国の人間活動は，とくに海岸付近に集中しており，しかもそこでは，津波や高潮などによる災害が顕著である。このような災害の防止軽減に関連して，災害の実態を調べ，災害の要因の力学的機構を明らかにし，その予測を可能なものとし，その対策を経済的かつ効果的なものとする必要がある。中村重久博士は，これに関連した諸問題について，これまでに数多くの研究をされてきた。なかでも，とくに海洋学的見地からの研究成果は，日仏海洋学会誌「うみ」にも論文として多数発表されており，1966年以来これまでに15篇にのぼっている。これらはいずれも海岸付近における津波・高潮など水位変動を波としてとらえ，災害の防止軽減との関連で力学的機構を明らかにしようとする立場にたってまとめられている。この間，津波や高潮など「長周期波の変形とその制御に関する研究」

をまとめ，工学博士の学位を授与されている。

実在の海岸付近での現象は単純ではないけれども，その現象を正しく把握するには力学的機構を明らかにする必要がある。この考えにたって，「沿岸付近の潮流と渦度」(うみ **4**(2)) をはじめとして「河口付近の津波・うねり」(うみ **4**(4)) のような力学的モデルを作り，興味ある結果を得た。また，わが国で初めて物理的類似性を応用した湾水振動の音波モデル (うみ **15**(3)) は，人工港湾の平面形状を計画する際に利用できる。実験や観測の結果の力学的説明のために，半無限海に面した直線状海岸でのエッジ波モデル (うみ **14**(1)，**14**(3-4)) や円孤状海岸でのエッジ波モデル (うみ **17**(1)) を展開し，漸近的微分方程式の手法などを応用して，エッジ波の沖向き波高分布特性や波数からみた共振条件を明らかにした。とくに，楕円孤状海岸 (うみ **19**(1)) については，岸沿いに伝わる線型波に周期解のほかに非周期解があらわれることを示し，周期解のみがあらわれる条件は楕円孤状海岸が円孤状に近い場合，波の周期が慣性周期に近い場合，水深が無限に深いとみなされる場合であることを明らかにした。

一方，中村博士は，数値実験が水理実験と相補的な関係にあることに留意して，海岸付近の津波や高潮の問題に有限差分法の応用をし，その力学的機構の解明に努められた。すなわち，「大阪湾の固有振動と高潮・津波との関係」(うみ **18**(2)，**18**(4)) では，大阪湾の高潮の実測潮位が固有振動の組合せでうまく説明できることを明らかにした。また，津波の数値実験によって，津波の波源と津波の高さおよび到達時刻について調べ，等価波源の必要条件について興味ある結果を発表した (うみ **19**(1)，**19**(3)，**20**(1))。とくに，1883クラカトア津波の数値実験 (うみ **20**(1)) では，津波を再現すべき等価波源の特性を推定し，従来未知であった海峡と外洋とへの津波エネルギー分配について興味ある結果を得ている。

中村博士は最近，白浜海洋観測塔周辺の水位変動についてとりまとめている (うみ **20**(4))。これは，これまでの研究における手法，成果をすべてつぎこんで得られたもので，これによって，津波，高極潮位および潮位偏差，波浪の極値統計としての特性が明らかになり，また，田辺湾内の周期約40分の水位変動は，田辺湾の静振あるいは陸棚振動としてとらえれられそうであるが，他方，数値モデルによって，沖合流速変動が沿岸水位の変動に影響を及ぼす可能性を示した。これは，太平洋岸の小湾での水位変動が黒潮の消長によって誘起され，その周期は小湾よりスケールの大きい海底地形によって定まるとみられうる例と考えられる。

中村博士は，現在もなお海洋学や防災科学の新しい方向をもとめて意欲的に研究に取り組んでおられる。本委員会は同博士の国内・国際的な活発な研究活動と顕著な研究業績を高く評価し，同博士を本賞の受賞者として推薦する。

学会賞受賞候補者推薦委員会
委員長　石野　誠

主　要　論　文

1965: A study on photoelectric current meters. Bull. Disaster Prevent. Res. Inst., Kyoto Univ., **15**(90), 63-70.

1966: 沿岸付近の潮流と渦度について. うみ, **4**(2), 108-110.

1966: A note on tidal vorticity. La mer, **4**(4), 216-219.

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み，**18**(2)，69-75.（ルーミスと共著）

1980: 大阪湾の固有振動と高潮・津波との関係（2）．うみ，**18**(2)，76-80.（ルーミスと共著）

1980: A note on statistics of historical tsunamis in southeast Asia. Proc. Internat. Conf. Engineer. Protect. Nat. Disasters, Asian Inst. Tech., Bangkok, 1980, p. 883-894.

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1981: On factors magnifying a storm surge. Proc. 19th Congr. Internat. Assoc. Hydraulic Res., Subject B(a), New Delhi, India, p. 47-54.

1981: 楕円孤海岸における長周期線型波とその安定性．うみ，**19**(1)，1-5.

1981: 大阪湾・紀伊水道の津波の数値モデル．うみ，**19**(3)，105-110.

1982: 数値実験からみた 1883 クラカトア津波．うみ，**20**(1)，29-36.

1982: 白浜海洋観測塔周辺の水位変動．うみ，**20**(4)，223-230.（吉岡・芹沢と共著）

賛　助　会　員

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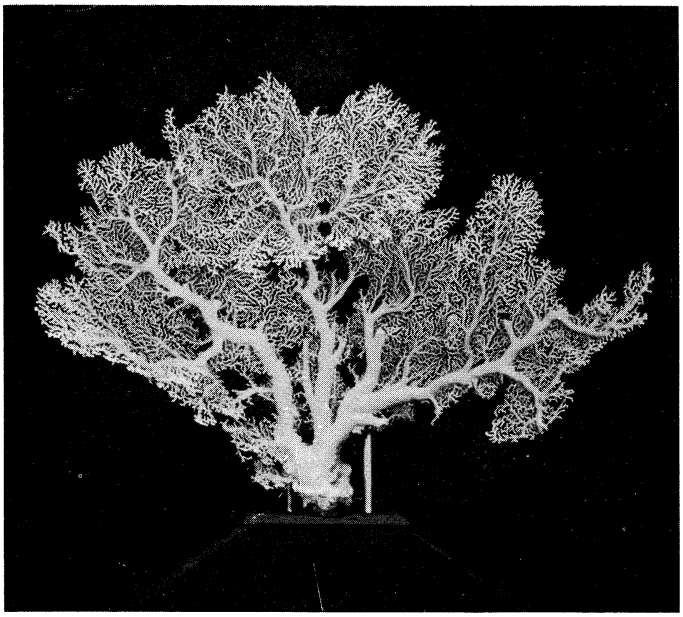
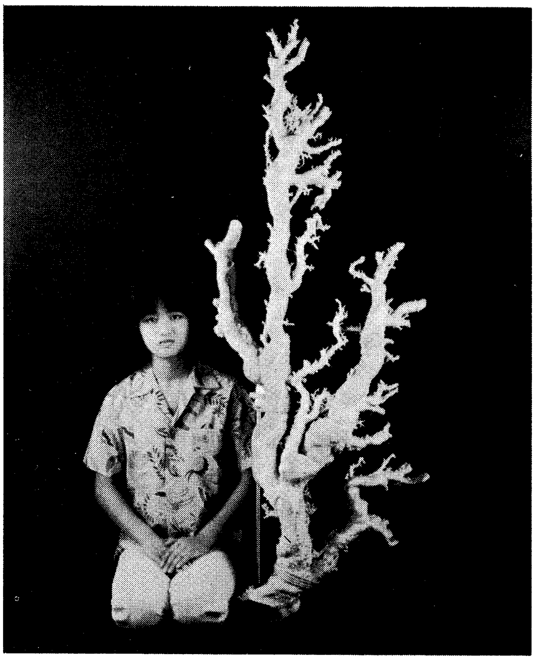


「クイーン・コーラル」　↑
深海潜水艇“はくよう”により採集された，世界で一番美しい珊瑚。
高さ 1m　幅 1.2m　重さ 12kg
採集場所　徳之島近海
採集年月日　昭和54年7月4日



世界最大の珊瑚　→
高さ 1.6m，重さ 35kg の歴史上最大といわれる“ジャンボサンゴ”
採集場所　沖縄近海
採集年月日　昭和49年5月

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Publications de la Société franco-japonaise d'océanographie

1. Collected Papers on the Carcass of an Unidentified Animal Trawled off New Zealand by the Zuiyo-maru. 1978. 83 pp. ¥ 2,000.

2. La mer (Edition spéciale pour la commémoration du vingtième anniversaire), Sommaire complet, Tomes 1-18 (1963-1980). 1981. 56 pp. ¥ 1,000.

3. Proceedings of the First JECSS (Japan and East China Seas Study) Workshop, 1981. 1983. 94 pp. ¥ 2,000.

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