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冬季日本海東部沖合域における大型カイアシ類群集と各水系の環境との関係

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Community structure of large-sized copepods in the eastern Sea of Japan in relation to the environment of water types, during winter.

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Abstract : Community structure of large-sized copepods（total length of adult: >2 mm）was analyzed by Shinagawa's methods using zooplankton samples collected from 0-500 m vertical hauls with NORPAC nets at 18 stations during winter of 1997 in the eastern Sea of Japan. Using the population density of the predominant 13 species of large sized copepods, fuzzy cluster analysis among 14 stations identified 3 station groups（A: south, B: northeastern, C: northwestern）in relation to the Subarctic Front adjacent to the Yamato Rise. According to the fuzzy cluster analysis among the 13 species, 3 species groups were identified. The population density of species group 1 (especially *Calanus sinicus*) was positively correlated to water temperature, and dominated in station group A where water temperature was high. Species group 2（*Metridia pacifica*, *Paraeuchaeta elongata*, *Mesocalanus tenuicornis*, *Neocalanus plumchrus*）was eurythermal and extended to all the station groups（especially station group B). Species group 3（especially *Neocalanus flemingeri, N. cristatus*）was negatively correlated to water temperature, and dominated in station group C where water temperature was low. These results and canonical correlation analysis suggest that the community structure of large-sized copepods is affected by the horizontal distribution of water temperature influenced by the Tsushima Warm Current.

Keywords : *Multivariate analysis, Fuzzy cluster analysis, Sea of Japan, Copepoda, Community*

1.　緒言

日本海は陸や敷居深度の浅い海峡に包囲され他の海洋から隔てられた海洋であり，温暖化など地球規模で起こる気象変動と，海況や生物量の長期変動との関係を究明する上で重要なモデル海域の一つと言える。しかし，本海域は水産資源の重要な餌生物である動物プランクトンの種別の定量的な分布調査がごく沿岸域に限られおり，沖合域では最近になってごく少数行われたのみである（PARK *et al.*, 1998; DOLGANOVA *et al.*, 1999)。特に荒天がちのため調査が容易でない冬季１月は皆無である。植物プランクトンの春季ブルーム（大増殖）を前にした重要な時期にも関わらず一般的な海洋調査すら十分に行われていない状況にある（HIROTA and HASEGAWA, 1999)。さらに，日本海は対馬暖流系水と亜寒帯系水の複雑な混在によって，暖海性生物および寒海性生物の重複分布域が太平洋に比べはるかに広くなることが知られ（西村，1974; 長沼，2000)，動物プランクトン群集の地理的差異の把握を大変難しくしている。以上のように調査が大変制約される中で得られた群集データを最大限かつ客観的に抽出し要約するためには，これまでの多くのプランク

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トン群集の研究のように単に種組成の類似度などを計算したり，群集組成の似た地点群や分布形の似た種群を分割ないし識別する（例えばPARK *et al.*, 1998）に留まらず，群集組成を規定する環境要因を定量的に解析する必要がある。

以上をふまえ本研究では，冬季の日本海東部沖合域全域の，動物プランクトンの現存量（湿重量），主要分類群の個体数や現存量の組成，中でも特に量的に卓越する大型カイアシ類の種類相を調べ，さらには連続的に移行する群集の識別および，群集組成と環境データとの統計的解析に優れた品川の群集解析法（品川，1984，1992，1999; 品川・多部田，1998）を適用して，群集構造と環境との関連を調べる。

2. 材料と方法

1997年1月9−26日に水産庁調査船の開洋丸によって，日本海沖合域を中心に計18地点で動物プランクトン試料を得た（Fig. 1，Table. 1）。採集は，濾水計（離合社製）を装着したノルパックネット（網目: 0.33mm）を用い鉛直曳で行った。昼夜に関係なく採集していることから，夜間に上昇移動するものによる量的な違いの影響を小さくするため，鉛直曳の深度は500 m深からとした。水深の浅い大和堆周辺（H2, H3）と山陰沖（J2）では海底付近からに留めた。

試料は採集後，直ちに5−10%中性ホルマリン海水にて固定保存した。動物プランクトンの主要分類群の組成は，適宜，採集標本をフォルサム式分割器を用いて分割し，分類群別の個体の計数と電子天秤を用いて湿重量の測定をすることで調べられた。成体で体長2 mm以上になるカイアシ類の大型種とそのコペポディッド幼体については，種別に計数し，濾水量（m^3）で割ったものに調査水深（m）を積算して個体数密度（ind./m^2）を計

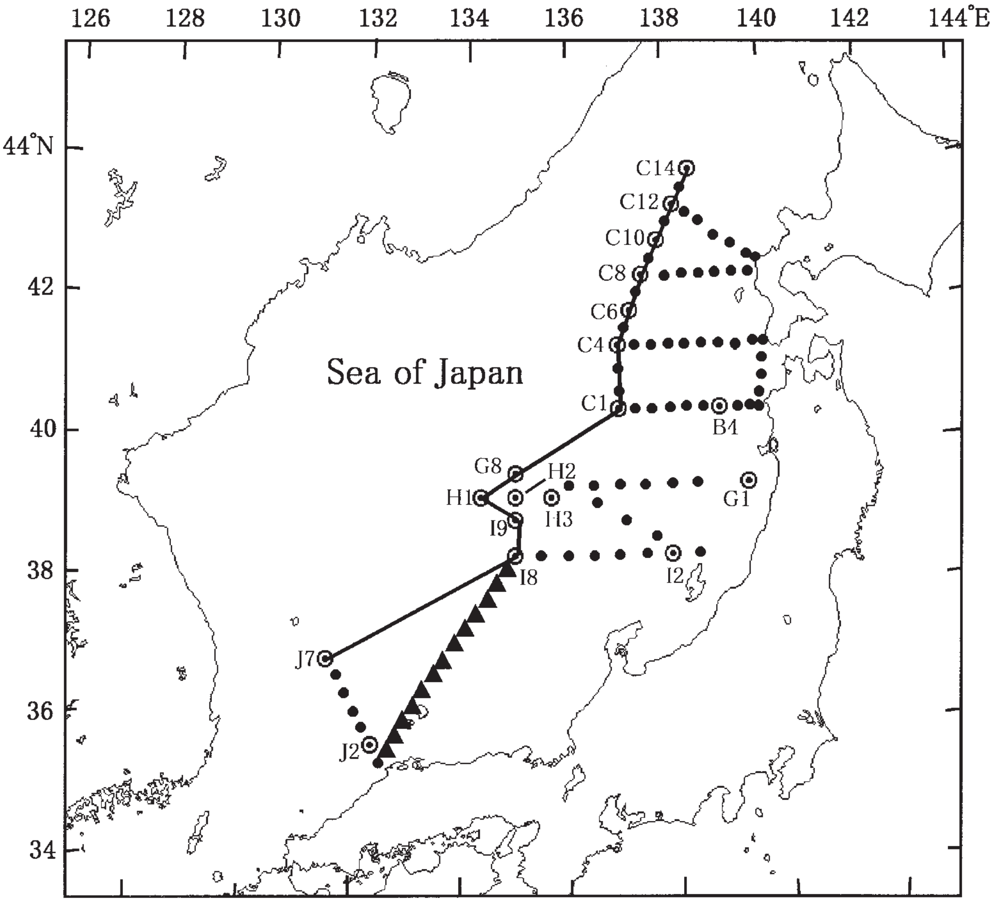

Fig. 1. Map of the Sea of Japan, depicting stations sampled during the cruise of the R/V Kaiyo-Maru (9–26th Jan., 1997). ◉: 18 stations sampled for zooplankton and CTD data labeled with the station number: B4-J7. ●: 59 stations investigated by CTD only. ▲: 13 stations investigated by XCTD. The solid line was used as a transect when studying the vertical profile of water temperature and salinity shown in Fig. 4A–B.

Table 1. Summary of sampling, 9–26th Jan., 1997.

Sampling Station	Date	Latitude (°N)	Longitude (°E)	Maximum sampling depth (m)	Bottom depth (m)
B4	1/9/97	40°35.1′	138°59.9′	500	3215
C1	1/10/97	40°35.1′	137°00.0′	499	3182
C4	1/10/97	41°29.9′	137°00.1′	500	3548
C6	1/11/97	42°00.0′	137°14.9′	500	3628
C8	1/11/97	42°30.0′	137°29.9′	500	3635
C10	1/12/97	43°00.0′	137°50.0′	500	3635
C12	1/12/97	43°30.0′	138°10.1′	499	3583
C14	1/12/97	44°00.0′	138°30.1′	499	3116
G1	1/15/97	39°30.0′	139°30.1′	492	557
G8	1/17/97	39°40.0′	135°00.0′	500	998
H1	1/17/97	39°19.7′	134°19.7′	500	1969
H2	1/17/97	39°20.0′	135°00.0′	229	305
H3	1/18/97	39°20.0′	135°40.4′	448	478
I2	1/23/97	38°30.0′	138°00.1′	501	1560
I8	1/24/97	38°30.1′	135°00.0′	500	2967
I9	1/24/97	39°00.0′	135°00.1′	499	2861
J2	1/26/97	35°45.0′	132°20.1′	198	235
J7	1/26/97	36°58.4′	131°27.6′	500	2090

算し，同様に現存量（wet weight/m^2）も求めた。

さらに，水温と塩分はCTD（WOCE仕様，Seabird製，SBE-9plus）により動物プランクトン調査地点に加えその周辺海域の計77地点において，また水温のみであるがXCTD（鶴見精機製TSK-XCTD）により13地点（1月25–26日）において，表面の水温・塩分はバケツで採水したものを棒状水温計とAutosal Laboratory Salinometer（Guildline製，8400A）により，それぞれ測定した。各地点の平均水温・塩分は，基準層（0, 10, 20, 30, 40, 50, 75, 100, 125, 150, 200, 300, 400, 500 m）の測定値から計算した。また，舞鶴海洋気象台による10地点（Sm1443–1452）の水温・塩分（1997年1月15–16日），19地点（TM1–19）の水温（1997年1月14–21日）や10地点（Sm1453–1462）の塩分（1月31–2月1日）のデータ（舞鶴海洋気象台，1997）も調査域の海洋構造の検討対象とした。クロロフィルa濃度（$\mu g \cdot l^{-1}$）は，動物プランクトン調査地点の8層（0, 20, 50, 75, 100, 200, 300, 500 m）からの採水試料を蛍光法により測定した。ガラス繊維濾紙（Whatman GF/F filter）で試水約100mlを濾過したあとにN, N-ジメチルホルムアミドで色素を抽出し（SUZUKI and ISHIMARU, 1990），分光蛍光光度計（日本分光製 FP-777）で測定した。また，

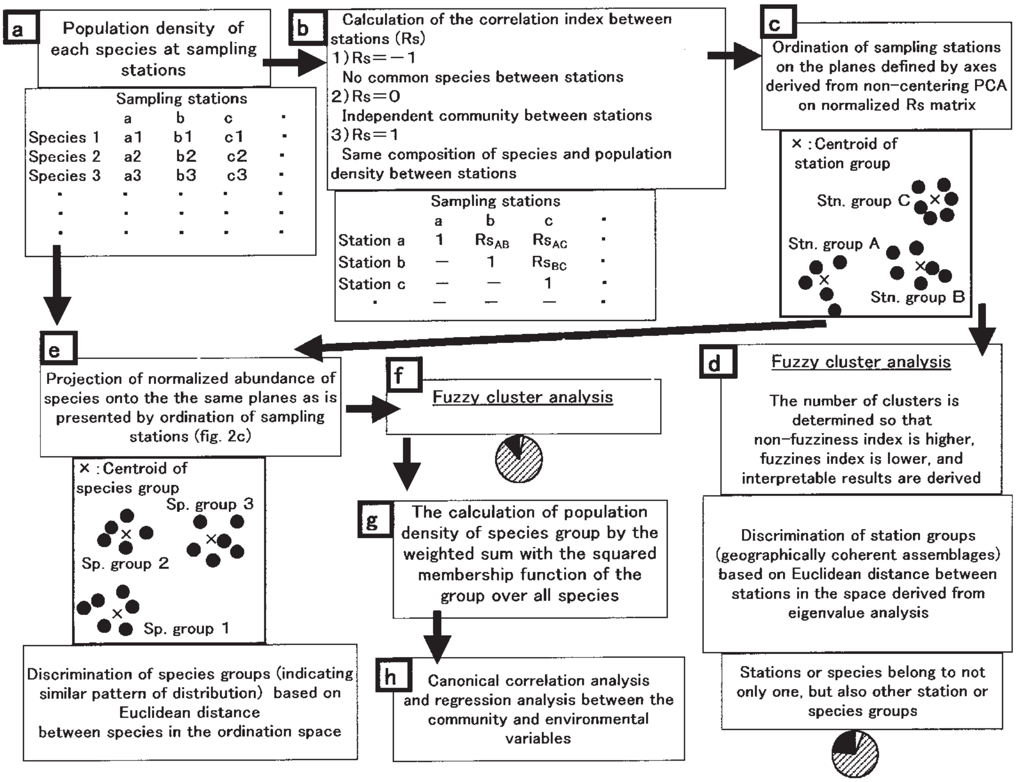

Fig. 2. Diagrammatic summary of the steps used in Shinagawa's community analysis.

クロロフィル *a* 濃度は，8層の中で最大となるものを各地点の代表値とした。

大型カイアシ類の群集解析は，群集区分に留まらず群集組成を規定する環境要因を解析する品川の一連の群集解析法により行った（Fig. 2）。まず，各地点の種の個体数組成（Fig. 2a）から計算した地点間相関指数（Rs, 品川 1984）の行列（Fig. 2b）に中心化しない主成分分析を適用し，各地点を寄与率の大きい軸（今回はⅠ-Ⅲの3軸）による座標空間に投影して（Fig. 2c），地点を座標づけした（Rsn法, 品川・多部田，1998）。次に各種を地点の座標づけと同じ主成分空間に射影して，種も座標づけした（Fig. 2e）。これらの座標空間内で群集組成・分布形が類似する地点・種の集まりを，ファジィクラスター解析（宮本, 1999）により，それぞれ地点群・種群として識別した（Fig. 2c–f）。群の分割数は，分割度（品川，1984のQ）や分割係数（品川, 1984のP）が大きく，あいまい度（品川, 1999のF）が小さく，かつ解釈が容易となるように試行計算を繰り返して定めた。この分割は二者択一的ではないので，各地点・種は所属率の配分比により複数の群へ帰属した（Fig. 2d, 2f, 品川, 1992）。さらに，各種の地点別個体数密度をその種の所属率の二乗の割合で重みづけした上で，これを種群別に合計し，種群の個体数密度を地点別に算出した（Fig. 2g）。加えて，群集変数群（地点別の種群の個体数密度や種類数など）と環境変数群（水温など）との間で正準相関分析（Canonical Correlation Aanalysis: CCA）を行い（品川・多部田, 1998），各地点を両変数群の共通一次空間に配置して，群集組成と環境変数の共通要因を推察した（Fig. 2h）。ただしこの際，種群の個体数密度は1を加えて常用対数に変換した値を用いた。最後に，群集変数を従属変数に，環境変数を独立変数にして回帰分析を行い，両者の関係を統計的に解析した（Fig. 2h）。その際，複数のモデル式を仮定して，それぞれのパラメータを重みづけの非線型最小二乗法（マルカール法）により推定し（中川・小柳, 1982），赤池情報量規準（Akaike's Information Criteria: AIC）を計算して最も有意なモデル式を選択した（鈴木, 1995）。AIC_0（従属変数が独立変数とは全く無関係に正規分布モデルに従う場合のAICの値）より小さいAICを得れば，式のあてはめは有効と判断した。

3. 結果

3.1. 海洋環境

100m深水温をみると沖合域（2-4℃）から沿岸域（12-14℃）に向かい顕著に昇温しており，中間的な水温帯となる100m深7℃等温線付近を亜寒帯収束線（森安，1972; 長沼，2000）とした。この収束線は，大和堆の南方から北海道西方沖（C10）にかけて大きく蛇行していた（Fig. 1, Fig. 3a）。一方，100 m深塩分では山陰沖（J2付近），大和堆（I9付近）に34.2以上の高塩分水

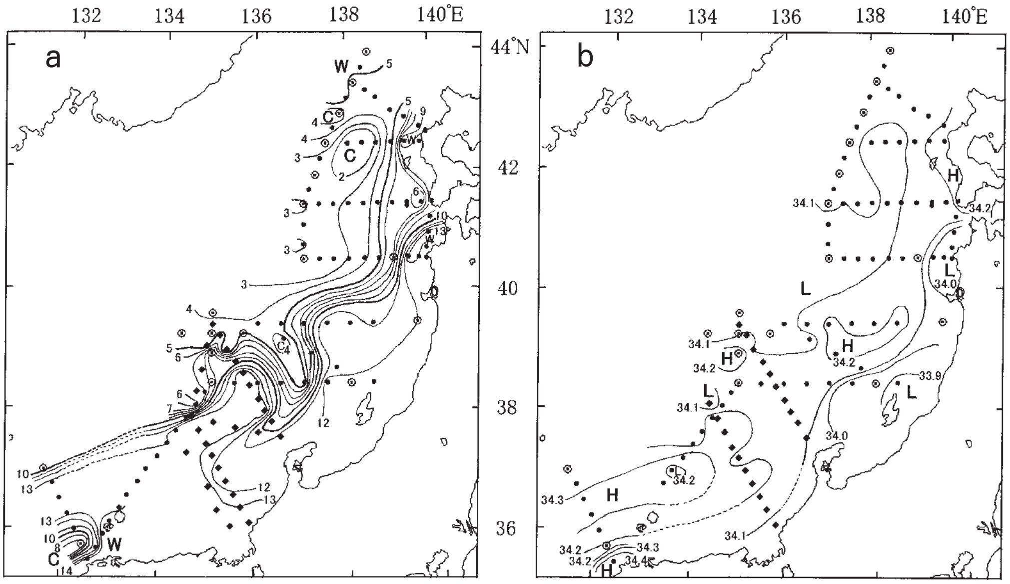

Fig. 3. Contours of isotherm（℃）(a) and isohaline（PSU）(b) at 100 m depth for 9th Jan.–1st Feb. 1997. W: Warmer area. C: Cooler area. H: Higher salinity area. L: Lower salinity area. ◆: Stations investigated by CTD by Maizuru Marine Observatory. Temperature（29 stations): 14–21th Jan., 1997 and salinity（20 stations): 15th Jan.–1st Feb., 1997. ◉, ●: See Fig. 1.

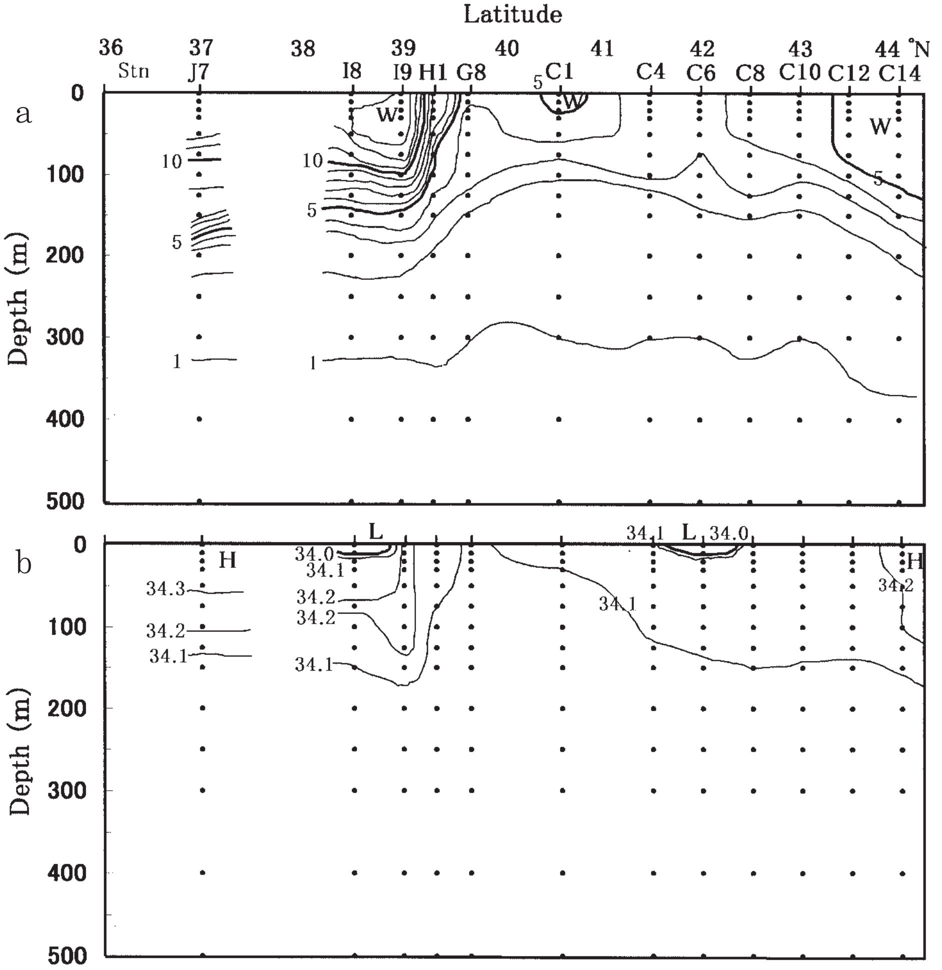

Fig. 4. Vertical sections of water temperature (℃) (a) and salinity (PSU) (b) at 12 sampling stations (see the solid line on Fig. 1). W: Warmer area. H: Higher salinity area. L: Lower salinity area.

が見られ，夏から秋に卓越する東シナ海沿岸由来とされる低塩分水（木谷, 1995）は認められなかった（Fig. 3b）。対馬暖流は，同時期の海洋速報によれば（舞鶴海洋気象台，1997），隠岐北西沖の36°N, 132°E付近から大和堆南方39°N, 136°E付近まで北東進した後，暖水域を時計回りに回り込んで能登半島沖の38°N, 137°E付近まで南下，その後再び北東進し佐渡北東沖の39°N, 139°E付近に達するとしており，亜寒帯収束線の南方に位置した。

水温鉛直断面（Fig. 4a）をみると，250 m以深の水温は全地点で2℃以下で，特に大和堆（H1付近）の北方の各地点（G8–C14）はどの水深でも5℃以下で水温の違いは僅かであったが，南方（I9–J7）では150 m以浅で4–13℃へと急上昇した。塩分の断面分布（Fig. 4b）でも34.2以上の高塩分水がI9以南の表層にみられ，高温・高塩分の対馬暖流系水（森安, 1972; 木谷, 1995）の流入の影響が認められた。一方で，34.1以下の低塩分水が150m以深に広く分布し，特に大和堆北部（G8）では表面まで達しており，対馬暖流系水（特にその中層水）に比べ低温・低塩分とされる亜寒帯系水（森安, 1972; 木谷, 1995での冷水域）の影響が認められた。

クロロフィル*a*濃度極大値は全測点で平均すると0.32 μg・l^{-1}であった。大和堆付近（H1–3）で0.45 μg・l^{-1}を越え，他の地点より高い値を示した（Fig. 5a）。

3.2. 動物プランクトン現存量と主要分類群の出現割合

動物プランクトン現存量（全地点の平均: 42.7g・m^{-2}）は水深が浅い（H2, G1, I2）か，沿岸に近い海域（I2）で30 g・m^{-2}未満とやや低い値を示したが，その他の地点で顕著な量的差異は認められなかった（Fig. 5 b）。この現存量を主要動物プランクトン分類群（貝形

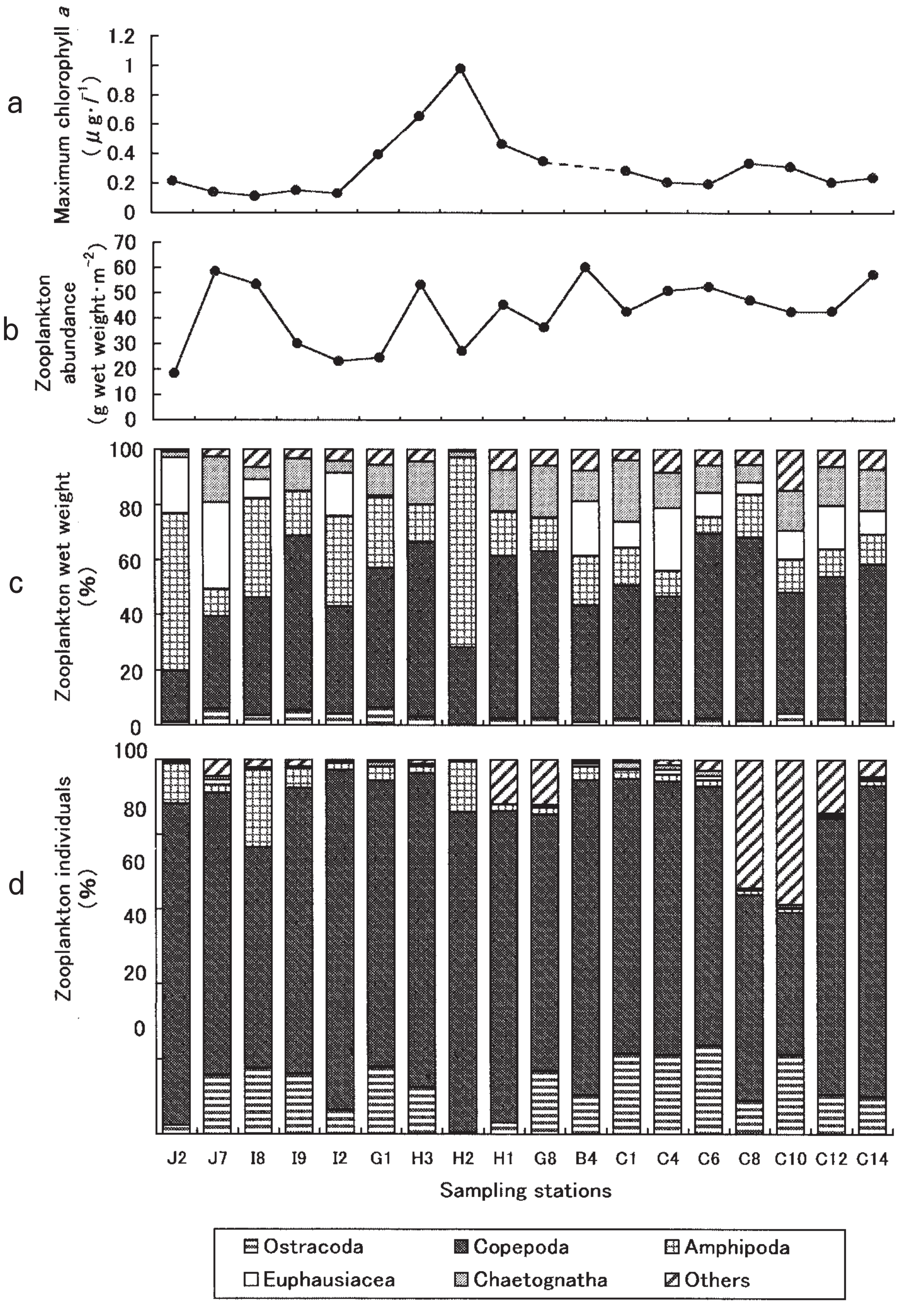

Fig. 5. Horizontal distribution of maximum of 0–500 m chlorophyll-*a* concentration (μg・l^{-1}) (a) and zooplankton abundance (g wet weight ・m^{-2}) (b). Relative wet weight (%) (c) and individuals (%) (d) of dominant zooplankton taxa. The sampling stations are arranged southwest to northeast from left to right.

Table 2. Large-sized copepod species whose adult body lengths were greater than 2mm, collected in the eastern Sea of Japan in winter.

	Mean abundance of copepodid and adult species over all stations(inds. • m^{-2})		Composition %	Abbreviation
◎	*Metridia pacifica*	10623.2	71.80	Mep
◎	*Neocalanus flemingeri*	1290.0	8.72	Nef
◎	*Paraeuchaeta elongata*	976.9	6.60	Pae
◎	*Neocalanus cristatus*	725.0	4.90	Nec
◎	*Mesocalanus tenuicornis*	398.5	2.69	Met
◎	*Neocalanus plumchrus*	211.7	1.43	Nep
◎	*Calanus sinicus*	204.2	1.38	Cas
◎☆	*Gaetanus minutus* (=*Gaidius variabilis*)	185.1	1.25	Gam
◎	*Lucicutia flavicornis*	40.2	0.27	Luf
◎	*Pleuromanma gracilis*	39.0	0.26	Plg
◎	*Eucalanus bungii*	30.2	0.20	Eub
◎	*Candacia dipinnata*	15.7	0.11	Cab
◎	*Eucalanus subtenuis*	10.4	0.07	Eus
	Paraeuchaeta sp.	9.8	0.07	
◎	*Eucalanus mucronatus*	5.1	0.03	
	Eucalanus attenuatus	3.1	0.02	
	Eucalanus subcrassus	3.0	0.02	
＊	*Heterorhabdus pacificus*	2.8	0.02	
	Eucalanus crassus	2.6	0.02	
	Pleuromanma xiphias	1.8	0.01	
	Gaetanus simplex	1.5	0.01	
	Pleuromanma abdominalis	1.4	0.01	
＊	*Undeuchaeta plumosa*	1.4	0.01	
＊★	*Pseudoamallothrix inornata* (=*Amallothrix inornata*)	1.1	0.01	
	Euchaeta sp.	1.1	0.01	
	Scottcalanus securifrons	1.1	0.01	
＊	*Chirundina streetsii*	0.7	<0.01	
	Euchirella spp.	0.7	<0.01	
	Gaetanus spp.	0.7	<0.01	
	Metridia okotensis	0.7	<0.01	
	Nannocalanus minor	0.7	<0.01	
＊	*Scottcalanus helenae*	0.7	<0.01	
	Spinocalanus sp.	0.7	<0.01	
	Undeuchaeta sp.	0.7	<0.01	
	Eucalanus hyalinus	0.6	<0.01	
＊	*Amallothrix valida*	0.4	<0.01	
＊	*Bradyidius pacificus*	0.4	<0.01	
＊	*Calanus jashnovi*	0.4	<0.01	
＊	*Candacia norvegica*	0.4	<0.01	
	Euchirella rostrata	0.4	<0.01	
	Gaetanus minor	0.4	<0.01	
	Lophorix sp.	0.4	<0.01	
＊	*Pontellopsis sternua*	0.4	<0.01	
	Pseudeuchaeta sp.	0.4	<0.01	
	Pseudochirella sp.	0.4	<0.01	
Total		14794.5	100.0	

Dominat species are listed at the upper.◎: 14 species used in community analyses.

＊: 9 species collected for the first time from the Sea of Japan.

☆ and ★ : Species correctly indentified by Markhaseva (1996) and Vyshkvartzeva (2000). Names in parenthesis indicate invalid species.

虫類，カイアシ類，端脚類，オキアミ類，ヤムシ類，その他）の組成で見ると，水深が浅い山陰沖（J2）および大和堆頂部（H2）の端脚類を除いて，カイアシ類が最も卓越した（Fig. 5c）。個体数組成では全点でカイアシ類が最優占した（Fig. 5d）。その他の分類群の個体数の割合がC8とC10に多いが，これはほぼ有孔虫によるもので現存量ではごく僅かに過ぎなかった。

3.3. 大型カイアシ類の種組成

全地点を通して，大型カイアシ類が19属36種得られ，うち日本海からの新記録種が10種であった（Table 2）。未同定個体は全て幼体であった。

個体数密度において全地点で最も優占したのは*Metridia pacifica*で45-87，平均71.8%であった。次いで*Neocalanus flemingeri*, *Paraeuchaeta elongata*, *N. cristatus*, *Mesocalanus tenuicornis*, *N. plumchrus*, *Calanus sinicus*, *Gaetanus minutus*の順に多く，これら8種だけで全大型カイアシ類の約98.8%を占めた。

3.4. 大型カイアシ類の群集構造

3.4.1. ファジィクラスター分析による地点群の識別

大型カイアシ類全36種のうちの優占種（5個体m^{-2}以上）14種を用いて地点の座標づけを行った（Fig. 2c）。ただし，調査水深が400 m以浅であると（H2, J2），表層種と深層種の組成の公平な地点間比較が困難になるので，2地点を座標づけから除いた。その結果，残り16地点の中でB4とJ7は第Ⅰ，Ⅱ軸上で他の14地点と座標上の距離が大きく隔たり，群集構成が特殊となった（Fig. 6左上）。そこで，この14地点（Fig. 6左上の点線内）の中での群集構造の違いをさらに明確にするため，J7でのみ出現した*Eucalanus macronatus*を除く13種のデータからRsによる14地点の座標づけを行ったところ，明らかに複数の地点群が認められた（Fig. 6の残り）。

そこで，第Ⅰ−Ⅲ軸による地点間ユークリッド距離に基づき，14地点についてファジィクラスター分析（Fig. 2d）を行った。その結果，3分割の場合の地点群のあいまい度が様々な分割数の中で最小で（0.614），分割係数・分割度は最大であった（0.824, 0.736）。結果として第Ⅰ，Ⅱ軸成分により地点群Aが，第Ⅲ軸成分で地点群BとCが識別できた（Fig. 6の残り）。地点群Aに所属率が高い地点は大和堆より南方（I2, I8, I9）で多く，地点群Bはそれより北方の東寄り（C8, C14, G1, H1, H3）に，Cは北方の西寄り（C1, C4, C6, C10, C12, G8）に多かった（Fig. 7）。

3.4.2. ファジィクラスター分析による種群の識別と各種群の分布

14地点の座標づけで得られた第Ⅰ−Ⅲ軸に基づき13種について種の座標づけを行ったところ，これも複数の種群が認められた（Fig. 2e–f, Fig. 8）。そこで，地点群の

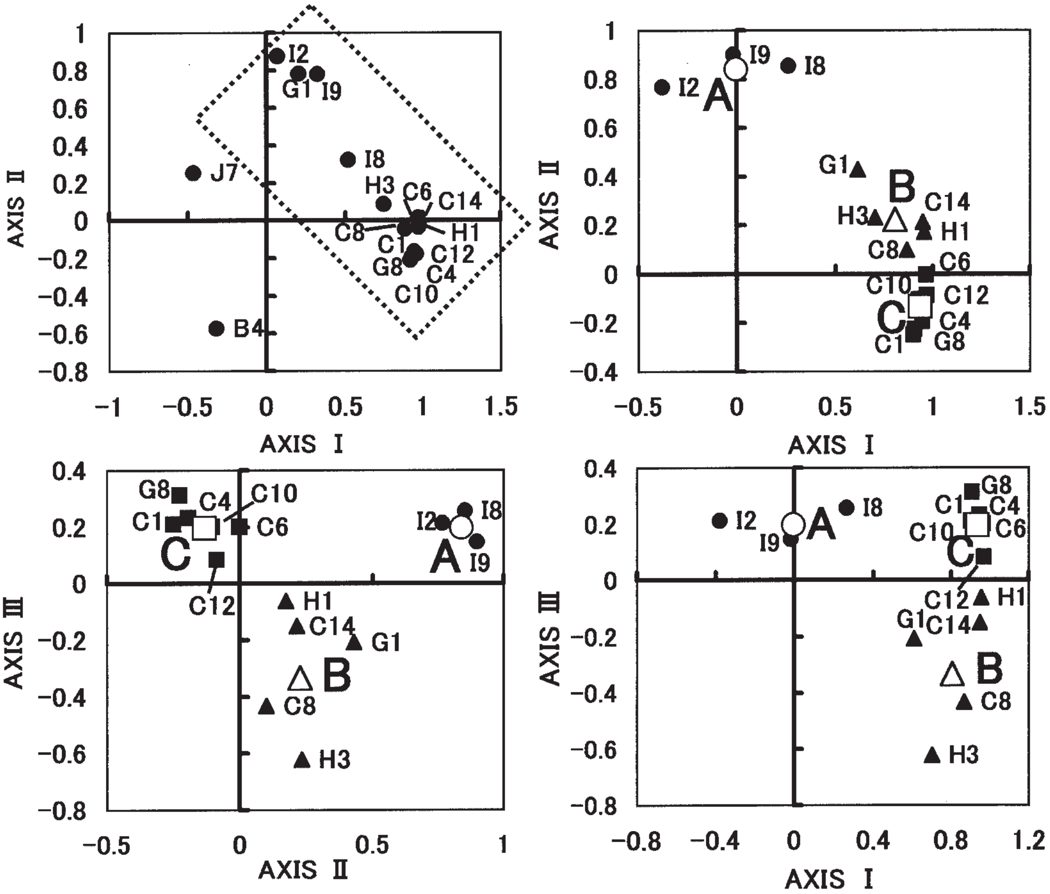

Fig. 6. Plot of sampling stations (based on large copepod community data) by non-centering ordination with use of Rs showing the relationships among the initial 16 stations by 14 species (top left), and among the selected 14 stations by 13 species (the remaining 3 plots). Plane defined by each pair of axes Ⅰ-Ⅲ. The highest three eigenvalues of the latter plots are 8.90, 2.62 and 1.06. The corresponding cumulative contributions are 63.6%, 82.3% and 89.9%. The solid symbols (●, ▲, ■) of the latter plots indicate the stations with the highest membership function to the following three station groups obtained by fuzzy cluster analysis. ○, △, □: Centroids for each station group A, B, C, respectively.

場合と同様に13種についてファジィクラスター分析をしたところ，こちらも3分割のときに種群の分割係数が最大であった（0.720)。結果として第Ⅰ軸成分により種群1が，第Ⅱ，Ⅲ軸成分で種群2と3が識別できた（Fig. 8)。

次いで，群集の連続的変化を表すために，各種群への種の所属率の値から3種群の個体数密度を全18地点についてそれぞれ計算し（Fig. 2g)，種群や優占種13種の分布の特徴を地点群との関係を考慮しながら検討した（Fig. 9)。種群1に所属率が高いものは6種で，その合計は山陰沖（J2，J7）に集中し，大和堆南方の地点群Aや秋田沖（G1）でも出現した。その分布は最優占する*Calanus sinicus*とよく一致していた。残り5種はごく少数であり，うち，*Eucalanus subtenuis*および*Lucicutia flavicornis*については，種群1への所属率は共に54–55%，種群2へはそれぞれ33, 27%となっており，両種群の中間に該当する曖昧な分布様式を示した。種群2に所属率が高いものは4種で，全地点に広く出現したが，特に大和堆から北方の地点群Bと青森沖（B4）で多い一方で，調査水深が浅い地点（H2, J2）で個体数密度が小さく，*Metridia pacifica*, *Paraeuchaeta elongata*および*Neocalanus plumchrus*の分布とよく一致した。種群3に所属率が高いものは3種で，山陰沖（J2, J7）および地点群Aを除く各地点で多く，北方の地点群Cで最大で，*Neocalanus flemingeri*および*N. cristatus*の分布とよく一致した。

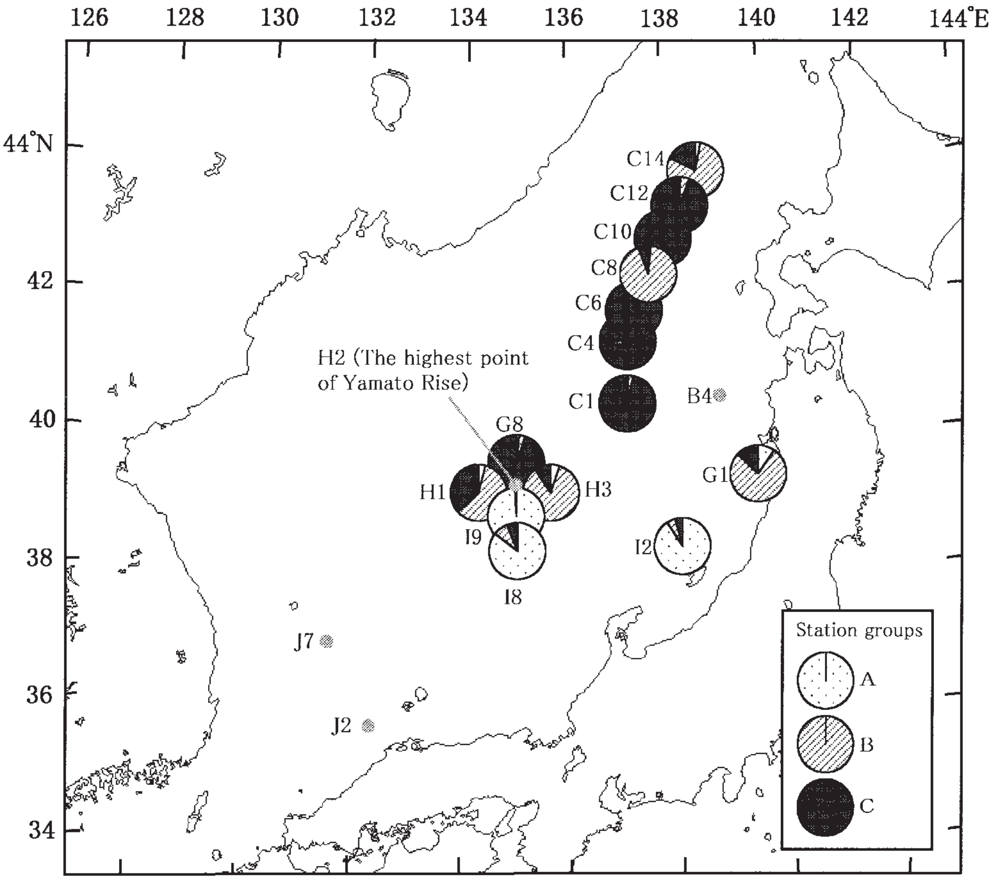

Fig. 7.　The composition of membership functions of each sampling station to 3 station groups obtained by fuzzy cluster analysis. ▨: Sampling station excluded from the fuzzy cluster analysis.

3.4.3.　地点群の環境の特徴と正準相関分析

群集構造の形成に関わる環境要因を検討するために，クロロフィル*a*が欠測のB4を除く17地点について環境変数群（0–500 m深の平均水温・塩分，クロロフィル*a*濃度極大値および水深）と群集変数群（各種群の個体数密度および種類数）との間で正準相関分析を行った（Fig. 2g）。第Ⅰ正準変量は0.1 %以下の水準で有意だが，第Ⅱ正準変量は有意でなかった。環境変数の因子負荷は，平均水温において最大で正であるのに対し，水深とクロロフィル*a*濃度極大値が弱い負であり，平均塩分はほとんど負荷がなかった（Table 3）。第Ⅰ正準変量による環境変数群（縦軸）と群集変数群（横軸）との関係を地点別に検討すると，各地点はほぼ一直線上に配列した（Fig. 10）。縦軸は因子負荷の高い水温の軸にほぼ相当しており，地点群Aに加え，J2, J7および地点群BのG1は正の大きな値であるから暖水の影響が強い一方で，地点群Cおよび地点群BのC8は負の大きな値で冷水性が強かった。残りの地点群B（C14, H1, H3）およびH2は地点群AとCとの中間の原点付近に集中していた。これらの地点はいずれも水温，塩分の水平傾度が他の地点に比べ大きく急変しており（Fig. 3a, Fig. 3b），対馬暖流系水と亜寒帯系水との潮境が近くにあったとみられる。

3.4.4.　平均水温と種群個体数密度・種数の関係

最後に，各種群の個体数密度と，優占種14種（*Eucalanus macronatus*も含む）の総種類数をそれぞれ従属変数とし，因子負荷の最大だった平均水温（Table 3）を独立変数とする回帰分析を行った（Fig. 2h）。一般に生物の分布が一つの環境傾度に規定される場合は，2次式の指数関数（正規分布）＋定数項として表せることが多い（Campbell, 1970参照）。ここでの定数は，分布限界が調査域より広く個体数密度がゼロに至らない種を考慮したものである。しかし統計的な意味での信頼性を保証するためには，モデル式からいくつかのパラメータを割愛するか，より簡単な1次または2次の整多項式で近似するのが現実的である。以上を考慮した5つのモデル

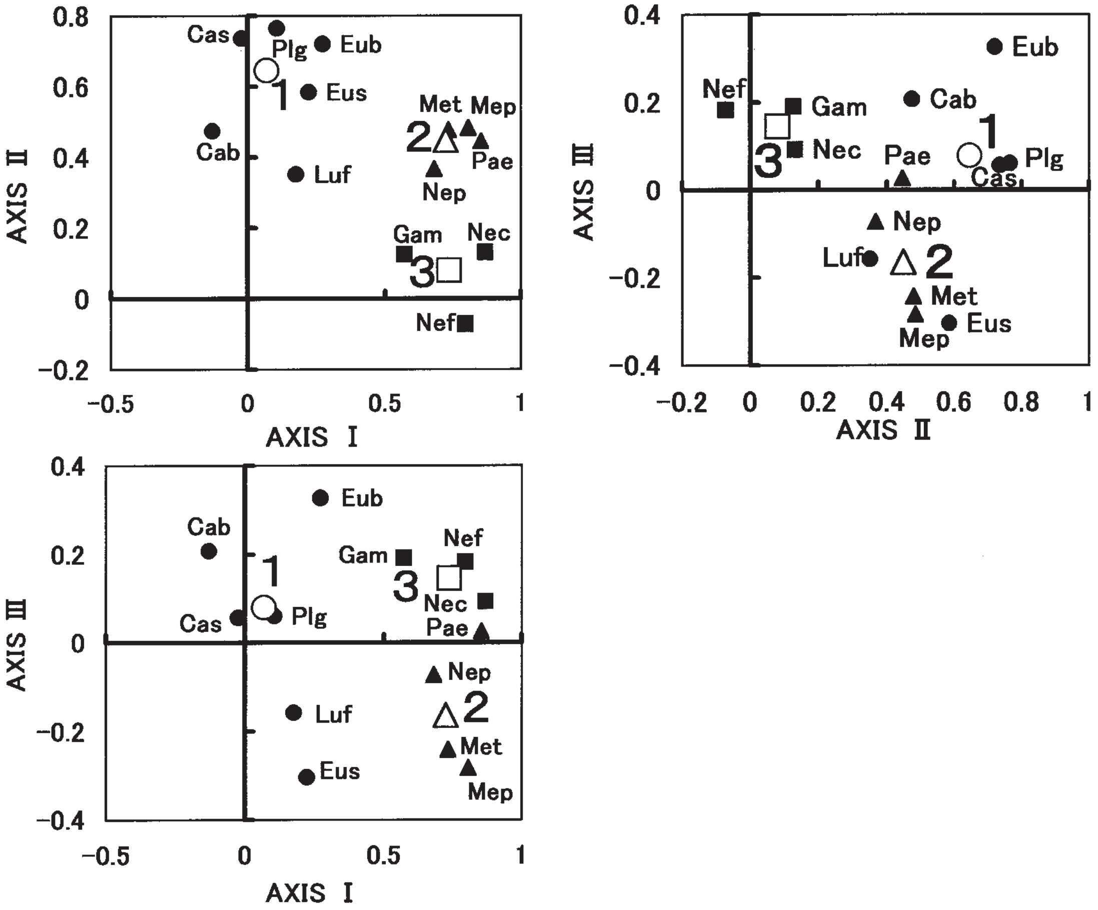

Fig. 8. Plot of large copepod species projected onto the same plane, as presented by ordination plot of 14 stations (Fig. 6), showing the relationships among 13 species and 3 species groups. The solid symbols (●, ▲, ■) indicate the species with the highest membership function to the following species groups obtained by fuzzy cluster analysis. ○, △, □: Centroids for each species group 1, 2, 3, respectively. See table 2 for explanation of species abbreviations.

Table 3. Factor loadings of environmental and community variables on canonical variate I.

		Factor loading
Environmental variables	Mean temperature between 0–500m	0.979
	Mean salinity between 0–500m	−0.013
	Maximum of 0–500m chlorophyll-*a* concentration	−0.199
	Bottom depth	−0.578
Community variables	Log number of species group1	0.956
	Log number of species group2	−0.193
	Log number of species group3	−0.900
	Number of species	0.692

Canonical correlation coefficient = 0.985 (significant correlation at $p < 0.001$, χ^2-test.).

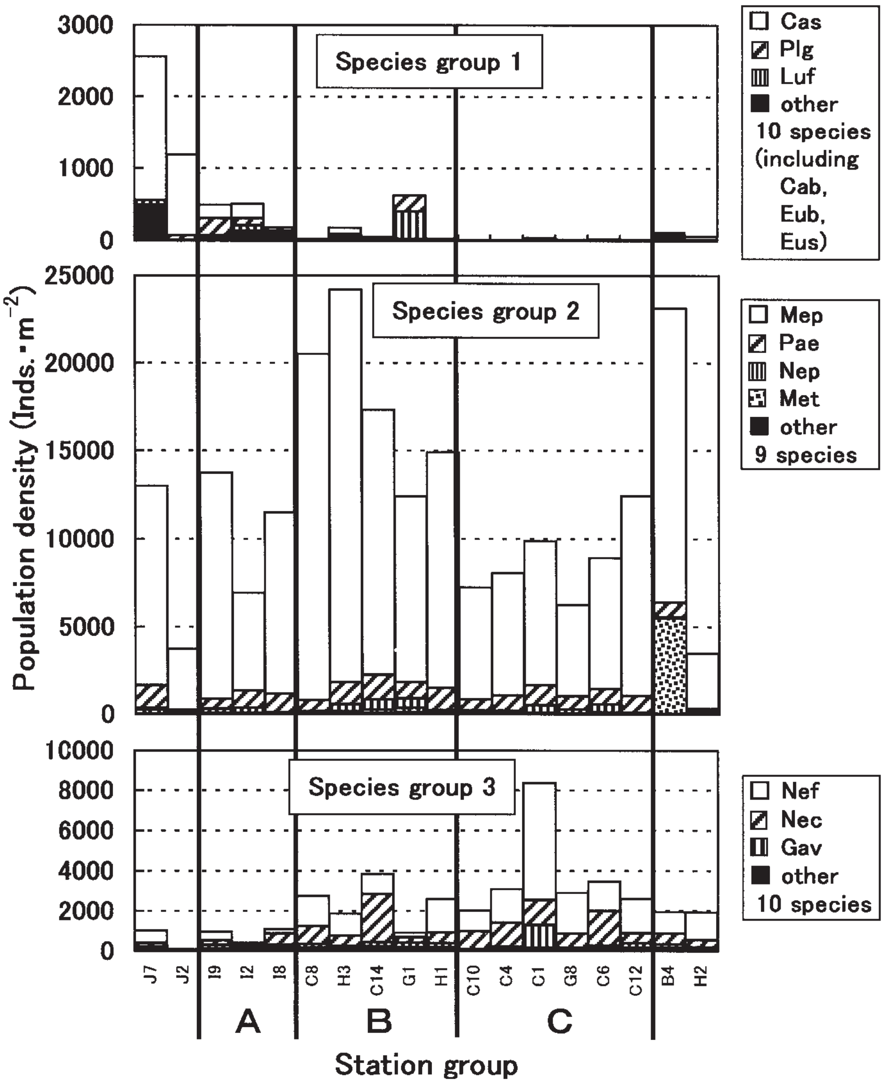

Fig. 9. Population density (inds.・m^{-2}) of 13 species of large-sized copepoda among 3 species groups. Sampling stations with the highest membership function of each station group (A–C) are arranged in descending order of membership function from left to right for each group. Stns. J2 and J7 on the far left, and Stns B4 and H2 on the far right, were excluded from the fuzzy cluster analysis. See table 2 for explanation of species abbreviations.

式を設定し（Fig. 11），その中からAICが最小となる式を選択した。その結果，種群1は定数項のない一次式の指数関数がよく当てはまり平均水温と正の相関で水温の上昇と共に急激に個体数密度が増大する傾向を示した。種群2は，大和堆頂部（H2）のみ近似曲線から離れ少ないものの，釣鐘型の二次式で近似され，5℃付近を極大とする広温性であった。種群3は一次式が適合し負の相関で水温の上昇と共に直線的に緩やかに減少した。総種類数も一次の多項式に適合し正の相関で，水温が上がると緩やかに増加した。

4. 考察

これまで冬季日本海沖合域の動物プランクトン現存量の調査は，ほとんど0–150 m深の採集によるものであり，亜寒帯収束線を境に南方海域が北方より少ないと考察されがちであった（Kawarada *et al.*, 1968; 鈴木, 1975; 森岡, 1976, 1985）。しかし，0–500 m深を調査した本研究では南北差は不明瞭であった（Fig. 5b）。これには，

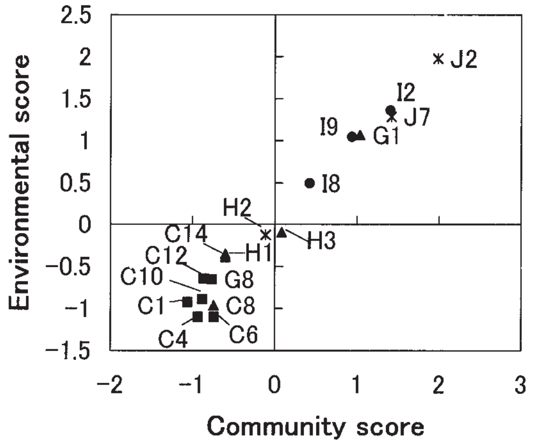

Fig. 10. Scatter diagram of 17 sampling stations according to the environmental score and community score of canonical variate I. *: Sampling stations excluded from the fuzzy cluster analysis. ●, ▲, ■: See Fig. 6. Additionally, sampling station B4 was excluded from CCA because of the lack of chlorophyll data.

本海域の中深層に多い*Metridia pacifica*や*Paraeuchaeta elongata*（Hirakawa and Imamura, 1993; Ikeda and Hirakawa, 1996）が多く採集された（Table 1, Fig. 9）ことが影響していると考えられる。また今回の調査地点の中で大型カイアシ類が青森沖（B4）で種数において最も多く採集され，この地点固有のものが9種も出現したが，いずれも僅かな個体数密度に過ぎなかった。

大型カイアシ類の群集組成から得られたA–Cの3つの地点群（Fig. 7）と海洋構造（Fig. 3–5）との対応を，正準相関分析（Fig. 10）の結果をふまえ検討すると，大和堆南方の地点群Aは対馬暖流系水域に，大和堆の北方沖合寄りのCは亜寒帯系水域に相当すると考えられる。大和堆の北方沿岸寄りの地点群Bは概してクロロフィル*a*濃度が全地点の平均より高く（Fig. 5a），特にH1, H3のすぐ南方に亜寒帯収束線があることから（Fig. 3a），混合水域に相当するのだろう。C14は調査域の最北端にも関わらず地点群Bに所属率が高くなるが（Fig. 7），これは対馬暖流がC14付近の海域まで複雑に蛇行し，水温がより南方のC1–12などに比して高くなったためであろう（Fig. 3a）。

対馬暖流系の地点群Aや山陰沖（J2, J7）に多い種群1（Fig. 9）は，その個体数密度が水温と正の相関となることから（Fig. 11），暖水種群と考えられる。そのうち*Calanus sinicus*は，調査水深の浅い地点を中心に山陰沿岸（J2）で最も多く採集されており（Fig. 9），Brodsky（1965）の報告と矛盾していない。ただし，その分布域の北限は，Brodsky（1965）やKun（1969）が示した北海道南西沖よりもかなり南偏していた。これは本調査が冬季に行われたものだからであろう。同じく種群1の*Candacia bipinnata*および*Eucalanus subtenuis*は沖合域の表層に多く分布し（陳・章, 1965; Hirakawa *et al.*, 1990），*Eucalanus bungii*は春季以外はほとんど中深層に分布し（Krause and Lewis, 1979），*Lucicutia flavicornis*は浅海から中深層にかけて日周鉛直移動幅が大きい種と報告されている（Minoda, 1971）。しかし，これら4種や同じく種群1の

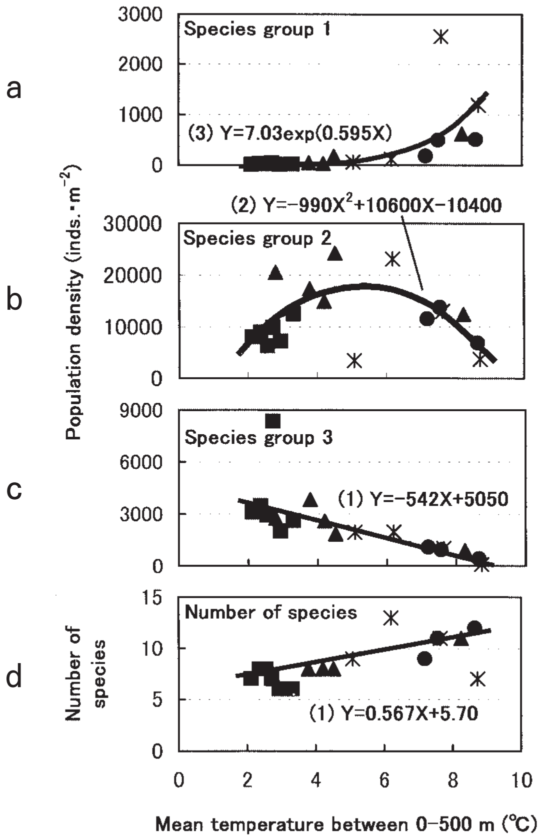

Fig. 11. Regression functions of the population density in each species group (Y) [a, b, c] and the number of species (Y) (d) in relation to the mean water temperature between 0–500 m (X); obtained by a non-linear least square method. The functions (regression line or curve) which yield the closest fit (i.e. lowest AIC value) was selected from the 5 following functions: (1) $Y=aX+b$. (2) $Y=aX^2+bX+c$. (3) $Y=a\exp(bX)$. (4) $Y=a\exp(bX)+c$. (5) $Y=\exp(aX^2+bX+c)$. *a,b,c*: Parameters included in the mathematical model. ●, ▲, ■, *: See Fig. 6.

*Pleuromamma gracilis*は，*Calanus sinicus*と比べごく僅かしか採集できいない。これら5種の生態を明らかにするためには，鉛直的な分布を考慮した詳しい調査が必要であろう。

全地点に広域だが，特に混合水域の地点群Bに多い種群2（Fig. 9）は，平均水温5℃付近に個体数密度の極大があり（Fig. 11），他の種群より広温性と考えられる。この種群のうち，*Metridia pacifica*は雑食性で浅海から中深層までと日周鉛直移動幅が大きく（IKEDA and HIRAKAWA, 1996），*Paraeuchaeta elongata*は肉食性で数百m以深に多い（HIRAKAWA and IMAMURA, 1993）。主な摂餌活動の場が表層付近でないことがこの種群の分布域を水平的に広くしているのだろう。また，種群2が水深の浅いH2やJ2で特に少ないのは，中深層からの鉛直的な進出が阻害されたからかもしれない。さらに，*Neocalanus plumchrus*は植物プランクトンを摂餌するために一部の時期に浮上するコペポディッド幼体を除いて中深層に多いと報告されている（TSUDA *et al.*, 1999）。11℃以上の水塊があると夜間の表層への上昇移動をやめる（MILLER and TERAZAKI, 1989）ことは，本種が地点群Aや山陰沖で少なかったことと関係していると考えられる。

亜寒帯系の地点群Cに多い種群3（Fig. 9）は，その個体数密度が水温と負の相関となることから（Fig. 11），冷水種群と考えられる。うち*Gaetanus minitus*はデトリタス食性の中深層性で（山口ら，1999の*Gaidius variabilis*），植食性の*Neocalanus flemingeri*（TSUDA *et al.*, 1999）や*N. cristatus*（KOBARI and IKEDA, 1999）も一時期のコペポディッド幼体を除いて中深層に多く，特に*N. cristatus*の分布は亜寒帯系水とよく対応すると言われる（KOS, 1972）。これら3種は中深層に主に生息しながらも餌料は植物プランクトンないし表層からの沈下物に依存する傾向が種群2よりも強いと考えられ，このことが分布の南下を妨げていると推測される。なお，種郡Ａ３*Neocalanus*属2種でも，大和堆頂部（H2），山陰沿岸（H2, J2）および本州沿岸寄り（G1, I2）で個体数密度が小さく，種群2の中深層種と同様に浅い水深の影響が考えられる。*N. cristatus*や特に*N. flemingeri*では種群2の*N. plumchrus*に比べコペポディッド幼体の加入がより寒冷な時期に起こっており（TSUDA *et al.*, 1999），両者の生態的特性の違いが分布傾向に現れたのかもしれない。

本研究により，異なった水系が複雑に混交する冬季の日本海東部沖合域における大型カイアシ類群集から座標づけやファジィクラスター分析を用いて3つの種組成が類似する地点群（A-C）および水平分布の類似する種群（1–3）を客観的に識別することができ，後者についてはそれぞれ合計の個体数密度も算出することができた。種群2は種群1と種群3の中間的な適水温を持つ混合水域種であることから，その識別が従来の群集解析では困難であったと思われる。さらに，各地点群の形成に水温が大きな影響を与えていることを正準相関分析によって明示し，各種群の個体数密度と0–500 m深平均水温との間の回帰分析を行って各種群の適水温を定量的に示した。特に種群2は，水平的に広域に分布し，水温と個体数密度との関係が線形的とならないために，従来は両者の間で有意な相関を示さないと済まされがちだったろう。しかし，平均水温5℃をピークとする，植物プランクトンの春季ブルームを控えた混合期を代表する卓越した種群であることを本研究で明らかにできた。

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Turbidity Distribution in the Surrounding Ocean Area of Miyake-shima Island after the Eruption of Mt. Oyama

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Abstract : The turbidity distribution around Miyake-shima was investigated by measuring beam attenuation, suspended solid (SS), suspended inorganic matter, and particle size distribution aboard the RT/V Umitaka-maru of Tokyo University of Fisheries. The investigation is a part of the project on “Influence of Miyake-shima Volcanic Activity on Fishing Environment” supported by Tokyo University of Fisheries. The observation was carried out on October 17–20, and November 17–19, 2000, three and four months after the eruption of Oyama. In the observations, high-turbidity waters with the beam attenuation coefficients 0.35–0.54 m^{-1} were observed in the pycnocline at the depth of 60–90 m on the east side of the island in October and on the northwest side of the island in November. The SS concentration of the high-turbidity water displayed extremely high values, 0.82 mg/l in October and 0.71 mg/l in November. The relationship between the turbidity (Y) and the SS concentration (X) was $Y=0.32X+0.14$, ($r^2=0.42$). The concentration of the suspended inorganic matter in the high-turbidity water also displayed extremely high values, 0.52 mg/l in October and 0.41 mg/l in November; these values correspond to 63.4% and 57.7%, respectively, expressed as the weight percent of inorganic matter in the total suspended solids. For the particles of the size of 8–14 μm, the particle volume concentration of the high-turbidity water (November, Stn. 3, depth of 75 m) was higher than that of the surface water at the same location. That is, the high-turbidity water layer is formed in the vicinity of the pycnocline and mainly contains a large amount of suspended inorganic particles. Therefore the origin of the high-turbidity water is considered to be deposited volcanic ashes from Miyake-shima.

Keywords : *Turbidity distribution, Miyake-shima Island, Volcanic ash, High-turbidity layer*

Introduction

An earthquake of the magnitude of 3 occurred in Miyake-shima Island on June 23, 2000. Mt. Oyama erupted on July 8 and 14, and the volcanic products (so-called volcanic ashes) were visibly observed. On August 18, volcanic smoke climbed higher than 5000 m, and an enormous quantity of volcanic ashes fell on Miyake-shima and its surrounding ocean area. Subsequent rainfalls washed away accumulated volcanic ashes from the coast to the surrounding ocean, causing discoloration of the ocean. The shallow water regions around Miyake-shima have bountiful marine resources such as spiny lobsters, abalones, agar weeds, etc. and fishery is one of the key industries. Because of these circumstances, there is a concern about the effects of sediments, which originate from volcanic ashes that have fallen into the ocean and ashes washed away from the island, on marine life of the surrounding ocean area.

In 1974 a comprehensive investigation of Nishinoshima-shinto Island, which was formed by the eruption of a submarine volcano, was carried out by Tokyo University of Fisheries. The report by MATSUIKE *et al.* (1975) is especially relevant to the present investigation. They investigated the turbidity of inner bay formed between Kyuto (old island) and Shinto

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(new island) of Nishinoshima and also the turbidity of the surrounding ocean area of the island. The results revealed that the water temperature of inner bay was 8℃ higher than that of the surrounding ocean water, and the amount of suspended matter was approximately 15 times larger. They also reported that a discolored ocean area, which was caused by the outflow of inner bay water to the surrounding ocean area, was observed within 0.5–0.6 nautical miles from the island.

NAKAO *et al.* (1978) investigated how the fallen ashes from the eruption of Usu Volcano affected the turbidity of Lake Toya. Their study involved an investigation of the sedimentation process of suspended matter. It was concluded that the suspended inorganic matter in the thermocline and in the middle water layer resulted from the following process: scouring of volcanic ash deposit by rain water, formation of muddy water and then turbidity current, intrusion of the turbidity current into the thermocline, and eventual settlement of ashes in the thermocline.

In the present investigation, we have studied detailed turbidity distributions in the surrounding ocean area of Miyake-shima after three months and also after four months from the time of Oyama eruption. The investigation is a part of the project by Tokyo University of Fisheries on “Influence of Miyake-shima Volcanic Activity on Fishing Environment”.

Observation Methods

The observations were carried out aboard the RT/V Umitaka-maru of Tokyo University of Fisheries on October 17–20, and November 17–19, 2000. Eight observation stations (Stns. 1, 2, 3, 4, 5, 6, 7, and 8) were set up around Miyake-shima in October, and in November three additional observation stations (Stns. C1, C2, and C3) were set up to the east of the island (Fig. 1). In addition, four observation stations (Stns. K1, K2, K3, and K4) were set up every 10’ in latitude between Miyake-shima and Izu-oshima as reference points. Measurements were performed for water temperature, salinity, fluorescence intensity, turbidity, water analysis, water color, and transparency. The water temperature, salinity, fluorescence intensity, and turbidity were measured with a CTD (OCTOPUS; ISHIMARU *et al.*, 1984) (Falmouth Scientific, Inc.). For the measurement of turbidity, an *in-situ* beam transmissometer with the path length 1 m and wavelength 527 nm was used. Water was sampled with 20 L volume Niskin bottles tied to the CTD; surface water was sampled with sampling buckets. The sampled water was used to determine the concentrations of suspended solid (SS) and suspended inorganic matter, and also to determine the particle size distribution. The concentration of SS was determined by filtering sample water through a Millipore HA filter (pore size, 0.45 μm), drying the filter cake at 60℃ for three days, and then weighing the residue. After determining the concentration of SS, we determined the concentration of suspended inorganic matter by heating the filter in a muffle furnace (550℃, one hour) and then weighing the residue. Particle size distribution was determined by freezing water samples on site, transporting them to the laboratory, thawing the samples, and then measuring the samples with a Coulter Counter Multisizer Ⅱ (Beckman-Coulter Electronics, LTD.) in the range of 1.8 – 60 μm. The water color was determined by the Forel-Ule color scale and the transparency was determined with a Secchi disc (diameter, 30 cm).

Results and Discussion

Distribution of water temperature, salinity, and turbidity

Fig. 2 shows vertical profiles of water temperature and salinity for October and November. Water temperature and salinity of the surface layer for October (Fig. 2, top) are 23.3–24.4 ℃ and 34.0–34.1 psu, respectively. Both the water temperature and salinity do not change down to the depth of 50 m indicating a mixed layer. A thermocline is observed from the depth of 50 m to approximately 70 m. The temperature decreases gradually below the thermocline, reaching 15 ℃ at the depth of 150 m. On the other hand, the salinity increases gradually and reaches 34.5 psu at the depth of 60 m, and there is almost no change below that depth. The water temperatures and salinities for November (Fig. 2, bottom) have similar

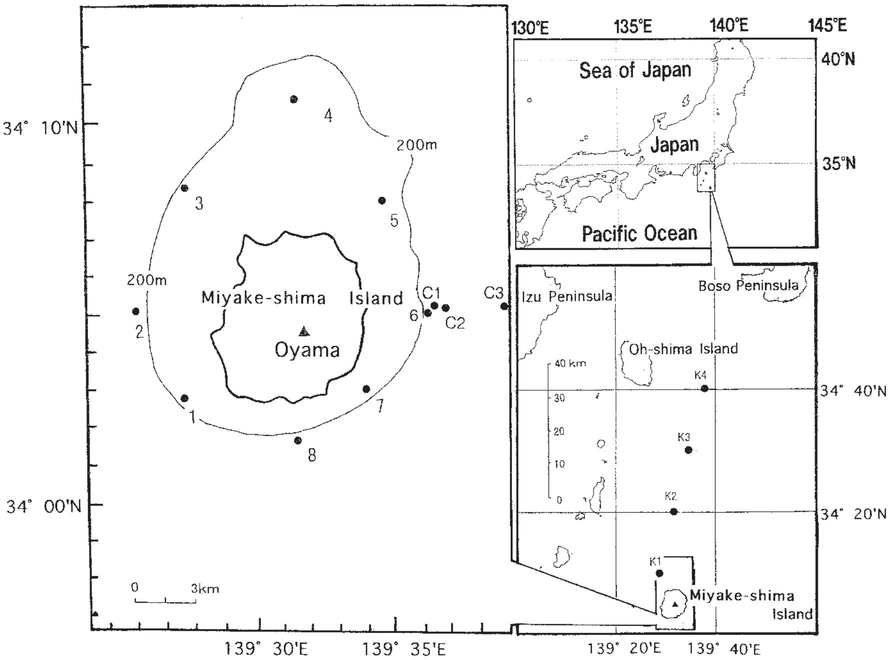

Fig. 1 Observation areas and the distribution of observation stations.

distribution patterns to those for October. The mixed layer, however, stretches by 10 m more to 60 m. Also the differences in water temperatures and salinities among different locations are greater than those for October. However, the water temperatures and salinities at eight observation stations around the island have nearly the same vertical profiles within each observation month.

The turbidity distribution around the island is discussed next. Discolored water area was not visibly detected in the surrounding ocean area of Miyake-shima in both October and November. Table 1 lists the transparency and the water color in the surrounding ocean area of the island; some data are missing because of nightfall. The transparencies and the water color for October are 19–31 m and 2–3, respectively, and those for November are 17–20 m and 2–3, respectively. In both the October and November observations, the transparency appears high from the west side to the north side of the island and it appears low on the other sides. The water color, however, has no dependence on the sea region.

Fig. 3 shows the vertical profiles of turbidity represented by beam attenuation coefficient for October and November. November data at Stn. 6 were obtained at 21:33. In October, rather large beam attenuation coefficients (0.45–0.60 m^{-1}) are observed near the surface at most stations. However, the beam attenuation coefficient drops steeply toward the depth of approximately 3 m. From that point down to the depth of 50 m, the beam attenuation coefficient gradually decreases but stays in the range of 0.2–0.3 m^{-1}. The beam attenuation coefficient reaches 0.16 m^{-1} around the depth of 100 m and stays close to a constant value below that depth at all stations. However, at Stn.6, which is located to the east of Miyake-shima, a high-turbidity layer at the depth of 60–90 m is observed with the beam attenuation coefficient of 0.35 m^{-1}.

The turbidity profiles for November show similar tendencies in October near the surface, however, from 3 m to the depth of 50 m, the beam attenuation coefficient stays almost constant in the range of 0.2–0.3 m^{-1}. The beam attenuation coefficient reaches 0.16 m^{-1} around the depth of 100 m and stays close to a constant value below that depth. One exception is seen at

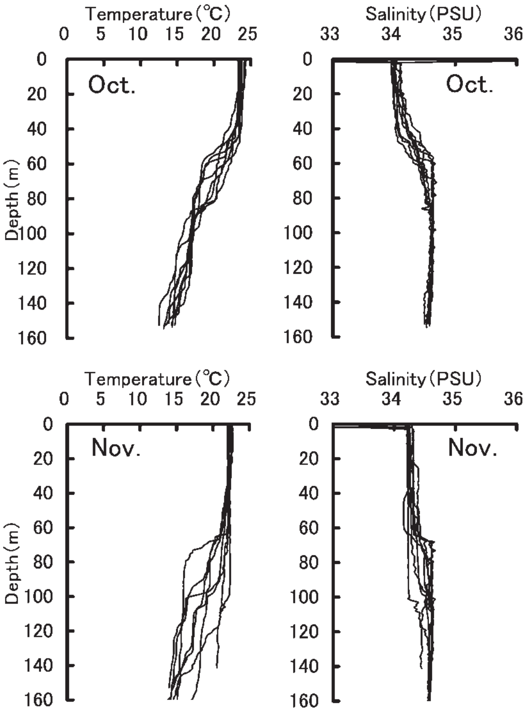

Fig. 2 Vertical profiles of water temperature and salinity for October and November.

Table 1. Transparency and water color for the ocean area around Miyake-shima for October and November.

Sta.		1	2	3	4	5	6	7	8
Oct.	Transparency	31	24	23	19	19	–	–	–
	Water color	3	2	2	2	–	–	–	–
Nov.	Transparency	–	–	–	20	–	17	18	19
	Water color	–	–	–	3	–	3	2	2

Stn. 3, which is located to the northwest of Miyake-shima. A high-turbidity layer at the depth of 60–90 m is observed with the beam attenuation coefficient of 0.54 m^{-1}. The depth of this high-turbidity layer is close to that of Stn. 6 for October.

Fig. 4 shows the vertical turbidity profiles observed in November around Stn. 6. Although a high-turbidity layer at the depth of 60–100 m of Stn. 6 is observed at 19:34, this layer is not observed two hours later at 21:33 (Fig. 4, top). In order to track this high-turbidity layer, turbidity profiles are studied at Stns. C1, C2, and C3 (Fig. 4, bottom). The beam attenuation coefficients at these three stations are around 0.2 m^{-1} from the surface to the depth of 150 m, and a high-turbidity layer is not observed. Therefore, it is considered that the distribution of high-turbidity water is localized.

Next, the vertical distributions of SS concentration are shown in Fig. 5. The SS concentration around Miyake-shima for October was in the range of 0.24–0.6 mg/*l* in the surface layer, and 0.23–0.38 mg/*l* at the depth of 50 m. The SS concentration at the depth of 75 m of Stn. 6 was very high (0.82 mg/*l*). For November the SS concentration in the surface layer was 0.22–0.49 mg/*l*, and 0.11–0.32 mg/*l* at the depth of 50 m. The SS concentration at the depth of 75 m of Stn. 3 was also high (0.71 mg/*l*). Thus, the distribution of the SS concentration corresponds well with that of the turbidity. Fig. 6 shows a relationship between the turbidity (beam attenuation coefficient) and the SS concentration. Their relationship is linear as shown. $Y=0.32X+0.14$, ($r^2=0.43$),

Where, Y is the turbidity (beam attenuation coefficient, m^{-1}), and X is the SS concentration (mg/*l*). A good correlation between the turbidity and the SS can be seen.

The turbidity of the surrounding ocean area of Miyake-shima was also studied with respect to the number of suspended particles. Fig. 7 shows the particle size distributions of November for the surface water of the surrounding ocean area of Miyake-shima (8 stations, solid lines) and of the sea area between Miyake-shima and Oshima (4 stations, broken lines). The particle size distributions for these two areas are different. That is, the particle size for the surface water around Miyake-shima spreads over a wide range (2–30 μm). The particle concentration especially for the sizes less than 5 μm is much higher for the surrounding area of Miyake-shima than that between Miyake-shima and Oshima. In addition, the concentration of particles number was ten times higher for the former than the latter.

Matsuike and Morinaga (1977) and also Matsuike *et al.* (1986) investigated the turbidity in the northwest Pacific Ocean. The beam attenuation coefficients for the high-current area of the Kuroshio are reported to be 0.11–0.12 m^{-1} (wavelength, 486 nm), and the beam attenuation coefficients for the Sagami

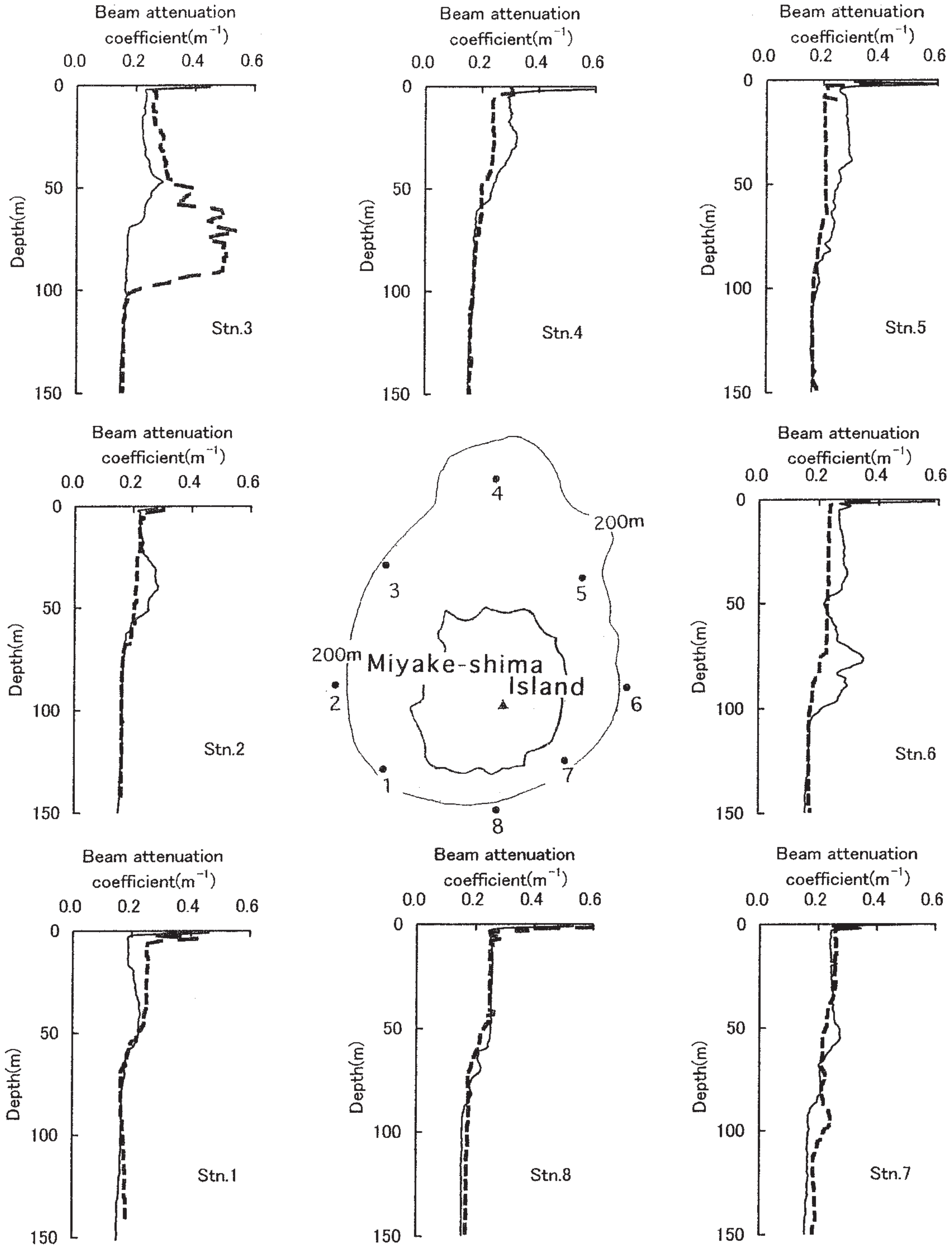

Fig. 3 Vertical profiles of turbidity for October (solid line) and November (broken line).

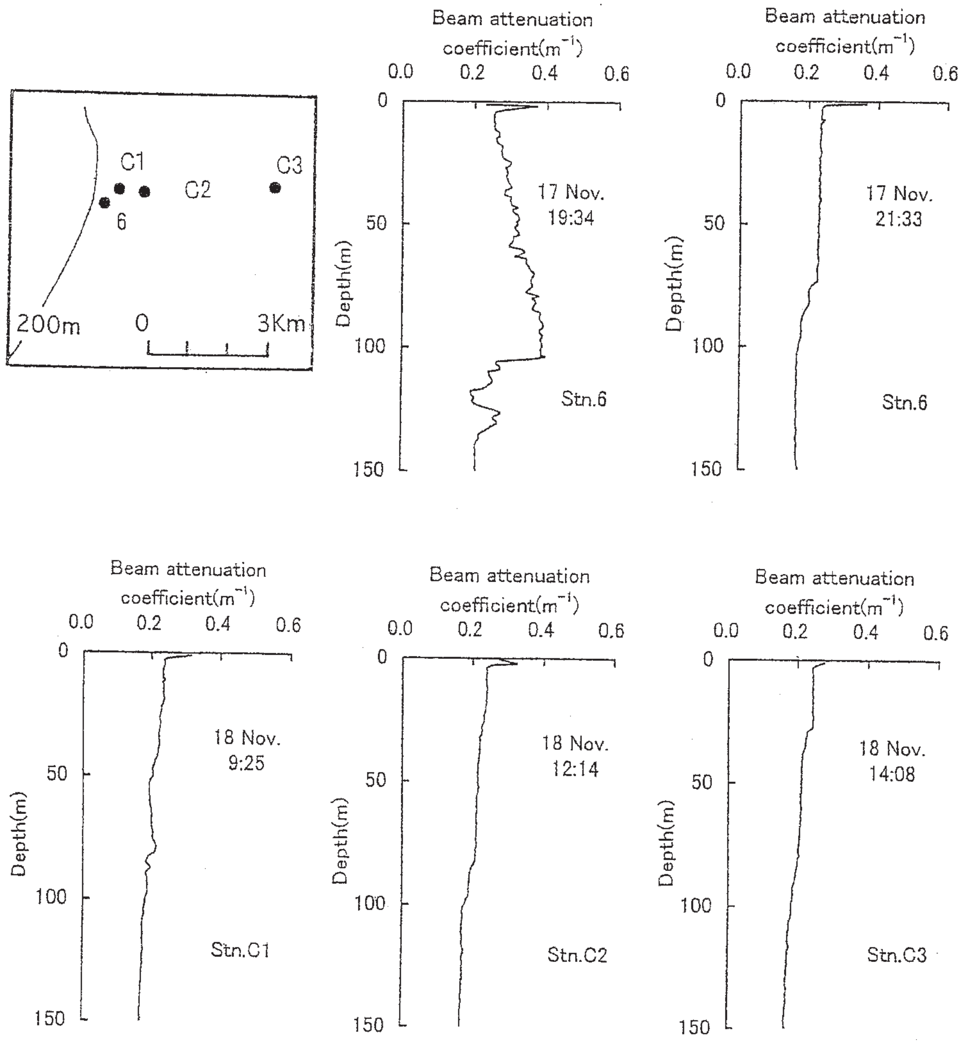

Fig. 4 Vertical turbidity profiles observed in November around Stn. 6.

Nada and its surrounding ocean area are reported to be 0.1–0.4 m^{-1} (wavelength, 486 nm). During the present investigation, the Kuroshio was flowing eastward at the distance of approximately 150 km south to Miyake-shima (Quick Bulletin of Ocean Conditions, 2000, Vol. 20 and 22, Hydrographic Department, Japan Maritime Safety Agency). Therefore, it is not considered that the Kuroshio affects the turbidity of the surrounding ocean area of Miyake-shima in the present observation. The measurement wavelength of the present investigation is different from the wavelength used in the investigation by the above-mentioned authors. However, the beam attenuation coefficients around Miyake-shima were in the range of 0.15–0.30m^{-1} (wavelength, 527 nm) except for the surface layer and the high-turbidity layer. Thus, the turbidity around Miyake-shima is considered to be similar to that of Sagami Nada. As mentioned above, the beam attenuation coefficients were 0.4–0.6 m^{-1} for some surface layers around Miyake-shima. These beam attenuation coefficients are somewhat higher than those of the Kuroshio and the Sagami Nada, and this phenomenon is considered to be the effects from the island. This phenomenon is also consistent with the

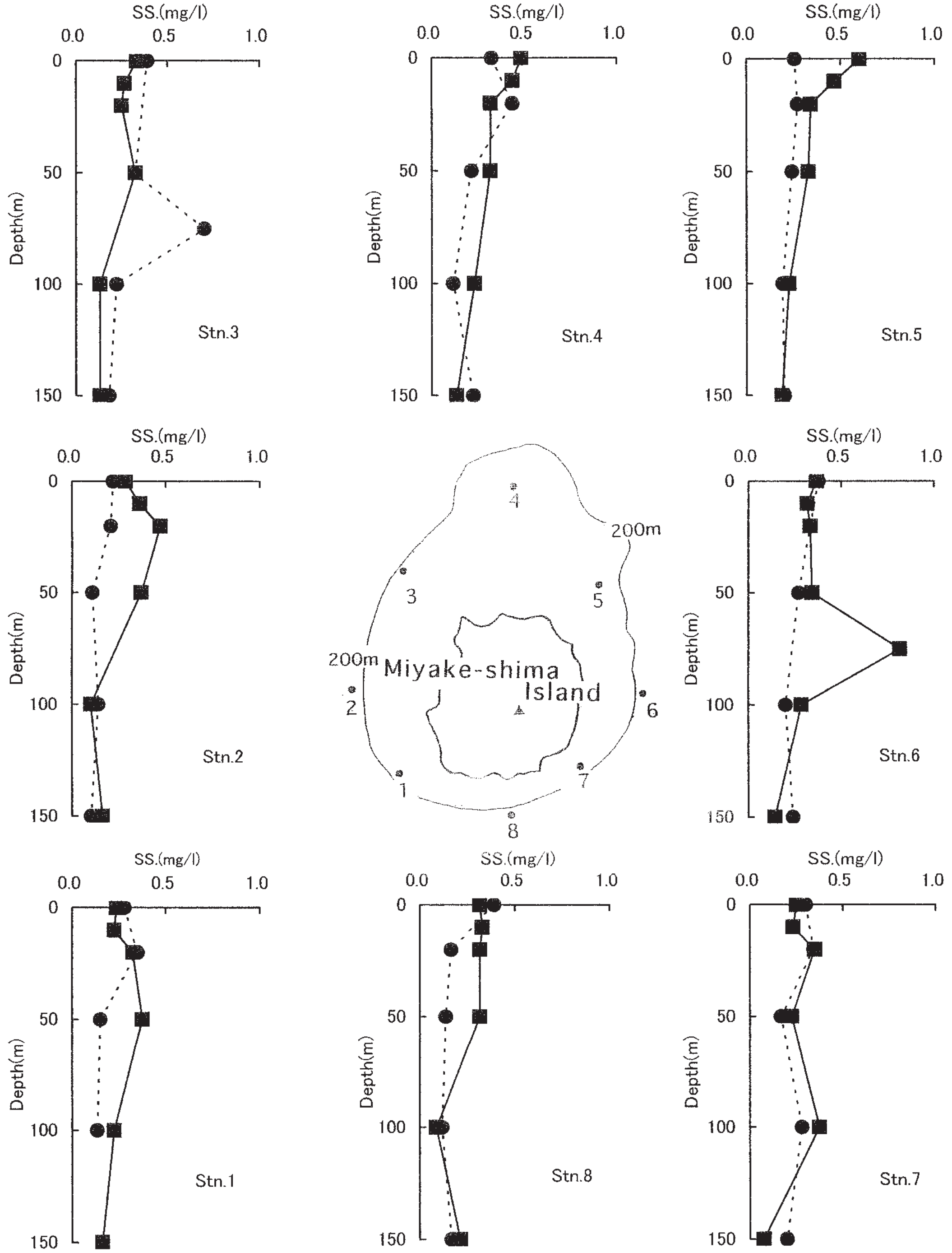

Fig. 5 Distribution of SS concentration. Solid line and dotted line indicate data for October and November, respectively.

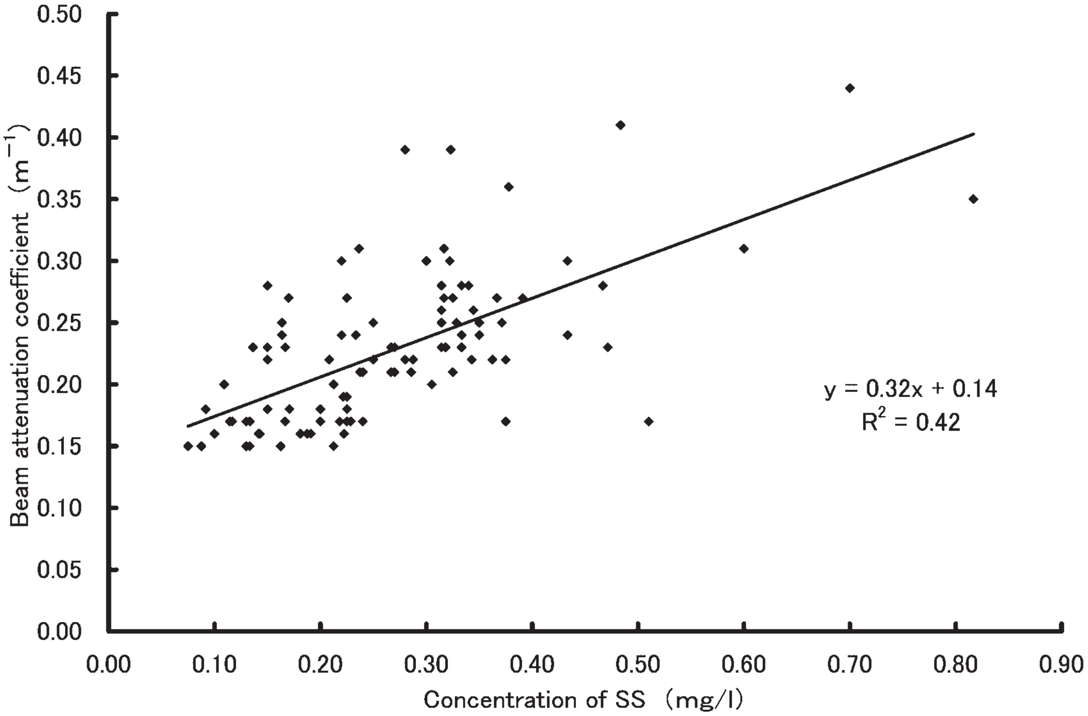

Fig. 6 Relationship between turbidity (Beam Attenuation Coefficient) and SS concentration.

observation that the concentration of the suspended particles less than 5 μm is approximately 10 times higher in the surface layer around Miyake-shima than in the surface layer of the sea area between Miyake-shima and Oshima (Fig. 7).

Characteristics of high-turbidity water

As described in the previous section, high-turbidity water layers were observed at Stn. 6 in October and at Stn. 3 in November at the depth of 60–90 m. The SS concentrations of this high-turbidity water were shown to be relatively high (0.71–0.82 mg/l). In this section we discuss the characteristics of the high-turbidity water in detail.

Fig. 8 shows the concentration distributions of suspended inorganic particles for October and November. The concentrations of suspended inorganic particles for October are 0.06–0.18 mg/l for the surface water, and 0.02–0.16 mg/l for the water at the depth of 50 m. And those for November are 0.04–0.27 mg/l for the surface water, and 0.04–0.25 mg/l for the water at the depth of 50 m. On the other hand, the high-turbidity layer observed at the depth of 75 m displayed a maximum concentration of 0.52 mg/l at Stn. 6 in October and 0.41 mg/l at Stn. 3 in November, respectively. The weight percentage of inorganic particles in the total suspended particles is calculated for October, becomes 21–31% for the surface water, but is very high (63.4%) for the high-turbidity layer water. For November, the percentage is 15–36% for the surface water at Stns. 1, 2, and 5, showing similar results to those of October, but is higher (55–70%) at other observation stations. The high-turbidity layer water at Stn. 3 for November has a high result (57.7%) like the case at Stn. 6 for October.

Next, the distributions of particle size are compared between the surface water and the high-turbidity layer water at the depth of 75 m. Fig. 9 shows the distribution of particle size for the surface water and the high-turbidity layer water at Stn. 3 for November. The particle volume concentrations for high-turbidity water are similar to that of the surface water

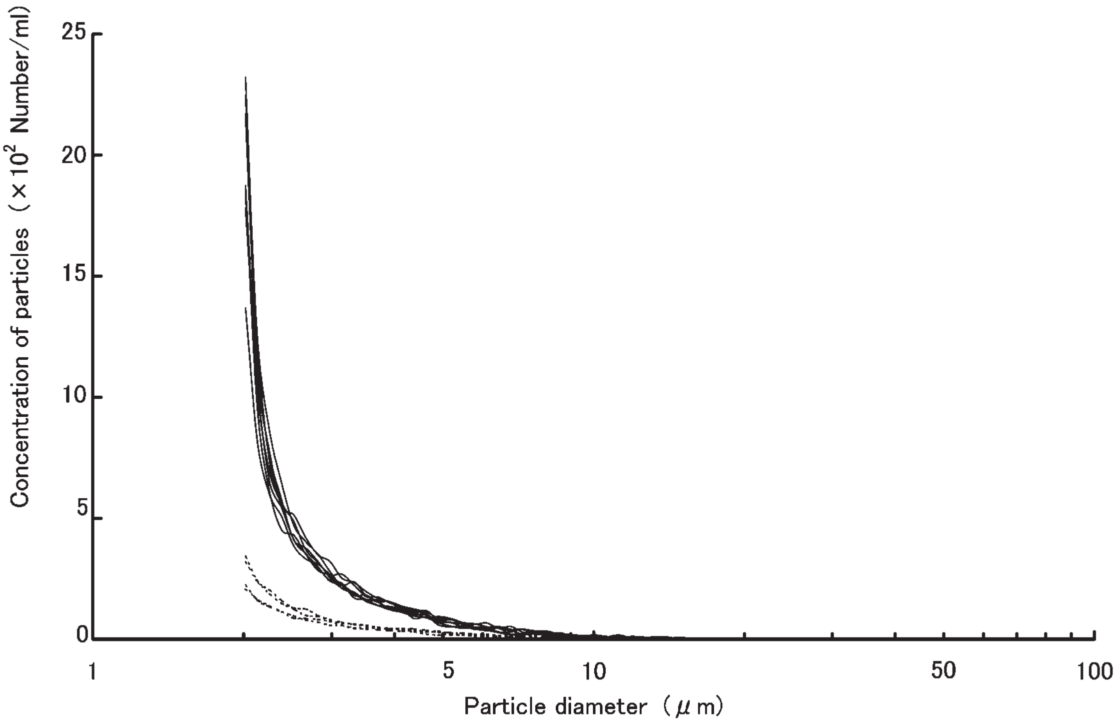

Fig. 7 Size distributions of particle number in the surface water for the surrounding ocean area of Miyake-shima (solid line) and for the sea area between Miyake-shima and Oshima (broken line) for November.

up to the particle size of 8 μm. However, the particle volume concentrations for high-turbidity water are higher for the particles with the size 8–14 μm than for the surface water. On the other hand, the surface water contains relatively larger particles (larger than 20 μm) than the high-turbidity water. Also the average particle size in the surface water (11.1 μm) is approximately equal to that of the high-turbidity water (9.7 μm).

The particles suspended in the high-turbidity water mainly consist of inorganic matter, and have the particle-size of 8–14 μm in diameter. Here, we calculate the sedimentation velocity (v) of the particles of the size 10 μm (D) by the following Stokes' equation;

$$v = \frac{1}{18} D^2 g \frac{\rho_s - \rho}{\mu}$$

where, g is gravitational acceleration, ρ_s is the density of particle, 2.5, ρ is the density of seawater, 1.023 g・cm^{-3}, and μ is the viscosity coefficient of seawater, 1.0×10^{-2} dyn・sec・cm^{-2}, respectively.

The sedimentation velocity in the mixed layer is estimated to be 8.04×10^{-3}cm/sec. Thus, it is found that the particles of the size 10 μm in the surface seawater takes about 8.6 days to reach the high-turbidity layer at the depth of 60 m.

Origin of high-turbidity water

In this section we discuss the relationship between the formation of the high-turbidity layer and the ocean constitution. Fig. 10 shows the vertical profiles of turbidity, water temperature, salinity, density (sig.-t), and fluorescence intensity at Stn. 6 for October and Stn. 3 for November; these are the time and locations when the formation of high-turbidity layers was observed. In case of Stn. 6 in October, the turbidity increases from the depth of 50 m, show a maximum at the depth of 75 m, and decreases below that. Seawater at the depth of 110 m is very clear. Also, the pycnocline with a gentle slope is seen from the depth of 50 m to 100 m. On the other hand, at Stn. 3 in

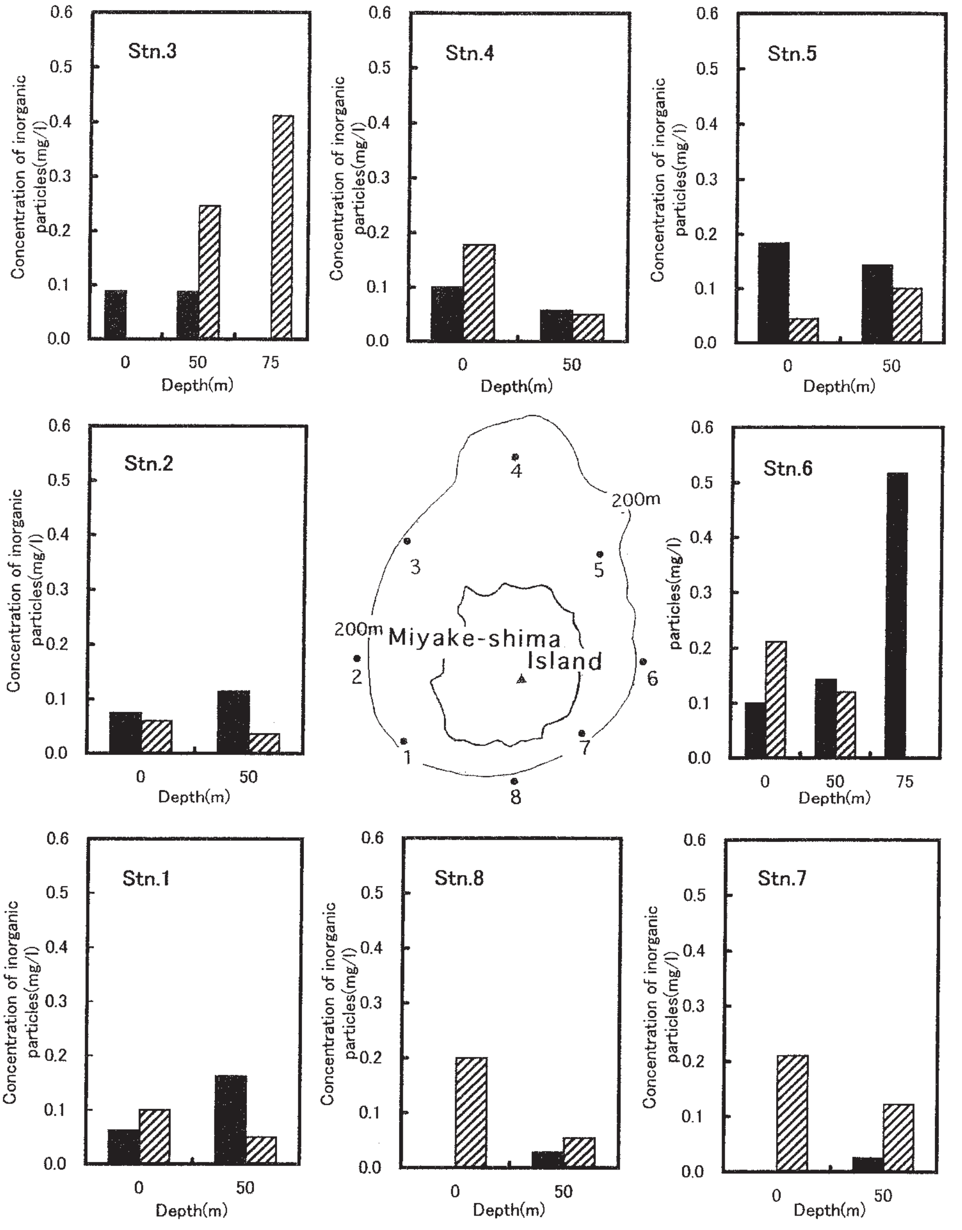

Fig. 8 Concentrations of suspended inorganic particles. Solid bars and striped bars indicate data for October and November, respectively.

The results are shown for the surface water and for the water at the depth of 50 m. The data are also included for the high-turbidity layer water at the depth of 75 m observed at Stn. 6 in October and at Stn. 3 in November. Observation data are missing for the surface water at Stns. 7 and 8 for October and at Stn. 3 for November.

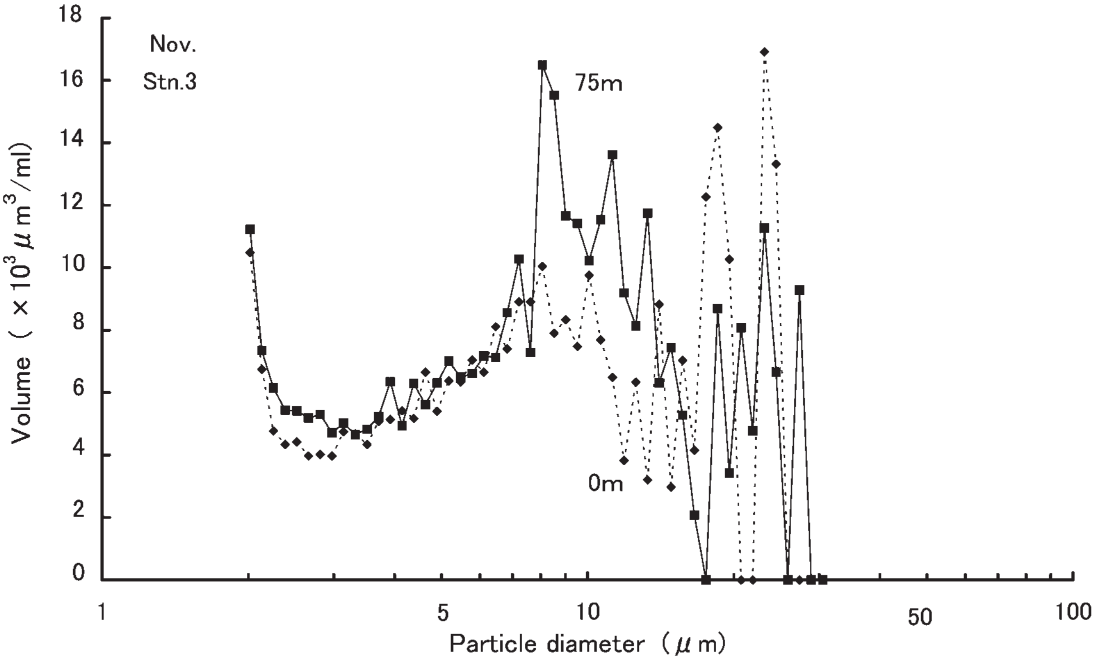

Fig. 9 Size distributions of particle volume at the depth of 0 m (broken line) and 75 m (solid line) at Stn. 3 for November.

November, the turbidity increases from the depth of 50 m, exist some maximum value between the depth of 60 m and 90 m, and decreases extremely deeper than the high-turbidity layer. The steep gradient pycnocline appears from the depth of 60 m to 100 m. For both October and November, the depth of the high-turbidity layer is found at the same depth where sudden changes take place in water temperature, salinity, and density.

JERLOV (1958) explained that suspended particles tend to settle, concentrate, and stay in the pycnocline because of a decrease in the sedimentation rate. NAKAO *et al.* (1978) reported that the concentration of the suspended matter, which is from the volcanic eruption, in Lake Toya displayed a maximum in the thermocline. It was explained that the muddy water, which contains volcanic ash deposits from the surrounding area, forms turbidity current, enters into the thermocline, and settles there at every rainfall. MIYAKE (1982) and MORINAGA (1983) observed similar phenomena in Funka Bay and the Antarctic Ocean, respectively. However, it is supposedly complicated to explain the phenomenon by the above mechanism if suspended particles are organisms (YAMAGUCHI and SHIBATA, 1981).

As shown in Fig. 10, the vertical profiles of turbidity and fluorescence intensity display different patterns at the depth of 60–90 m for both Stn. 6 and 3. The trend is especially noticeable at Stn. 6. As a result, the particles distributed at these locations could not consist of phytoplankton. In addition, the content of suspended inorganic particles in the suspended particles was 63.4% at Stn. 6 and 57.7% at Stn. 3 as described before. They are much higher than the values of approximately 20% in the water mass of open ocean (for example MATSUIKE *et al.*1983). Thus, it is confirmed that the content of inorganic particles is very high in the high-turbidity layer.

It is unlikely that inorganic suspended particles were carried to these locations from other places by ocean current because the Kuroshio was flowing eastward at the distance of 150 km south to Miyake-shima at the time of observation. Accordingly, the origin of inorganic suspended particles is considered to be from volcanic ashes due to the volcanic activity or from deposited ashes that were washed out together with clay and sand by rainfall. MATSUYAMA *et al.* (2002) presumed that the origin of particles in the high-turbidity layer is from fallen ashes because the high-turbidity water is distributed on the leeward side. For instance, the wind direction at Stn. 6 in October was from the northwest and at Stn. 3 in November was from the southeast. However, there was no eruption of the volcano on October and November, 2000. Also, the volcanic ashes did not almost fall.

MORIKAWA (1996) studied the intrusion process of muddy water at Lake Biwa and determined the size of particles in the high-turbidity water, which is formed in the pycnocline, to be 5–10 μm. In the present investigation, the observed particle size range of most populated particles in the high-turbidity water was 8–14 μm. This range of particle size agrees well with that of the high-turbidity water of Lake Biwa. This fact implies a possibility that the high-turbidity layer observed offshore Miyake-shima is formed by the intrusion of turbid water to the pycnocline.

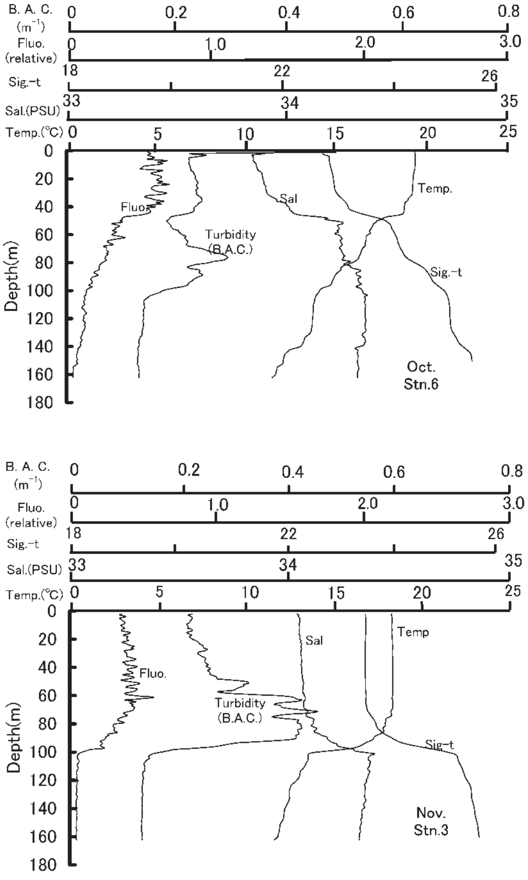

Fig. 10 Vertical profiles of water temperature, salinity, density (sig.-t), turbidity (Beam Attenuation Coefficient; B.A.C.), and fluorescence intensity at Stn. 6 (October) and at Stn.3 (November).

Based on the above discussion and the two reasons described below, we presumed that the suspended particles in the high-turbidity layer are deposited ashes that were washed out from the island together with clay and sand by rainfall. The first reason is that the high-turbidity water is localized to a horizontal direction, and the second is that there were rainfalls one week before of each observation (October 9–16, 49 mm; November 10–17, 84 mm).

In future we should investigate the process of outflow and the behavior of high-turbidity water by performing a space-time study for the shallow water area around Miyake-shima.

Summary

The turbidity distribution around Miyake-shima at three and four months after the eruption of Oyama was investigated.

1) The high-turbidity waters with the beam attenuation coefficients 0.35–0.54 m^{-1} were observed in the pycnocline at the depth of 60–90 m on the east side of the island in October and on the northwest side of the island in November.

2) The SS concentration of the high-turbidity water displayed extremely high values, 0.82 mg/*l* in October and 0.71 mg/*l* in November. The relationship between the turbidity and the SS concentration shows a good correlation.

3) The concentration of the suspended inorganic matter in the high-turbidity water also showed extremely high values, 0.52 mg/*l* in October and 0.41 mg/*l* in November. The weight percents of inorganic matter in the total suspended solids correspond to 63.4% and 57.7%, respectively.

4) For the particles with the size 8–14 μm, the particle volume concentration for the high-turbidity water was higher than that for the surface water at Stn. 3 in November.

That is, the high-turbidity water layer is formed in the vicinity of the pycnocline and mainly contains a large amount of suspended inorganic particles. Therefore the origin of the high-turbidity water is considered to be deposited volcanic ashes from Miyake-shima.

Acknowledgement

The present investigation is a part of the research project in Tokyo University of Fisheries, "Influence of the Miyake-shima Volcanic Activity on Fishing Environment". The authors express their sincere appreciation to the project leader, Professor Masaji MATSUYAMA, the investigators, and also the captain of RT/V Umitaka-maru, Professor Yasusuke TAKASU and his crew members of Tokyo University of Fisheries for their cooperation during the present investigation.

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葛西人工渚西浜（東京湾湾奥部）の魚類相

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Ichthyofauna of artificial tideland in Kasai Marine Park, Tokyo Bay

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Abstract : A total of 26,814 fish specimens were collected by monthly seine-net（mesh size 0.8mm）samplings at Kasai artificial tideland in the inner Tokyo Bay from September 2000 to August 2001. These fishes represented 31 species（including Gobiidae spp. counted as one species）of 17 families and were recognized as developmental stages of larvae, juveniles or young. The major fish species were three gobiid species, *Gymnogobius macrognathos*, *G. castaneus* and *Acanthogobius flavimanus*, and ayu, *Plecoglossus altivelis altivelis*, occupying 40.3%, 8.2%, 18.8% and 9.1%, respectively, of the total number of individuals. The number of fish species categorized as "transient", in which some developmental stages occurred, was 22, contributing 99.7% of the total number of individuals, and the diversity of fish community expressed as Shannon-Wiener's diversity index was 0.81, secondly high among 13 tidelands in the inner Tokyo Bay.

These results suggest that the Kasai artificial tideland would be rich in fish assemblage and functions as a nursery ground for fishes.

Keywords : *Tokyo Bay, artificial tideland, fish fauna, larvae, juveniles*

1. はじめに

東京湾の内湾部（富津と観音崎を結ぶ線よりも北の海域）は，かつては干潟や浅瀬が広がり，豊かな生態系が構成されている地域であった。しかし，1970年代頃までには埋め立てや浚渫によって自然の干潟や浅瀬の多くは失われてしまい，それらを生活の基盤として利用していた魚類は少なからず影響を受けてきた可能性がある（例えば，加納ら（2000））。このような状況下において，東京湾の各所では，さまざまな方法によって魚類相の調査が行われ（岩田ら，1979；清水，1990；林ら，1993；那須ら，1996；甲原•河野，1999；加納ら，2000，2002；荒山ら，2002），各魚種の出現様式については，すでに多くの情報が蓄積されている。

東京湾湾奥部の江戸川と荒川の河口前縁に1975年に造成された葛西人工渚では，東京都環境保全局が1982年から地曳網による調査を東浜で実施しているものの，採集された魚種の総合的な解析は行なわれていないのが実情である。失われた干潟域の再生計画を進めていく上で，葛西人工渚が魚類の生活の場としてどのような役割を果たしているのかを明らかにすることは，重要な意味を持つと考えられる。

そこで本研究では，2000年９月から2001年８月までの１年間にわたって葛西人工渚の西浜で地曳網による魚類の採集を行い，出現魚種の生活史型や発育段階の特徴に基づく利用様式から，魚類の成育場としての葛西人工渚

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西浜の役割について検討した。さらに，東京湾のいくつかの地点との比較から，葛西人工渚西浜の魚類相の特徴についても明らかにした。

2.　材料と方法

採集は東京都江戸川区の葛西人工渚の西浜で行った（Fig. 1）。本調査地点は，江戸川と荒川の河口前縁に人工的に造成された砂泥底の前浜干潟である。

採集期間は2000年９月から2001年８月で，毎月１回の採集を行った。採集に用いたのは小型地曳網（袖網部の

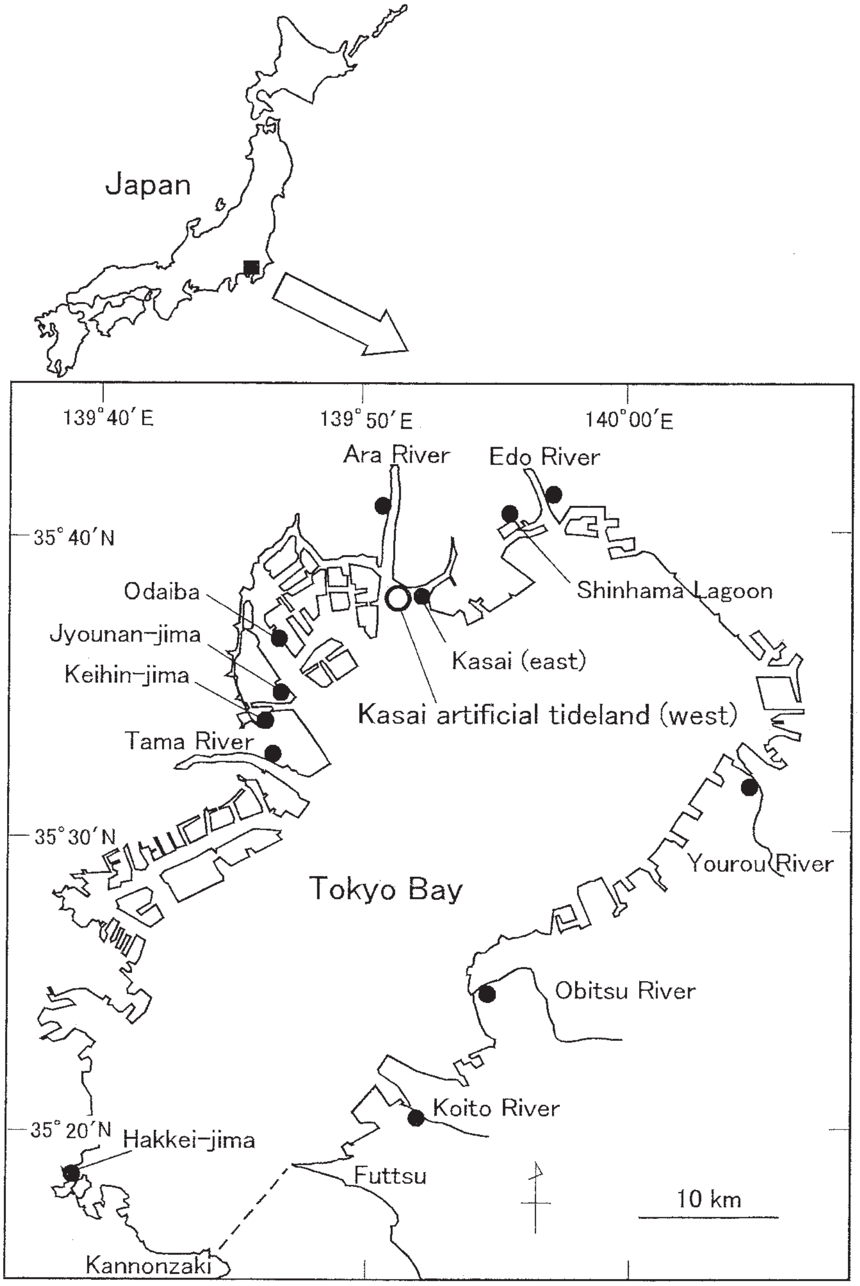

Fig. 1.　Map showing the present sampling site at Kasai artificial tideland (open circle) and 12 other tidelands (solid circles) in Tokyo Bay.

長さ4m，深さ1m，目合2mm；胴網部の長さ3.5m，目合0.8mm。Kanou *et al.*（2002)を参照）で，汀線に対してほぼ平行に50m曳網した。曳網後に棒状水銀温度計とアタゴ社製海水濃度屈折計で水温と塩分を計測した。採集物は現場でただちに5％海水ホルマリンで固定し，東京水産大学魚類学研究室に持ち帰った。研究室では採集物から魚類のみを選別し，種の同定，個体数の計数，体長の測定を行った。種の同定は，主に沖山（編）（1988）と中坊（編）（2000）に従った。また，魚種リストの科の配列，標準和名，学名は中坊（編）（2000）に従った。体長の測定方法はLeis and Trnski（1989）に従った。

採集された魚類の発育段階は，加納ら（2000）にしたがい，以下の4つに区分した：仔魚－鰭条が定数に達していないもの；稚魚－鰭条が定数に達し鱗も出始めているが，体形や模様が成魚と異なるもの；若魚－鱗の分布や模様がほぼ完成し体形も成魚に近いが未成熟のもの；成魚－性的に成熟しているもの。さらに，海水魚，河口魚，両側回遊魚といった生活史型，および発育段階に基づく干潟の利用様式も加納ら（2000）に従った。

月間での種組成の類似度を比較するためにJaccard（1901)の群集係数を求めた。また，後述する地点間の魚類相の比較では，地点ごとに1年間に採集された各種の個体数データを対数変換（$\mathrm{Log}_{10}(X+1)$）した後に，Bray-Curtisの類似度指数PS$_2$（例えば，小林（1995)）を求めた。類似度に基づくクラスター分析は群平均法で行った。各地点の魚類相の多様度は，Shannon-Wiener関数（例えば，小林（1995)）により算出した。比較した地点は，本研究とほぼ同様の手法で行なわれた東京湾の以下の12地点である：葛西人工渚の東浜，お台場，城南島（東京都環境保全局，2000)；多摩川，荒川，江戸川，養老川，小櫃川，小糸川，新浜湖（加納ら，2000）；京浜島（那須ら，1996)；八景島（田辺・林，1999)。

本研究で用いた標本は，70％エチルアルコール中で保存し，東京水産大学水産資料館の仔稚魚コレクションに以下の番号で登録・保管されている：MTUF-P(L)9693〜9729，9846〜9878，9900〜9988。

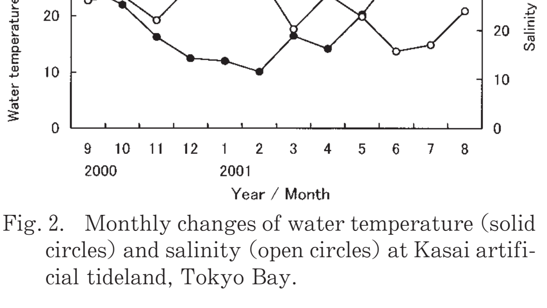

Fig. 2. Monthly changes of water temperature (solid circles) and salinity (open circles) at Kasai artificial tideland, Tokyo Bay.

3. 結果

3.1 水温と塩分

調査地点の水温は，9月から2月にかけて下降し，その後上昇した（Fig. 2）。最高水温は2001年7月の31.2℃，最低水温は2001年2月の10.1℃であった。一方，塩分はおおむね冬に高く夏に低い傾向がみられ，最高は2000年1月の34，最低は2001年6月の15であった（Fig. 2）。

3.2 種数と個体数，優占種，多様度

本研究で採集された魚類は8目17科31種以上（未同定種もふくむ）で，総個体数は26,814個体であった（Table 1）。

種数は9月から1月にかけて減少し，最少は1月の2種であった（Fig. 3）。2月から7月にかけては多少の変動はあるものの増加し，最多は7月の13種であった。一方，個体数は9月から1月にかけては低い値で推移し，1月の40個体が最少であった（Fig. 3）。3月から5月にかけては増加し，5月の10,457個体が最多となった。

科別の種数はハゼ科が最も多く12種以上で，次いでニシン科とイソギンポ科，フグ科の2種であった（Table 1）。残りの13科では1種だけが出現した。個体数でもハゼ科が最も多く（19,470個体），全体の72.6％を占めた。次いでニシン科（3,322個体，12.4％），アユ科（2,429個体，9.1％）であった。最も個体数が多かった種はエドハゼで，10,799個体，全体の40.3％を占めた（Table 1）。次いでマハゼ（5,032個体，18.8％），アユ（2,429個体，9.1％），ビリンゴ（2,190個体，8.2％），サッパ（1,994個体，7.4％），コノシロ（1,328個体，5.0％），スズキ（1,328個体，5.0％）であった。

多様度は0.81であった。

3.3 出現魚種の季節変化

採集期間のうち，3〜5月を春期，6〜8月を夏期，9〜11月を秋期，12〜2月を冬期として，各魚種の出現期間を明らかにした（Table 1）。

春期だけに出現した種は，ウキゴリ，ビリンゴ，ニクハゼ，ヒメハゼの4種であった。春期に最も多く出現し，2期以上にわたって採集された種は，コノシロ，アユ，スズキ，エドハゼ，マハゼ，イシガレイの6種であった。なお，アユとマハゼは6か月以上連続して出現した。

夏期だけに出現した種は，トウゴロウイワシ，ヨウジウオ，チチブ，アベハゼ，アカオビシマハゼ，クサフグ，フグ科不明種の7種であった。夏期に最も多く採集され，2期以上にわたって採集された種は，サッパとヒモハゼの2種であった。

秋期だけに出現した種は，マゴチとシロギスの2種であった。秋期に最も多く採集され，2期以上にわたって採集された種は，ヒイラギであった。

冬期だけに出現した種は，ギンポとイソギンポの2種

Table 1. Fishes collected at Kasai artificial tideland in Tokyo Bay from September 2000 to August 2001

Family and Species	Individual No.	Rank	%	Month	Size range (SL, mm)	Developmental stage	Life style category	Life cycle category
Engraulidae								
Engraulis japonicus	9			3, 5,10–12	12.0–35.0	L-J	T	M
Clupeidae								
Konosirus punctatus	1328	6	5.0	5–8	4.5–68.3	L-Y	T	M
Sardinella zunasi	1994	5	7.4	7–11	6.1–104.5	L-Y	T	M
Osmeridae								
Plecoglossus altivelis altivelis	2429	3	9.1	1–4, 11–12	7.0–87.2	L-Y	T	Am
Mugilidae								
Mugil cephalus cephalus	11			2, 5–6	15.0–25.0	J-Y	T	M
Atherinidae								
Hypoatherina valenciennei	13			7	16.7–30.1	L-J	T	M
Syngnathidae								
Syngnathus schlegeli	1			6	59.0	Y	P&S	M
Scorpaenidae								
Sebastes inermis	3			2–3	9.3–21.7	L-J	T	M
Platycephalidae								
Platycephalus sp.	2			11	55.6–78.6	Y	P&S	M
Percichthyidae								
Lateolabrax japonicus	1328	6	5.0	2–6	12.5–185.5	L-Y	T	M
Sillaginidae								
Sillago japonica	15		0.1	9	13.2–42.9	J-Y	T	M
Leiognathidae								
Leiognathus nuchalis	111		0.4	5, 7–10	7.1–56.0	L-Y	T	M
Pholididae								
Pholis nebulosa	28		0.1	1–2	9.7–28.9	L	P&S	M
Blenniidae								
Omobranchus elegans	12			7, 9–10	8.8–12.3	L-J	P&S	M
Parablennius yatabei	7			2	7.6–22.1	L	P&S	M
Gobiidae								
Acanthogobius flavimanus	5032	2	18.8	2–7, 12	8.0–74.4	L-Y	T	E
A. lactipes	130		0.5	2, 7, 9–11	6.3–37.5	L-Y	T	E
Eutaeniichthys gilli	18		0.1	3, 6–8	5.0–22.7	L-J	T	E
Favonigobius gymnauchen	13			3, 5	18.1–44.4	J-Y	T	E
Gymnogobius castaneus	2190	4	8.2	3–5	6.8–31.2	L-Y	T	E(M)
G. heptacanthus	21		0.1	5	19.5–25.7	J-Y	T	E
G. macrognathos	10799	1	40.3	4–7, 11	6.8–39.0	L-Y	T	E
G. urotaenia	138		0.5	3–5	11.7–26.2	L-J	T	Am
Mugilogobius abei	305	10	1.1	8	6.4–12.0	L-J	T	E
Tridentiger obscurus	378	9	1.4	7–8	5.6–14.5	L-J	T	E
T. trigonocephalus	2			6–7	10.4–11.0	J	P&S	E(M)
Gobiidae spp.	444	8	1.7	5–6, 9–10	3.7–12.9	L	-	-
Pleuronectidae								
Kareius bicoloratus	34		0.1	2–3	14.4–43.3	J-Y	T	M
Triacanthidae								
Triacanthus biaculeatus	16		0.1	7–9	6.9–43.0	L-Y	T	M
Tetraodontidae								
Takifugu niphobles	2			7	10.7–12.5	J	P&S	M
Tetraodontidae sp.	1			6	8.0	J	P&S	M

Developmental stage (L, larva; J, juvenile; Y, young), life style category (P&S, passersby and strays; T, trransient), Life cycle category (Am, amphidromous fishes; E, estuarine fishes; M, marine fishes). Percentages in individuals of each species to total fishes are only given when they exceed 0.1%.

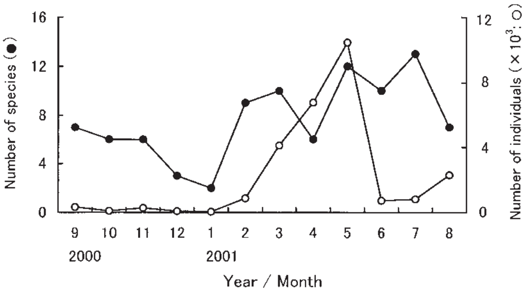

Fig. 3. Monthly changes of species (solid circles) and individual (open circles) numbers of fishes collected at Kasai artificial tideland, Tokyo Bay.

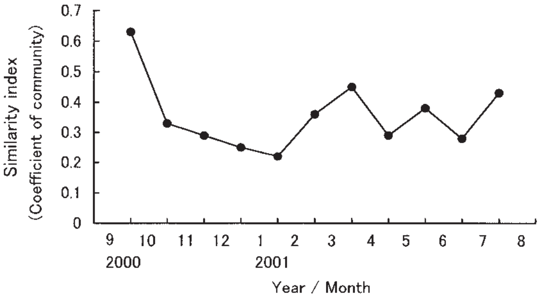

Fig. 4. Similarity index between consecutive months for the species composition of fishes collected at Kasai artificial tideland, Tokyo Bay.

Table 2. Monthly changes of individual numbers and developmental stages in nine dominant species collected at Kasai artificial tideland in Tokyo Bay

		2000				2001							
Rank	Species	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
1	*Gymnogobius macrognathos*	-	-	1, Y	-	-	-	-	1829, LJ	8892, LJ	76, JY	1,JY	-
2	*Acanthogobius flavimanus*	-	-	-	1, Y	-	1, L	1373, LJ	3606, LJ	47, LJY	3,Y	1,Y	-
3	*Plecoglossus altivelis altiveli*	-	-	195, L	70, LJ	36, LJ	819, LJY	1284, LJ	25,JY	-	-	-	-
4	*Gymnogobius castaneus*	-	-	-	-	-	-	568,L	799, LJ	823, LJY	-	-	-
5	*Sardinella zunasi*	20, JY	6, Y	64, Y	-	-	-	-	-	-	-	13, LJY	1891, LJ
6	*Konosirus punctatus*	-	-	-	-	-	-	-	-	553,L	391, L	312, LJY	72, JY
6	*Lateolabrax japonicus*	-	-	-	-	-	9,LJ	833, LJY	459, LJY	22,Y	5, Y		-
8	*Tridentiger obscurus*	-	-	-	-	-	-	-	-	-	-	377, LJ	1,J
9	*Mugilogobius abei*	-	-	-	-	-	-	-	-	-	-	-	305, LJ

Developmental stage (L, larva; J, juvenile; Y, young). -, not collected.

であった。

その他の魚種では2期以上にわたって出現したが，とくに出現のピークは見られなかった。

3.4 連続する月間の種組成の類似度

連続する月間の種組成の類似度で最も高かったのは2000年9-10月の0.63で，その後は徐々に減少し，2001年1-2月に最低（0.22）を記録した（Fig. 4）。2001年2-3月以降は類似度0.28から0.45の間で波状に変化した。平均は0.36だった。

3.5 優占種の発育段階別の出現様式

上位10種の個体数の合計は26,227個体で，全個体数の97.8%を占めた（Table 1）。以下に，個体数の多い順に，ハゼ科不明種を除く9種の発育段階別の出現様式を記す（Table 2）。

エドハゼでは，仔魚が4月と5月に，稚魚が4月から7月に，若魚が6月と7月，および11月に出現した。とくに，仔稚魚は4月に1,829個体（4月に採集された全個体数の27.0%を占める），5月に8,892個体（85.0%）と多く出現した。

マハゼでは，仔魚が2月から5月に，稚魚が3月から5月に，若魚が5月から7月，および12月に出現した。とくに，仔稚魚は3月に1,373個体（33.3%），4月に3,606個体（53.3%）と多く出現した。

アユでは，仔魚が11月から3月に，稚魚が12月から4

月に，若魚が2月と4月に出現した。とくに12月から2月には，個体数は19～71個体と少ないが，月ごとの割合では90.0～96.7%を占めた。また，11月には195個体（72.8%），3月には1,284個体（31.2%）が出現した。

ビリンゴでは，仔魚が3月から5月に，稚魚が4月と5月に，若魚が5月に出現した。4月には799個体（11.8%），5月には823個体（7.9%）と多く出現した。

サッパでは，仔魚が7月と8月に，稚魚が7月から9月に，また若魚が7月から11月に出現した。とくに8月は1,891個体（82.5%）と多く出現し，そのほとんどが仔稚魚であった。

コノシロでは，仔魚が5月から7月に，稚魚と若魚が7月と8月に出現した。とくに6月と7月には391個体（55.1%）と312個体（38.8%）が出現した。

スズキでは，仔魚と稚魚が2月から4月に，また若魚が3月から6月に出現した。とくに3月には833個体（20.2%）と多かった。

チチブでは，仔魚が7月に，稚魚が7月と8月に出現した。とくに7月には377個体（46.9%）が出現した。

アベハゼでは，8月に305個体（13.3%）の仔稚魚が出現した。

3.6 出現魚種の生活史型および干潟の利用様式

採集された魚類のうち生活史型が明らかになったのは30種26,370個体であった。

河口魚は10種18,888個体で，生活史型が明らかとなった個体数の71.6%を占めた。河口魚のうち，滞在型は見られなかった。一時滞在型は9種で，個体数では河口魚の99.99%を占めた。このうち，アベハゼとヒモハゼ，チチブでは仔魚と稚魚が，エドハゼ，ビリンゴ，マハゼ，アシシロハゼでは仔魚から若魚が，ニクハゼとヒメハゼでは稚魚と若魚が出現した。通過・偶来型はアカオビシマハゼ1種で，稚魚が出現し，個体数では河口魚の0.01%にすぎなかった。

海水魚は18種4,915個体で，生活史型が明らかとなった個体数の18.6%を占めた。海水魚のうち，一時滞在型は11種で，個体数では海水魚の98.5%を占めた。このうち，カタクチイワシ，トウゴロウイワシ，メバル，ナベカでは仔魚と稚魚が，サッパ，コノシロ，スズキ，ヒイラギ，ギマでは仔魚から若魚が，シロギスとボラでは稚魚と若魚が出現した。通過・偶来型は7種で，個体数では海水魚の1.5%を占めた。このうち，ギンポ，イソギンポでは仔魚が，クサフグ，フグ科不明種では稚魚が，ヨウジウオ，マゴチ，イシガレイでは若魚が出現した。

両側回遊魚は，一時滞在型のアユとウキゴリの2種のみが出現し，個体数は2,567個体で，生活史型が明らかとなった個体数の9.8%を占めた。ウキゴリでは仔魚と稚魚が，またアユでは仔魚から若魚が出現した。

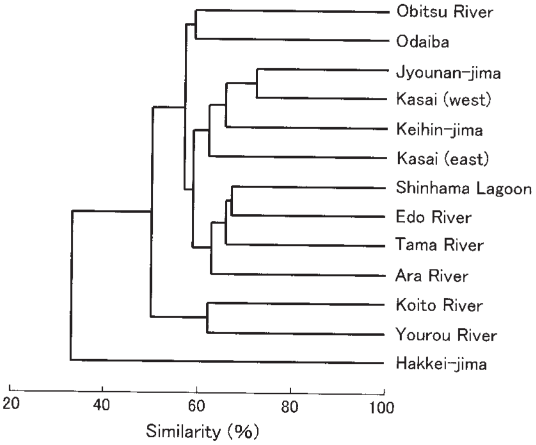

Fig. 5. Dendrogram of 13 tidelands in the inner Tokyo Bay, based on Bray-Curtis similarity index for fish communities.

3.7 東京湾内湾の他地点との比較

本研究をふくむ東京湾内湾13地点のクラスター分析の結果をFig. 5に，また，これらの地点の環境特性や採集結果，多様度，個体数の上位4種をTable 3に示す。

クラスター分析の結果，八景島とその他12地点に大きく二分され，さらに後者は小糸川と養老川のクラスターとその他10地点に大別された。本研究の調査地点である葛西人工渚西浜は後者の10地点に含まれ，その中でも葛西人工渚東浜や京浜島，城南島と一つのクラスターを形成した。

多様度では小櫃川が最も高く0.89で，次いで葛西人工渚西浜，葛西人工渚東浜，京浜島の0.81であった（Table 3）。一方，多様度が最も低いのは小糸川で，0.25であった。

葛西人工渚西浜で採集された上位4種のうち，アユを除くエドハゼとマハゼ，ビリンゴのハゼ科魚類は他の6～12地点で上位4種に数えられた（Table 3）。最も多くの地点で上位4種となったのはマハゼ（13地点）で，次いでビリンゴ（11地点），エドハゼとボラ（7地点）であった。一方，1地点でしか上位4種に数えられなかったのはアユ（葛西人工渚西浜）とサッパ（葛西人工渚東浜），コボラおよびトウゴロウイワシ（両種とも八景島）で，ヒメハゼは2地点，ニクハゼは3地点で上位4種となった。

4. 考察

4.1 ハゼ科魚類とアユの優占

本研究の結果，葛西人工渚西浜では，ハゼ科魚類とアユが優占することが明らかになった。

ハゼ科魚類では優占種が月ごとに変化した。すなわち，3月と4月にはマハゼが，5月にはエドハゼが最優占種

Table 3. Comparison of ichthyofauna among the 13 tidelands in Tokyo Bay

	Kasai (west)[1]*	Kasai (east)[2]*	Odaiba[2]*	Jyounan-jima[2]	Obitsu R.[3]	Yourou R.[3]	Koito R.[3]	Ara R.[3]	Edo R.[3]	Tama R.[3]	Shin-hama L.[3]	Keihin-jima[4]	Hakkei-jima[5]*
Environmental conditions													
Location of tideland	a	a	a	a	b	b	b	b	b	b	b	a	a
Mean salinity (SD)	24.7(5.5)	17.6(9.6)	22.0(4.4)	18.9(6.1)	21.0(5.8)	15.4(7.1)	18.3(7.6)	13.6(4.8)	26.5(2.1)	11.3(5.6)	24.3(5.5)	16.3(5.5)	33.8(2.4)
Total no. of individuals	26814	7673	12198	8027	5368	1808	10015	8518	7360	13097	15222	18052	2580
Total no. of species	31	30	23	40	31	14	26	23	32	26	20	35	32
Mean no. of species (SD)	7.5(3.2)	8.3(2.3)	6.3(3.5)	8.5(4.5)	10.7(5.4)	4.0(2.6)	6.2(4.1)	7.8(3.7)	7.1(6.3)	6.9(3.1)	4.9(3.8)	7.4(3.1)	5.9(4.4)
Diversity (H')	0.81	0.81	0.56	0.77	0.89	0.57	0.25	0.45	0.78	0.52	0.40	0.81	0.63
Four dominant species (rank)													
Gymnogobious macrognathos	(1)	(2)	+	(2)	+	–	–	+	(4)	(1)	(2)	(1)	–
Acanthogobius flavimanus	(2)	(4)	(2)	(1)	(1)	(1)	(1)	(1)	(2)	(2)	(1)	(3)	(3)
Plecoglossus altivelis altivelis	(3)	+	+	+	+	+	–	+	+	+	–	–	–
Gymnogobius castaneus	(4)	(3)	(3)	(3)	(4)	(4)	+	(4)	(1)	(4)	(3)	(2)	–
Sardinella zunasi	+	(1)	–	+	–	–	–	+	+	+	+	+	+
Mugil cephalus cephalus	+	+	(4)	(4)	+	(2)	(2)	(3)	+	(3)	(4)	+	+
Lateolabrax japonicus	+	+	+	+	(2)	(3)	(4)	(2)	(3)	+	+	+	+
Favonigobius gymnauchen	+	+	+	+	(3)	+	(3)	+	+	+	–	+	+
Gymnogobius heptacanthus	+	+	(1)	+	+	–	+	–	+	+	+	(4)	(1)
Chelon macrolepis	–	–	–	–	–	+	–	–	–	–	+	+	(4)
Hypoatherina valenciennei	+	–	+	+	–	–	–	–	+	–	+	+	(2)

[1]Present study, [2]Environmental Pprotection Bureau, Tokyo Metropolitan Government (2000), [3]Kanou et al. (2000), [4]Nasu et al. (1996), [5]Tanabe and Hayashi (1999).

Location of tideland: a, outside river mouth and/or lagoon; b, (inside) river and/or lagoon. *, artificial tideland. +, <fourth; -, not collected

であった。6月にはハゼ科不明種が多く出現したが，7月にはチチブが，8月にはアベハゼが，9月にはハゼ科不明種とアシシロハゼが優占種であった。ハゼ科魚類が内湾や河口域で優占することはすでに多くの海域から報告されており，また東京湾の干潟域では一般的な事象であることが知られている（Table 3；加納ら，2000)。

一方，アユは冬季の11月から2月にかけての優占種であった。アユが優占種として出現する地点は，東京湾内湾の干潟域では葛西人工渚西浜以外に報告されていない（Table 3）。本種は，東京湾内湾の河口干潟域の調査（加納ら，2000）では，全体の0.07%にあたる40個体が採集されているにすぎない。また，多摩川（河野ら，1994)，京浜島（那須ら，1996)，八景島（田辺・林，1999)，城南島やお台場（東京都環境保全局，2000）などの他の干潟域の調査でもほとんど採集されていない。

アユの仔魚は，河口域浅所と砂浜海岸砕波帯の両者で多く出現するものの，その優占度は砕波帯において高いことが知られている（藤田，1998)。ただし，砕波帯によってアユの出現量はかなり異なり，例えば土佐湾（木下，1993）や鹿島灘（須田・五明，1995）では多いが，山口県の土井ヶ浜（内田ら，1998）では少ない。同様の現象は，東京湾外湾の砕波帯間の比較でも確認されている（荒山ら，2002)。内田ら（1998）は，このようなアユの出現量の相違には，近隣の大きな河川の有無が関連している可能性を示唆した。葛西人工渚は，荒川と江戸川という2つの大規模河川の河口前縁に位置する前浜干潟である。立地条件からすれば波浪が生じる地点だが，沖に潜提が設置され，流れや波浪による影響の少ない穏やかな海況が保たれている。このような，内湾部の他の干潟域とは異なる環境特性が，本調査地にアユ仔稚魚が集積する理由の一つと考えられる。

なお，東京湾では，自然の前浜干潟が埋め立てによりほとんど失われてしまったという経緯がある。したがって，アユのように前浜干潟を生活史の初期に利用する魚類にとって，葛西人工渚のような人工海浜の果たす役割は大きいものと考えられる。

4.2　成育場としての意義

生活史型が明らかとなった30種のうち，河口魚が10種（総個体数の71.6%)，海水魚が18種（18.6%)，両側回遊魚が2種（9.8%）であった。さらに，河口魚の9種（河口魚の個体数の99.99%)，海水魚の11種（海水魚の個体数の98.5%)，両側回遊魚の2種（両側回遊魚の個体数の100%）が一時滞在型であった。全体では，一時滞在型は22種（総個体数の99.7%）で，通過・遇来型は8種（0.3%）である。この結果は，葛西人工渚西浜がいろいろな魚種の一時的な滞在の場を提供していることを示している。これは，東京湾内湾の干潟域は滞在型や一時滞在型魚類の定住の場あるいは一時的な成長の場として利用されている，という加納ら（2000）の指摘を支持するものである。

荒山ら（2002）は，連続する月間の種組成類似度が東京湾内湾の干潟域（平均0.42）において東京湾外湾の砕波帯（平均0.29）よりも高いことから，干潟域は砕波帯よりも長期間の成長の場であることを指摘した。葛西人工渚西浜での連続する月間の種組成類似度は，年間を通して比較的安定した数値を示し（平均0.36)，その点からも本調査地が魚類の一時的な滞在の場あるいは成長の場として機能していることが示唆された。

4.3　地点間の比較

地点間の群集の類似度に基づくクラスター分析の結果，東京湾内湾の干潟域は，葛西人工渚西浜を含む12地点と八景島の2つに大きく分かれた。八景島（海の公園）は，葛西人工渚と同じく人工的に造成された前浜型の干潟であるが，塩分が平均33.2であり，他の干潟（11.3–26.5）と比較して高い傾向がみられる（Table 3）。そういった環境特性の違いが魚類相に反映された可能性もある。また，このグルーピングの結果からも，葛西人工渚西浜の魚類相は，東京湾内湾の干潟域における一般的な魚類群集の特徴をもっていることが示された。

葛西人工渚西浜の年平均種数は7.5種，多様度は0.81であった（Table 3）。年平均種数は，東京湾で唯一の自然干潟である小櫃川河口干潟（10.7種, 加納ら(2000)）と比べるとやや低いものの，それでも上位から数えて5位にあたる。また，多様度は小櫃川河口干潟（0.89）に次ぐ2位であった。この数値から判断する限り，葛西人工渚西浜の魚類相はかなり豊かである。しかし，河口域において魚類の種数や多様度は海に向かうほど増加することも知られており（Neira *et al.*, 1992)，葛西人工渚西浜のような前浜干潟と，河口干潟や潟湖干潟のデータを単純に比較することはできない。今後は，環境の異なるさまざまな立地の干潟について，より定量的なデータを収集していくことが望まれる。また，自然状態の干潟の機能的な役割のどの程度を人工海浜が果たしているのか，あるいは人工海浜の環境は普遍的に豊かなのか，といった疑問を解決するためにも，自然干潟と人工海浜の両方において経年的なデータを蓄積していく必要がある。

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Fatty acid composition of *Acartia clausi, Pseudocalanus elongatus* and *Temora longicornis* associated with their diet in the eastern English Channel during a spring bloom of *Phaeocystis* sp.

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Abstract : On the basis of two three hours resolution Lagrangian surveys conducted during three days at the beginning and the end of the 1998 spring bloom in the Eastern English Channel, we investigated the fatty acid composition of both particulate organic matter (POM) and dominant calanoid copepods (*Acartia clausi, Temora longicornis, Pseudocalanus elongatus*). Phytoplankton biomass was higher during the first than the second survey, and *Phaeocystis* sp. was the predominating algal genus (ca. 90% of total diversity), with diatoms in lower proportions. Cryptophytes and dinoflagellates were always in low levels (<1%). Three fatty acids (14:0, 16:0, 18:0) were predominant in POM, and accounted for 75% to 96% of the total fatty acids. Unsaturated fatty acids were mainly composed by essential fatty acids ($\omega 3$ and $\omega 6$ fatty acids). Our major finding here was the highest proportions of unsaturated fatty acid, especially 20:5ω3 (EPA) and of 22:6ω3 (DHA), in copepods relatively to POM. More specifically, *T. longicornis* and *A. clausi* lipid compositions were similar, with high 20:5ω3 and 22:6ω3 contents when compared to *P. elongatus* which was characterised by a higher proportion of 18:1 ω9. This suggests omnivorous and carnivorous diets for the former ones and the latter, respectively. The observed shifts in POM fatty acid composition led to a decrease in the total fatty acid contents, but no change in the fatty acid composition has been observed for the three investigated species. *T. longicornis* was nevertheless more sensitive to changes of the dietary fatty acid composition than the two other species. Finally, we stress that the species-specific evolution of the EPA to DHA ratio indicates that the fatty acids mobilization occurred differently in each species.

Keywords : *zooplankton, copepods, fatty acids, POM, English Channel*

1. Introduction

Copepods are the largest and most diversified group of crustaceans, and are the most numerous organisms in the marine zooplankton communities, accounting for more than 70% of the zooplankton fauna (RAYMONT, 1983). Planktonic copepods are regarded as a fundamental link between primary producers and various higher level predators such as fishes. In particular, they play a salient role in the energy transfer from lower to higher trophic levels *via* lipids that are one of the most important sources of energy in the marine food web (WATANABE, 1982: SAITO and KOTANI, 2000).

It is now well established that most of

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marine copepods are characterised by elevated lipid contents. Contents and ratios of fatty acids (hereafter referred to as FA) in copepods are known to vary depending on the diet composition, and often reflect the lipid content of algae, which fluctuates with taxonomic groups (SARGENT and FALK-PETERSEN, 1988: GRAEVE *et al.*, 1994). Moreover, the FA composition of copepods also changes following the position of the algae life cycle and physiological state, and the development stages of copepods (OHMAN, 1988). Many authors provided detailed fatty acid composition of copepods (FRASER *et al.*, 1989a, b: HAGEN *et al.*, 1993: GRAEVE *et al.*, 1994). In particular, they found high amounts of $\omega 3$ polyunsaturated FAs (PUFAs) and more accurately high amounts of essential FAs (EFAs) such as the 20: $5\omega 3$ (icosapentaenoic acid: EPA) and the 22: $6\omega 3$ (docohexaenoic acid: DHA) (FRASER *et al.*, 1989a), which can represent a considerable proportion of the total FAs. These FAs, and especially their availability, are crucial for growth, reproduction and survival (STΦTTRUP and JENSEN, 1990: JONASDOTTIR *et al.*, 1995). Previous studies conducted on copepod lipid composition showed that the main part of fatty acids is directly incorporated from the diet. In addition, WEERS *et al.* (1997) demonstrated that crustaceans are able to selectively incorporate and accumulate these fatty acids. Copepods also may synthesise longer PUFAs chains by elongation and desaturation of shorter algal FAs such as the 18: $3\ \omega 3$ (GULATI and DEMOTT, 1997). DESVILETTES *et al.* (1997) indicated that calanoid copepods may bioconvert 18: $3\omega 3$ in 22: $6\omega 3$.

Studies about lipid composition of phytoplankton classes showed that some of algae contain low levels of longer PUFA chains, which are crucial for copepods that are generally assumed to be unable to produce significant amounts of these PUFAs (NANTON and CASTELL, 1998). Among these algae, the worldwide distributing and bloom-forming microalga *Phaeocystis* sp. is known to contain very low levels of unsaturated FAs (CLAUSTRE *et al.*, 1990: NICHOLS *et al.*, 1991: COTONNEC *et al.*, 2001). Although this alga is considered as a non valuable food for grazers (HANSEN and BŒKEL, 1991: HANSEN, 1995: BRETON *et al.*, 1999, 2000: GASPARINI *et al.*, 2000), copepods consume it (BRETON *et al.*, 2000: COTONNEC *et al.*, 2001). However to our knowledge, the impact of the FA composition of *Phaeocystis* sp. on copepods' FAs has not been yet investigated. The Eastern English Channel constitute an appropriate area to study this impact because each year it is the siege of a phytoplankton spring bloom mainly dominated by *Phaeocystis* sp. The objective of the present work is thus to describe the FA compositions of three of the major calanoid species (i.e. *Pseudocalanus elongatus, Temora longicornis* and *Acartia clausi*) encountered in the English Channel (BRYLINSKI *et al.*, 1984) in relation with the temporal evolution of the FA composition of their diet. In that way, we infer the effects of the temporal variation of the dietary FA composition on the FA composition of copepods during a *Phaeocystis* spring bloom from two three-days Lagrangian surveys that have been specifically designed to avoid any potential changes of both phytoplankton and zooplankton communities.

2. Material and methods

Study area

The Eastern English Channel is characterised by strong hydrodynamic conditions resulting from a combination of a megatidal regime, straight narrowing and shallow waters (50 maximum depth). The fluvial supplies, distributed from the Bay of Seine to Cape Griz-Nez, generate a coastal water mass drifting nearshore, northward and separated from the offshore Atlantic-like waters by a tidally controlled frontal area (BRYLINSKI and LAGADEUC, 1990: LAGADEUC *et al.*, 1997). In particular, the dilution plume of the Somme estuary acts as a retention zone where organisms would be retained for a period depending on winds (speed and direction) before drifting northwards. This coastal flow (Fig. 1a; BRYLINSKI *et al.*, 1991) is characterised by its freshness, turbidity (DUPONT *et al.*, 1991) and phytoplankton richness (BRYLINSKI *et al.*, 1984). Moreover, the dissipation of tidal energy is basically regarded to be responsible for the vertical homogenisation of inshore and offshore water masses (50 m maximum depth).

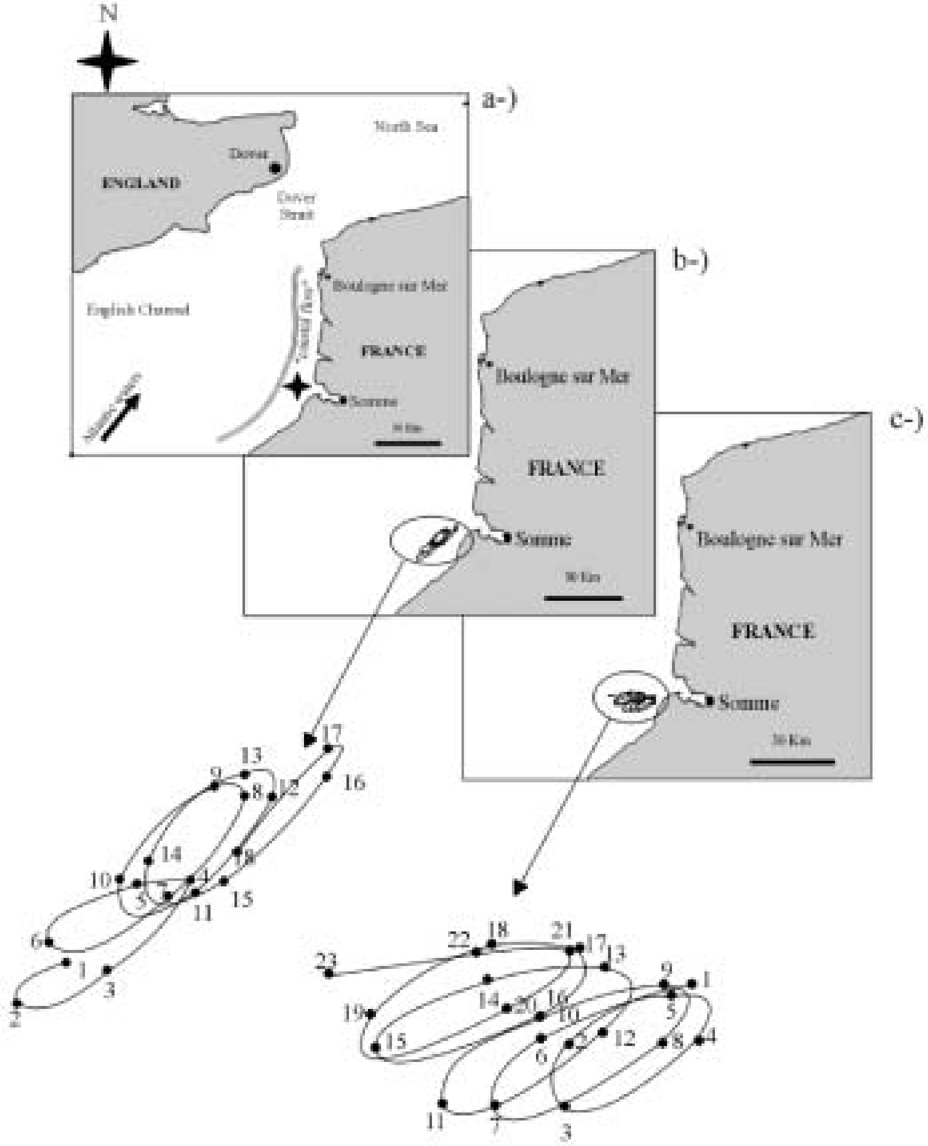

Fig. 1: Sampling area in the Bay of Somme (southeastern English Channel) showing the drogue deployment position (a) and trajectories of drogues over 3 days the 9–11 April (b) and 27–30 April (c) 1998. Numbers indicate sampling stations.

Sampling

Two surveys were conducted in the coastal waters in front of the Bay of Somme (Fig. 1a) where the water column is well-mixed. A drogue was launched closed to the frontal zone for each survey after prospecting using a CTD profiler along a transect from the Bay to offshore. The drifter was composed of a cylindrical sock 8 m long attached to a buoy at 2 m below the surface. Its geographical position was determined from satellite tracking (Argos system). Sampling was carried out close to the drifter every 3h over a 3 day period from April 9th to 11th (cruise 1) and from April 29th to 30th (cruise 2) 1998. Eighteen stations were thus sampled during cruise 1 and 23 in cruise 2.

Vertical profiles of both salinity (PSU), temperature (℃) and density (kg.m^{-3}) were recorded with a Sea-Bird 25 Sealogger CTD probe. An index of stratification (Sp) was estimated using the following relation (IBANEZ *et al.*, 1993): $Sp = \Sigma x_i - pk$, where x is the density at each depth, p is the slope between two successive points and k is the averaged density of the water column at each station. Water samples were collected every three hours with Niskin bottles in the sub-surface waters (5m depth) and at 1.5m to the bottom of the water column. Phytoplankton composition (60ml sample preserved in acid Lugol's iodine solution and phytoplankton composition estimated from observations carried out on 10ml of seawater with a Zeiss inverted microscope (× 400) according to the Ütermohl sedimentation technique; ÜTERMOHL, 1958), nutrient (i.e. nitrate and silicate) concentration (20ml frozen samples, analysed using a Technicon autoanalyzer II; TREGER and LE CORRE, 1971) and chlorophyll-*a* concentration (500ml filtered Whatman GF/F filters, stored in liquid nitrogen to avoid pigment destruction by light or chemical or biochemical endogenous enzymes, extracted with 90% acetone, assayed in a Kontron model sfm 25 spectrofluorometer with an excitation at 407nm and emission at 660nm and the chl-*a* concentration calculated using standards and predetermined calibration factors) were estimated for each sampled depth. Lipid compositions of particulate organic matter (POM) and zooplankton were estimated from 500ml filtration using Whatman GF/F filters (precombusted at 450℃ for 12h to remove organic material) and from WP2 zooplankton net (200 μm mesh-size) oblique hauls. Filters were then stored at −20℃ in 2ml of methanol, and zooplankton organisms at −20 ℃ until analysis. As FA compositions did not show significant temporal variations throughout the two cruises, we present only one out of two sample for POM and zooplankton (i.e. 9 and 11 samples for cruises 1 and 2 respectively).

Fatty acids

Fatty acids were extracted according to BLIGH and DYER (1959). For copepods, pools of 300 individuals of each species (CV and CVI) were sorted under a binocular microscope at 0 ℃ under cool light and subsequently gently and carefully rinsed. The fatty acid C23: 0 was used as an internal standard to quantify the FA concentrations. The fatty acids were converted to methyl esters according to METCALFE and SCHMITZ (1961). A nitrogen atmosphere was always maintained. Methyl esters were separated from other lipids (i.e. hydrocarbons and sterols) using HPLC interfaced with an UV absorbance detector (Waters Lambda Max model 841 spectrophotometer at 206 nm). The separation was done on two associated normal phases' columns, the first containing Lichrosorb diol and the second Lichrosorb Si–60. Gas Chromatography (GC) of the methyl esters was carried out with a Hewlett Packard model 5890 series II apparatus equipped with a flame ionisation detector. The methyl esters were separated using a FFAP (Free Fatty Acids Phase) polar phase capillary column 25 m in length ×0.32 mm internal diameter. Hydrogen was used as carrier gas from 86 to 115 kPa. The detector temperature was maintained at 240℃. Peaks were identified by means of reference standards.

3. Results

Hydrology

The drogues followed elliptical paths with the major axis aligned with the tidal axis and approximately parallel to the coastline (Fig. 1b, 1c). This implies that the tidal current was the principal force operating on the drogues. The drogue paths nevertheless clearly differed between our two surveys. In cruise 1, the drogue remained in the coastal waters along the French coast and drifted northward. In contrast, the drogue deployed during cruise 2 drifted toward the offshore waters. This suggests that the direction (west in cruise 1, north-est in cruise 2) and the speed of the wind (3.73m.s^{-1} in cruise 1, 4.74m.s^{-1} in cruise 2) were other force operating on the drogue drift.

The water column was vertically well-mixed during all the sampling periods as shown by the index of stratification (Fig. 2). No temporal gradients in temperature and salinity were observed during the drift of the drogue at the in cruise 1. In contrast, temporal gradient of

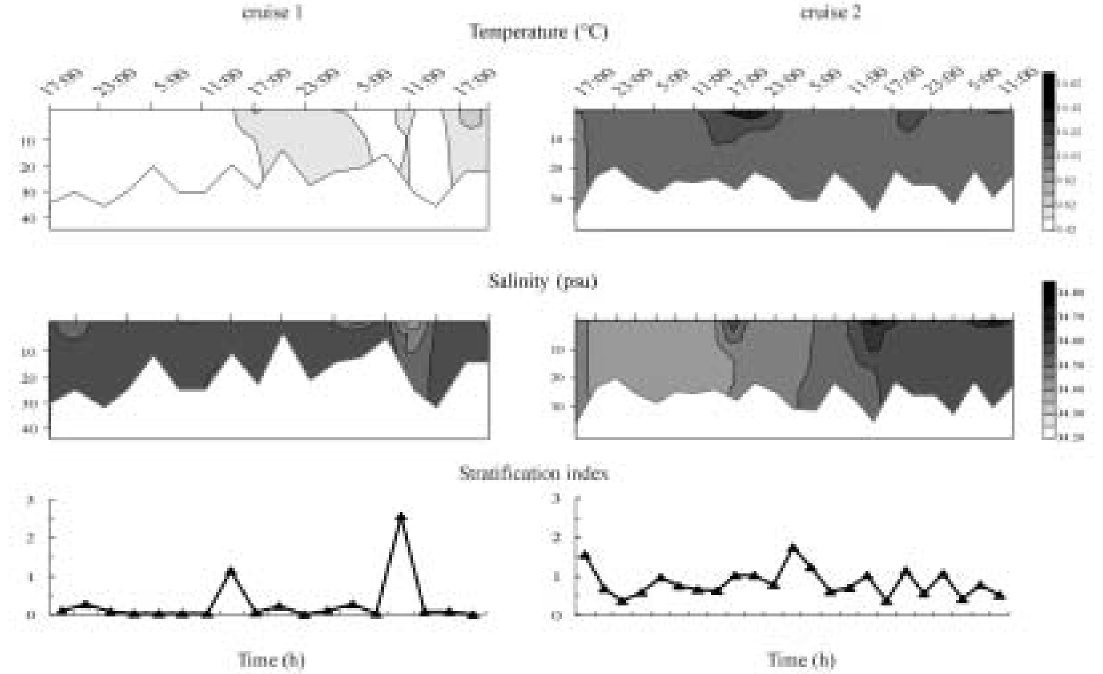

Fig. 2: Vertical distribution of salinity (PSU), temperature (℃) and stratification index during the cruise 1 (9–11 April 1998) and cruise 2 (27–30 April 1998).

salinity was observed during cruise 2 (Fig. 2) suggesting a change of water mass. Between the two surveys, both temperature and salinity increased due to the seasonal changes.

Nutrients

All results are expressed in mean and standard deviation concentrations (m±SD $\mu M.l^{-1}$). Nitrate was depleted in cruise 1 (Fig. 3). The silicate concentration was low (0.8 ± 0.4 $\mu M.l^{-1}$). The high concentration observed close to the bottom probably results from a resuspension of sediments (QUISTHOUDT, 1987). In cruise 2, nitrate was detected in the water column with a mean concentration of 0.2±0.1 $\mu M.l^{-1}$. Similarly, silicate was also found in higher concentration than in cruise 1 (2.3±1.6 $\mu M.l^{-1}$). Two periods can nevertheless be distinguished during this survey. The first one was characterised by significantly lower nitrate concentration (0.01±0.04 $\mu M.l^{-1}$) than the second one (0.4±0.2 $\mu M.l^{-1}$; U-test, $p > 0.05$). No significant variation was observed between the surface and the bottom throughout the two surveys for these nutrients (Kolmogorov-Smirnov test, $p > 0.05$).

Phytoplankton biomass and composition

The prymnesiophyte *Phaeocystis* sp. was the dominant phytoplankton species, and represents around 92% of total phytoplankton cells for the two surveys (Table I). The second group was composed of centric diatoms such as *Rhizosolenia* sp. In cruise 2, pennal diatoms appeared such as *Nitzschia* sp. and *Raphoneis* sp. The Cryptophytes and dinoflagellates were in low proportion throughout the two surveys.

The Chl *a* concentrations were similar in the surface and near the bottom (Kolmogorov-Smirnov test, $p > 0.05$) during the two surveys (Fig. 3). No significant trend in phytoplankton biomass was observed throughout the two surveys, even during the hydrographic change detected during the second survey. Finally, the phytoplankton biomass was significantly higher during the second survey ($p > 0.05$).

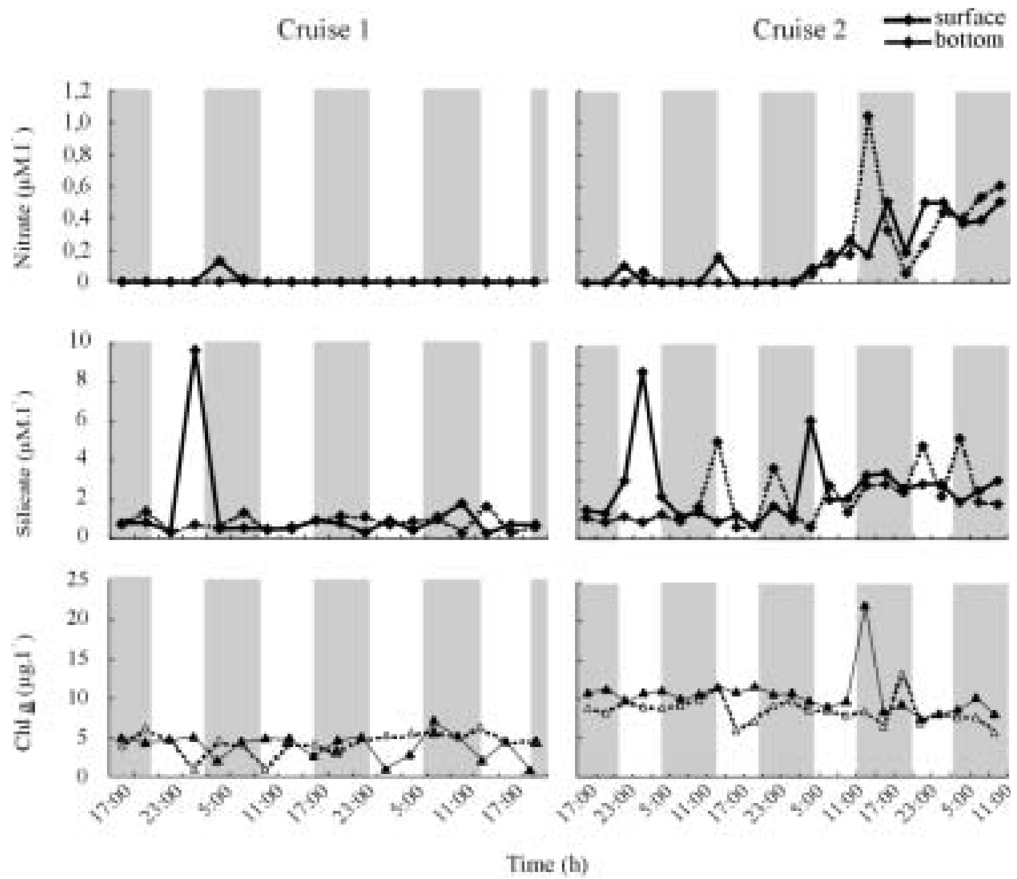

Fig. 3: Nutrient (μM.l^{-1}) and Chl.-*a* concentrations (μg.l^{-1}) at the subsurface and at 1.5m to the bottom during the two surveys. The shaded areas indicate the night-time sampling.

Table 1. Phytoplankton classes 10cell^{-1} observed in six and ten samples at the surface and the bottom during 9–11 and 27–30 April 1998
– :not observed:<1:cell density from 1001 to 10,000 cell^{-1}

	9–11 April		27–30 April	
	surface	bottom	surface	bottom
Prymnesiophycee				
Phaeocystis sp.	240	343	443	504
Diatomophycees				
Biddulphia sp.	–	–	1	<1
Rhizosolenia sp.	24	28	22	47
Thalassiosira sp.	<1	<1	–	–
Nitzschia sp.	–	–	<1	–
Raphoneis sp.	–	–	<1	–
Cryptophycees	<1	1	1	<1
Dinophycees	1	2	<1	<1

POM fatty acids

During the two surveys, a majority of saturated FAs was observed in both surface and bottom waters (Table II). Three (14: 0, 16: 0, 18: 0) were particularly dominant, accounting for 75 and 96% of the total FAs in cruises 1 and 2, respectively. Other saturated FAs (19: 0; 20: 0; 21: 0; 22: 0; 24: 0) were found in lower proportions. Low concentrations of unsaturated FAs were observed throughout the studies. The branched fatty acids (*a*15: 0, *i*15: 0, and *a*17: 0, *i*17: 0) were detected during the two studies. They nevertheless represented less than 2% of the total FA content.

Temporal changes in the FA composition of POM total FAs were characterised by a decrease in unsaturated FAs from 1.28% to 0.28% between the two cruises. No significant

Table 2. Fatty acid composition of total lipid extracted from the particulate organic matter sampled. The data represent mean and SD proportions of nine and eleven samples during 9–11 April and 27–30 April 1998 respectively taken at regular intervals of six hours. –:not detected, SatFAs: saturated FAs: Mono FAs: monounsaturated FAs; PUFAs: polyunsaturated FAs; BrFAs: branched FAs.

	9–11 April		9–11 April	
	surface	bottom	surface	bottom
14:0	36.77± 6.91	41.93± 4.76	37.69± 9.97	34.74± 7.46
15:0	2.78± 0.44	2.96± 0.65	2.84± 1.12	2.95± 0.51
*a*16:0	–	–	–	–
*i*16:0	0.32± 0.29	0.32± 0.37	0.05± 0.17	0.16± 0.28
16:0	36.48± 2.92	31.90± 4.31	38.36± 2.95	38.77± 2.94
17:0	1.21± 0.23	1.11± 0.13	1.73± 1.06	1.55± 0.35
*a*18:0	–	–	–	–
*i*18:0	0.13± 0.24	–	–	–
18:0	13.28± 3.44	11.39± 1.84	14.67± 4.46	16.59± 3.50
19:0	0.19± 0.29	0.15± 0.36	–	–
20:0	0.84± 0.88	0.92± 0.27	0.96± 0.77	0.58± 0.73
21:0	0.74± 0.75	0.37± 0.57	–	0.04± 0.10
22:0	1.80± 1.22	1.93± 0.53	2.12± 1.07	2.39± 2.19
24:0	0.03± 0.03	0.16± 0.38	–	–
16:1ω7	0.17± 0.22	–	0.04± 0.14	0.25± 0.43
16:1ω9	–	–	–	–
18:1ω7	–	–	–	–
18:1ω9	–	–	–	–
20:1	0.11± 0.32	–	–	–
22:1	0.02± 0.06	–	–	–
16:2ω4	–	–	–	–
16:3	0.04± 0.12	–	–	–
18:2ω6	–	–	–	0.13± 0.35
18:3ω6	0.74± 0.47	–	–	0.06± 0.16
18:3ω3	–	–	–	–
20:4ω6	1.18± 1.02	0.18± 0.20	–	–
20:5ω3	0.14± 0.39	–	–	–
22:6ω3	0.29± 0.54	–	0.03± 0.03	0.35± 0.60
*a*15:0	0.62± 0.32	0.83± 0.18	0.82± 0.47	0.60± 0.44
*i*15:0	0.72± 0.43	0.89± 0.13	0.47± 0.41	0.51± 0.36
*a*17:0	0.26± 0.14	–	–	0.12± 0.22
*i*17:0	0.10± 0.22	–	–	–
Sat FAs	95.60±17.92	94.63±14.90	98.42±21.58	97.98±18.25
Mono FAs	0.31± 0.63	–	0.04± 0.14	0.25± 0.43
PUFAs	2.40± 2.54	0.17± 0.19	0.03± 0.03	0.54± 1.10
BrFAs	1.70± 1.12	1.72± 0.30	1.29± 0.88	1.23± 1.02

changes in the percentages of these FAs were shown between the two part of the survey "cruise 2". The monounsaturated FAs and PUFAs were the most diversified in cruise 1. Three monounsaturated FAs were then encountered in cruise 1 (16: 1ω7, 20: 1, 22: 1), whereas only one was identified in cruise 2 (16: 1ω7). The unsaturated FAs were mainly composed by the EFAs (i.e. 20: 4ω6, 20: 5ω3, 22: 6ω3) in cruise 1 with a dominance of 20: 4ω6. Two other PUFAs (16: 3 and 18: 3ω6) were observed during this survey. Only two PUFAs dominated by 22: 6ω3 were present in cruise 2.

Fatty acid composition of copepods

As stated above, the fatty acid composition of POM did not differ throughout the cruise 2, despite the observed change in the water column hydrographic structure. The global fatty acid composition of copepods has thus been considered without referring to this hydrographic structural change. The FA composition of all copepod species showed similar characteristics throughout the two surveys:

- the unsaturated FAs tended to be predominant in all copepod species (Tables III and IV). The EFAs composed the main part of these unsaturated FAs with high proportions of 20: 5ω3 and 22: 6ω3. In particular, the 20: 5ω3 tended to be predominant relatively to the 22: 6ω3. The 16: 1ω7 and the 18: 3ω6 , as well as the other unsaturated fatty acids (i.e. 16: 1ω9, 16: 2ω4, 16: 3, 18: 1ω7, 18: 2, 18: 3ω3, 20: 1 and 22: 1) were found in low proportion in all species;
- the branched fatty acids were detected in low proportions in all copepod species comprising less than 3% of the total FA content;
- the saturated FAs were generally found in low proportions in the three copepod species, and exhibited similar trends. Some saturated FAs such as the 14: 0 and 16: 0 were nevertheless significantly less abundant in *P. elongatus* than in the two other species. Moreover, the FA composition of *T. longicornis* resembled that more of *A. clausi* than of *P. elongatus*. A notable characteristic in the total FA composition of *P. elongatus* can be related to the higher proportion of 18: 1ω9 (around 20% and 14% of the total FA in the cruises 1 and 2 respectively) when compared to the two other species (<3% of the total FA content). A higher EPA (i.e. 20: 5ω3) to DHA (i.e. 22: 6ω3) ratio was also found in *P. elongatus* than in the two other species.

The fatty acid composition of the three copepod species exhibited detailed differences with the POM during the two surveys. In particular, the unsaturated fatty acids were qualitatively and quantitatively more important in the copepods than in the POM. The saturated FAs 14: 0, 16: 0 and 18: 0 characterising the *Phaeocystis* sp. were thus dominant in POM, whereas copepod exhibited high proportions of 20: 5ω3, 16: 1ω7 and 22: 6ω3. Some of unsaturated FAs were found in high proportions in copepods (16: 2ω4, 16: 3 and 18 carbon chain FAs) when compared with the POM where they were only found as traces or absent.

Although a low decrease in the proportions of the unsaturated FAs were recorded, no significant changes were observed in the FA composition of copepods between the two cruises. A slight increase of saturated FAs has been simultaneously observed. Some FAs nevertheless showed significant variations between the two surveys. The 16: 3 in low proportion in cruise 1 was not detected in cruise 2. By contrast, the 16: 1ω9 increased significantly although this fatty acid remained in low level in the POM. Some variations of the EPA to DHA ratio were also observed. This ratio decreased in *A. clausi* from 1.69 to 1.01, whereas it increased in *T. longicornis* from 1.19 to 1.85. This ratio remained constant (2.17) throughout the study period in *P. elongatus*. Finally, a general decrease of the total copepod FA content was observed in the three copepod species between the two surveys. The FA contents of *A. clausi* and *T. longicornis* thus increased up to factors of 2 and 4, respectively. On the opposite, the total FA content decreased down to a factor of 3 in *P. elongatus*.

4. Discussion

The hydrography of the Bay of Somme is characterised by well-mixed waters. Mann and Lazier (1991) showed that tidal- and wind-induced mixing processes are the most important features within the coastal zones. In particular, our study pointed out that the tidal advection was the dominant process driving the flow field in the nearshore waters of the Bay of Somme. As shown by the drogue paths, the plume of dilution of Bay of Somme works as a hydrological retention zone as demonstrated by Grioche *et al.*, (2000).

In our study, the FA composition allowed to point out the composition of the POM. In particular, the high proportions of the 14: 0, 16: 0, and 18: 0 suggest that the *Phaeocystis* sp. represented a considerable part of the phytoplankton (Claustre *et al.*, 1990: Nichols *et al.*, 1991). While the 18: 1ω9 is also reported as being a marker of the *Phaeocystis* sp. in the Irish Sea (Claustre *et al.*, 1990), it has not been detected in our study. This observation could be related to the limiting nitrate concentrations observed during the phytoplankton spring bloom in the Eastern English Channel

Table 3. Mean and SD proportions of fatty acids and total lipid content of three species of copepods collected in nine samples of zooplankton during 9–11 April 1998.
−: not detected; Sat FAs:saturated FAs; Mono FAs: monounsaturated FAs; PUFAs: polyunsaturated FAs; Br FAs: branched FAs.

Fatty acids	*A.clausi*	*P.elongatus*	*T.longicornis*
14:0	11.32± 5.97	6.46± 3.15	12.07± 5.41
15:0	0.81± 0.65	0.33± 0.15	0.60± 0.27
*i*16:0	0.22± 0.44	0.03± 0.05	0.11± 0.09
16:0	21.19±11.15	17.25± 7.54	22.33±10.09
17:0	0.72± 0.39	0.42± 0.19	0.50± 0.23
*i*18:0	0.16± 0.31	0.08± 0.08	0.05± 0.05
*a*18:0	0.70± 0.10	2.27± 1.15	1.76± 0.60
18:0	4.29± 3.84	2.57± 1.23	2.55± 0.99
19:0	−	0.04± 0.11	−
20:0	1.03± 1.82	0.01± 0.03	−
21:0	−	−	−
22:0	0.07± 0.13	−	0.04± 0.03
16:1ω7	11.90± 6.61	9.00± 5.96	7.44± 2.99
16:1ω9	0.19± 0.38	0.02± 0.05	0.32± 0.24
18:1ω7	2.79± 1.32	0.34± 0.25	2.93± 2.05
18:1ω9	2.37± 0.93	20.23± 9.54	1.34± 0.57
20:1	0.98± 1.14	0.27± 0.48	0.38± 0.47
22:1	0.17± 0.19	0.14± 0.16	0.24± 0.23
16:2ω4	0.32± 0.17	0.53± 0.26	0.43± 0.17
16:3	0.42± 0.43	0.04± 0.10	0.02± 0.04
18:2ω6	1.02± 0.70	0.83± 0.29	0.56± 0.25
18:3ω6	1.31± 0.71	0.96± 0.42	0.58± 0.21
18:3ω3	5.54± 3.96	2.68± 2.41	1.34± 2.30
20:4ω6	0.79± 0.61	1.28± 0.50	1.38± 0.53
20:5ω3	18.87±12.87	22.69± 8.69	22.80±12.19
22:6ω3	11.18± 2.05	10.72± 3.50	19.29±13.65
*i*15:0	0.66± 0.47	0.14± 0.08	0.13± 0.12
*a*15:0	0.24± 0.30	0.04± 0.06	0.14± 0.10
*i*17:0	0.32± 0.41	0.58± 0.40	0.62± 0.20
*a*17:0	−	−	−
Sat FAs	40.50±24.80	29.49±13.40	40.00±17.26
Mono FAs	18.40±10.57	30.00±16.45	12.65± 6.55
PUFAs	39.45±12.51	39.74±46.41	46.41±29.35
Br FAs	1.22± 1.19	0.76± 0.54	0.89± 0.42
Total FA content ($\mu g. \mu g^{-1}$)	0.10	0.14	0.10

Table 4. Mean and SD proportions of fatty acid and total lipid content of three species of copepods collected in nine samples of zooplankton during 27–30 April 1998.
−: not detected; Sat FAs: saturated FAs; Mono FAs: monounsaturated FAs; PUFAs: polyunsaturated FAs; Br FAs: branched FAs.

Fatty acid	*A.clausi*	*P.elongatus*	*T.longicornis*
14:0	12.89± 2.88	5.89± 3.42	14.50± 9.51
15:0	0.66± 0.14	0.36± 0.26	0.36± 0.16
*i*16:0	0.19± 0.16	0.02± 0.05	0.11± 0.07
16:0	29.34± 4.25	23.25±14.92	24.73±14.04
17:0	0.95± 0.98	1.11± 0.89	0.26± 0.18
*i*18:0	0.15± 0.21	0.02± 0.04	−
*a*18:0	−	−	−
18:0	8.07± 5.13	5.23± 4.64	2.54± 1.65
19:0	−	−	−
20:0	0.11± 0.27	−	−
21:0	−	−	−
22:0	−	−	0.15± 0.27
16:1ω7	4.43± 1.68	8.47± 6.21	8.54± 5.41
16:1ω9	0.65± 0.26	0.96± 0.84	1.60± 1.05
18:1ω7	0.21± 0.20	0.93± 1.25	0.46± 0.28
18:1ω9	1.85± 0.66	13.83± 5.75	0.67± 0.41
20:1	−	0.12± 0.41	−
22:1	0.21± 0.35	0.09± 0.15	0.12± 0.17
16:2ω4	0.24± 0.55	0.04± 0.07	−
16:3	−	−	−
18:2ω6	1.62± 0.22	1.54± 0.97	0.98± 0.55
18:3ω6	4.36± 3.95	5.66± 5.89	1.35± 0.88
18:3ω3	1.58± 1.29	0.79± 0.97	0.56± 0.38
20:4ω6	0.20± 0.26	0.74± 0.46	1.07± 0.76
20:5ω3	15.11± 5.82	19.30±10.21	25.18±14.15
22:6ω3	14.97± 4.86	8.92± 6.72	13.75± 7.71
*i*15:0	0.02± 0.06	0.01± 0.16	0.12± 0.12
*a*15:0	0.42± 0.10	0.18± 0.04	0.13± 0.21
*i*17:0	1.63± 0.40	2.34± 0.10	−
*a*17:0	−	0.15± 1.60	2.92± 2.00
Sat FAs	50.37±13.05	35.67±23.15	42.68±26.08
Mono FAs	7.35± 3.15	22.46±14.61	11.40± 7.32
PUFAs	38.08±16.94	38.08±25.28	42.88±24.42
Br FAs	2.07± 0.56	2.64± 1.90	3.04± 2.12
Total FA content ($\mu g. \mu g^{-1}$)	0.05	0.04	0.02

(GENTILHOMME and LIZON, 1998) as SARGENT *et al.* (1985) who demonstrated that *Phaeocystis* sp. may contain high level of unsaturated fatty acids when nutrients are not limiting. Alternatively, the observed low concentrations of the 20: 5ω3, 16: 3ω4 and 16: 1ω7 indicate a low abundance of diatoms (VOLKMAN *et al.*, 1981), while the low concentrations, if any, of 18: 3, 20: 1 and 22: 6ω3 suggest a low abundance of both Cryptophytes (CHUECAS and RILEY, 1969) and dinoflagellates (SARGENT *et al.*, 1985: CONTE *et al.*, 1994: BüHRING and CHRISTIANSEN, 2001). These results have been confirmed with the algal cell counting (see Table I). Alternatively, the detection of branched FAs (*i* and *a* 15: 0 and *a* and *i* 17: 0) underlines the presence of heterotrophic bacteria in the field.

Our results also showed a temporal trend in the POM between our two surveys. The nutrient concentrations increased from the first to the second survey (cf. Fig. 3), presumably because of enhanced regeneration processes induced by the microbial activity. PEPERZACK *et al.* (1998) thus showed that the microbial loop is enhanced during the spring bloom of *Phaeocystis* sp. in the North Sea. As a consequence, the phytoplankton biomass increases. This increase nevertheless mainly results from the development of *Phaeocystis* as shown by the microscopic observations (see Tab. I). The proportions of the saturated FAs do not seem to be affected by the development of this alga. The observed increase in silicate concentrations, essential for diatoms, indicates that diatoms became less prevalent in cruise 2. The microscopic counts and the decline of diatoms FAs markers fully corroborate this result. In addition, one must note that the FAs markers of Cryptophytes and Dinoflagellates decreased and increased, respectively. On the opposite, the constant proportions of bacterial markers suggest that the concentration of heterotrophic bacteria did not change throughout the *Phaeocystis* bloom. Our results about the temporal evolution of the phytoplankton composition during the spring bloom in the north-eastern of the English Channel were consistent with those of BRETON *et al.* (2000). We stress that many biochemical compounds have a key role in the nutritive value of sestonic particles. As shown by some authors (*e.g.* ALGHREN *et al.,* 1997: BRETT and MULLER-NAVARRA, 1997) the level of PUFAs such as EFAs can be considered as a good indicator of the nutritive value, high PUFAs concentrations revealing high nutritive values and conversely. Taking into account these considerations, the higher phytoplankton concentrations observed at the beginning of April were then less nutritive than the late April ones.

The calanoid copepod species *A. clausi*, *T. longicornis* and *P. elongatus* are commonly found throughout the spring in the French coastal waters of the Eastern English Channel. In particular, they represent key components in larval and juvenile fish diet. To our knowledge these species nevertheless received little, if any, attention. Numerous authors have nevertheless reported the detailed fatty acid composition of many copepod species (LEE and HIROTA, 1973: OHMAN, 1987: HAGEN *et al.*, 1993; GRAEVE *et al.*, 1994). In particular, they found high amounts of $\omega 3$ polyunsaturated FAs such as the 20: $5\omega 3$ and the 22: $6\omega 3$ that are characteristic of copepod tissues (KATTNER *et al.*, 1981: SARGENT and WHITTLE, 1981: FRASER *et al.,* 1989a: GRAEVE *et al.*, 1994: EDERINGTON *et al.*, 1995). These fatty acids were identified in many copepod species (LEE *et al.*, 1971: KATTNER *et al.*, 1981: FRASER *et al.*, 1989a, b: GRAEVE *et al.*, 1994). In the present study, the 20: $5\omega 3$ and the 22: $6\omega 3$ were recorded in high proportions in the three copepod species. *P. elongatus* nevertheless exhibited a high level of 18: $1\omega 9$ when compared to the two other species. This result thus represents the first field investigations that corroborate observations by FRASER *et al.* (1989a) from a nutrient-enriched seawater enclosure experiment. Many authors described this FA as being a constituent of carnivorous copepods (ALBERS *et al.*, 1996: PHLEGER *et al.*, 1998: NELSON *et al.*, 2001). *A. clausi* and *T. longicornis* would thus be omnivorous or herbivorous (FRASER *et al.*, 1989a: CRIPPS and HILL, 1998). Finally, the low proportions of the 18: $1\omega 7$ found in the three copepod species corroborate the carnivorous diet of *P. elongatus* and the omnivorous diet of the two other species as suggested by BüHRING and CHRISTIANSEN (2001).

The FAs have also been used to understand the trophic relationships between POM and copepods. In the present work, the relatively low proportions of saturated FAs (14: 0, 16: 0 and 18: 0) in copepods could indicate that *A. clausi*, *T. longicornis* and *P. elongatus* graze on *Phaeocystis*. The presence of 16: 1, 16: 3, 20: 4 $\omega 6$ and 20: $5\omega 3$ also indicates ingestions of diatoms, Cryptophytes (18: 3) and dinoflagellates (22: $6\omega 3$). Moreover, the higher proportions of unsaturated FAs in copepods than in the POM, together with lower proportions of saturated FAs, suggest a selective ingestion of these phytoplankton classes relatively to the *Phaeocystis*. The diet and selection of food particles by these copepods were studied more accurately for the survey conducted at the beginning of April in COTONNEC *et al.* (2001).

In brief, copepods selectively grazed on Cryptophytes, non-selectively on diatoms, and they also apparently selectively grazed on *Phaeocystis* even if this selection probably results from a low rejection of this alga. *T. longicornis* appeared to be more selective than *A. clausi*. A selective incorporation and accumulation of the unsaturated FAs also have to be considered to explain the high proportions of these FAs in copepods as suggested by WEERS *et al.* (1997). In particular, a bioconversion of these FAs cannot be excluded. The 20: $5\omega3$ and 22: $6\omega3$ characteristic of copepod tissues (SARGENT and WHITTLE, 1981) could also result from a selective incorporation, a long-term storage and/or a biotransformation from an initial compound as 18: $3\omega3$.

As shown by our results, the fatty acid profiles of the three copepod species were not very affected by the temporal evolution of the dietary FA composition observed between the two surveys. Certain unsaturated FAs tended to decrease but not significantly. This nevertheless suggests that a long-term decline of the unsaturated FAs in the POM could affect the FA composition of copepods. A considerable decline of the total FA content occurred in each copepod species indicating a mobilisation of lipid reserves between the two surveys. The most important lipid mobilisation occurred in *T. longicornis* whereas *A. clausi* and *P. elongatus* exhibited the lowest and the intermediate one, respectively. The low reserve mobilisation in *A. clausi* could result from a high ingestion of animal preys, such as ciliates, rich in FAs. Further investigations should thus take this compartment into account very carefully to provide valuable informations for future understanding of the pelagic food chain structures and functions.

Although the proportions of FAs do not seem affected by the mobilisation of the lipid reserves in copepods, the EPA to DHA ratio changed with the decrease in dietary nutritive value. This ratio changes specie-specifically in association with the variation of the essential FA composition of the diet. Although both *A. clausi* and *T. longicornis* are omnivorous (MARSHALL, 1973: COTONNEC *et al.*, 2001) they exhibited two distinct evolutions of their EPA to DHA ratio. The 22: $6\omega3$ (DHA) content seems to be more affected than the 20: $5\omega3$ (EPA) content by the diet changes in *T. longicornis*. In opposition, the EPA content declines more than the DHA in *A. clausi* during the study period. This difference may be due to variations in metabolic interconversion of these two FAs (SARGENT and WHITTLE, 1981). However, copepods are known to select their food particles (TACKX *et al.*, 1989; 1990: MORALES *et al.*, 1991; 1993: GASPARINI *et al.*, 2000: KOUASSI *et al.*, 2001). Thus, the result may also reflect a different evolution of a diatom-based vs. flagellates-based diet with the temporal changes of the FA composition of the POM. *A. clausi* may graze more dinoflagellates than *T. longicornis*, which may consume more diatoms despite the decline of these algae. *P. elongatus* exhibited a constant EPA to DHA ratio indicating constant proportions of these essential FAs despite the changes of dietary FA profiles. The difference of the diet between *P. elongatus* known to be more omnivorous (MARSHALL, 1973: COTONNEC *et al.*, 2001) and the two other species could explain this result. However, the study of the distribution of EPA and DHA throughout the different lipid classes (i.e. phospholipids, triacylglycerols and wax esters) in these copepod species could also be an interesting way to explain the differences of variations of EPA to DHA ratio observed in our work. FRASER *et al.* (1989a) showed that EPA and DHA are mainly located (i) in the lipid reserves through the triacylglycerols (TAG) in *T. longicornis*, and (ii) in the cell membrane through the phospholipids in *P. elongatus*. That may explain the results obtained for the EPA to DHA ratio in our study.

The method used in our study shows that the nutritive pool of copepods is high dominated by the alga *Phaeocystis* sp. and by small amounts of diatoms, Cryptophytes and dinoflagellates during the phytoplankton spring bloom in the Eastern English Channel. Furthermore, the dietary FA composition changes throughout the phytoplankton spring bloom in the English Channel. Our results suggest that *T. longicornis* would be able to survive less efficiently than *P. elongatus* and *A. clausi* because their lipid reserves are highly affected by the temporal evolution of the dietary FA composition. The difference in diet (i.e. omnivorous or carnivorous) and selectivity are thought as being the major reasons for may be responsible of this result. Ultimately, the approach introduced in the present paper could be conveniently used to study the effect of the differential occurrence of diatoms and *Phaeocystis* in the Eastern English Channel to higher trophic levels. Indeed, as recently demonstrated, the relative abundance of diatoms and *Phaeocystis* could be controlled by the North Atlantic Oscillation (NAO) *via* a differential competitivity for nutrients and light induced by turbulent and mixing processes (SEURONT and SOUISSI, 2002). Using the informations related to both the fatty acid composition of these different phytoplankton species (as well as their nutritive values) and the differential diets of *A. clausi*, *T. longicornis* and *P. elongatus*, we stress here that the model proposed by SEURONT and SOUISSI (2002) could efficiently be used to predict the trophodynamic status and the relative abundance of these three copepod species, that could be valuably used in future ecosystem models in this specific area. In addition, one must note that the study area is characterised by extremely high turbulence intensities (the turbulent energy dissipation rates have been shown to fluctuate from 10^{-4} to 10^{-6} $m^{-2} \cdot s^{-3}$ during a tidal cycle; SEURONT, 1999: SEURONT *et al.*, 2002). Now, considering the importance of turbulence in the predator-prey encounter and ingestion rates as a function of both the abundance and the size spectrum of the phytoplankton preys (SEURONT, 2001: SEURONT *et al.*, 2001), the present study could be used as a first step in future attempts of understanding the potential effects of physically induced differential grazing rates on zooplankton trophodynamics, and ultimately population dynamics *via* egg production rates.

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The activity of double diffusive convection investigated through the density ratio distribution in the Mixed Water Region (MWR) off Joban-Kashima and Sanriku Coasts to the north-east of Honshu, Japan

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Abstract : The activity of double diffusive convection in the Mixed Water Region (MWR) off Joban-Kashima and Sanriku Coast is investigated by using CTD data obtained from 1996 to 2000 in September or October. More than 60% of fluid column down to 500db (σ_θ is almost above 27.0) are unstably stratified to double diffusive convection. However, the activity of double diffusive convection differs year by year, namely, in 1998 and 2000, double diffusive convection is active, but not in 1996, 1997 and 1999. Our results indicate that active double diffusive convection should occur intermittently in MWR year by year. In years when double diffusive convection is active, $\sigma_\theta = 26.8$ surface which characterize the North Pacific Intermediate Water (NPIW) is sandwiched by the salt finger layers above and diffusive convection layers below. This suggests that double diffusive convection should modify a source water of NPIW originated at the further north region of MWR while its southward extension.

Keywords : *double diffusive convection, salt finger, diffusive convection, density ratio, Turner angle, modification of water mass, NPIW*

1. Introduction

In the area where surface evaporation exceeds precipitation (this area usually corresponds to the subtropical gyre, see figure 2 by SCHMITT, 1994), warm and salty layer usually lies above underlying cold and fresh layer with the net stratification being stable. In this case, salt finger convection should occur because of faster diffusion of heat than salt. On the other hand, oscillatory diffusive convection should occur in the lower layer in the sub-polar region where warm and salty layers frequently exists under cold and fresh water. These two convections are called as double diffusive convection (e.g. TURNER, 1973). The activity of double diffusive convection is well described by the density ratio or the TURNER angle defined as,

$$\text{Density Radio } R_\rho = \frac{\alpha\overline{\theta_z}}{\beta\overline{S_z}}$$

$$\text{Turner Angle } Tu = \tan^{-1}\left(\frac{R_\rho+1}{R_\rho-1}\right), \qquad (1)$$

where $\overline{\theta_z}$ and $\overline{S_z}$ are mean vertical gradients of potential temperature and salinity, respectively. $\alpha = \frac{1}{\rho}\frac{\partial\rho}{\partial\theta}$, $\beta = \frac{1}{\rho}\frac{\partial\rho}{\partial S}$ are the thermal expansion and haline contraction coefficients, respectively. When R_ρ is larger than 1 (Turner angle ranges between 45° and 90°), salt finger convection occurs. When R_ρ is ranged between 1 and 2, convection is so active that salt and heat are efficiently transported downwards, but the downward transport of density due to salt exceeds than that of heat eventually results in the intensification of net density gradient. As for diffusive convection, R_ρ should be ranged between 1 and 0 (TURNER angle between $-45°$ and $-90°$), and the activity of convection is also intensified as R_ρ becomes unity, and the

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net density gradient is also intensified. This curious behavior of double diffusive convection has a marked contrast to turbulent mechanical mixing in which stratification is eventually weakened or destroyed. Therefore, double diffusive convection has a potential to modify the water mass properties in the ocean in a different manner from that due to mechanical mixing.

In the region off Joban-Kashima and Sanriku coast, the Kuroshio and Oyashio directly contact each other. The Kuroshio and Oyashio Waters show a distinct contrast in water properties as characterized by relatively warm and salty Kuroshio and cold and fresh Oyashio waters. These two water masses are often intruded each other showing complicated fine and microstructures favorable for the onset of double diffusive convection (e.g. NAGASAKA *et al.*, 1995). Then, double diffusive convection should play a significant role in modification of water masses in this region. This region, called as the Mixed Water Region (MWR), has gathered attentions of physical oceanographers because the source water of North Pacific Intermediate Water (NPIW), having salinity value ranged 33.3PSU～33.4PSU and potential density is $\sigma_\theta=26.65$, should be modified to obtain its characteristics (33.8PSU～34.1PSU and $\sigma_\theta=26.8$) by some mixing processes in this region (TALLEY, 1993; TALLEY *et al.*, 1995). TALLEY and YUN (2001) proposed that cabbeling and double diffusive convection could explain the total increment of density ($\Delta\sigma_\theta=0.15$). They used a simple T-S diagram analysis, and concluded that $\Delta\sigma_\theta=0.07$ is increased by cabbeling and the rest by double diffusive convection. On the other hand, INOUE *et al.* (2003) investigated these mixing processes in more detail by using neutral surface analysis, and concluded that the total increments of density by cabbeling and double diffusive convection are almost the same and is about $\Delta\sigma_\theta=0.03$, respectively. This value is almost half of that proposed by TALLEY and YUN (2001). Thus, the role of double diffusive convection in the MWR is still undetermined. This might be due to the lack of detailed knowledge on the activity of double diffusive convection in MWR.

In the present study, we try to investigate the activity of double diffusive convection in MWR off Joban-Kashima and Sanriku Coasts mainly through the statistical analysis using histogram plots of R_ρ (Tu) at various density surfaces. The data are described in section 2. The histogram and T-S diagram analysis are presented in section 3. Summary and discussion are given in section 4.

Table 1 Observations

Date	Instruments
15Oct. －17Oct. 1996	CTD, XBT
20Oct. －22Oct. 1997	CTD, XCTD
10Sep. －13Sep. 1998	CTD, XCTD
10Sept. －13Sep. 1999	CTD
10Sep. －12Sep. 2000	CTD

2. The data

The Research and Training Vessel Shinyo-Maru, Tokyo University of Fisheries is used to occupy the stations off Joban-Kashima and Sanriku Coasts located to the northeastern part of Honshu, Japan. All the observations are summarized in Table 1. Neil Brown Mark III CTD is used to detect oceanic structures down to 500db where σ_θ almost exceeds 26.8. Temperature and conductivity data are matched by using recursive filter to reduce the unwanted spikes. The remnant spikes or density inversions, which are not completely removed by this filter, are removed by eye. Salinities are calibrated with salinity measurements of bottle sampled salinities. These data are averaged to 1db intervals, and then running averaged over 11db bin. To obtain R_ρ defined in equation (1), the least square fit over 11db data is adapted to obtain temperature and salinity gradients. α and β are calculated from temperature and salinity data at a centered depth of 11db data bin by using EOS80. Tu is then calculated by using equation (1). An example of vertical profile of Tu obtained in October 1998 is shown in Fig. 1. Strong salt fingering (Circled, $1<R_\rho<2$) and diffusive convection layers (Squared, $0.5<R_\rho<1$) are piled up alternatively in the vertical showing interleaving layers originated from the Kuroshio and Oyashio Waters, and the strong mixing events are anticipated due to double diffusion. In the following analysis, Tu is divided at an one degree interval from $-90°$ to $90°$. The number of

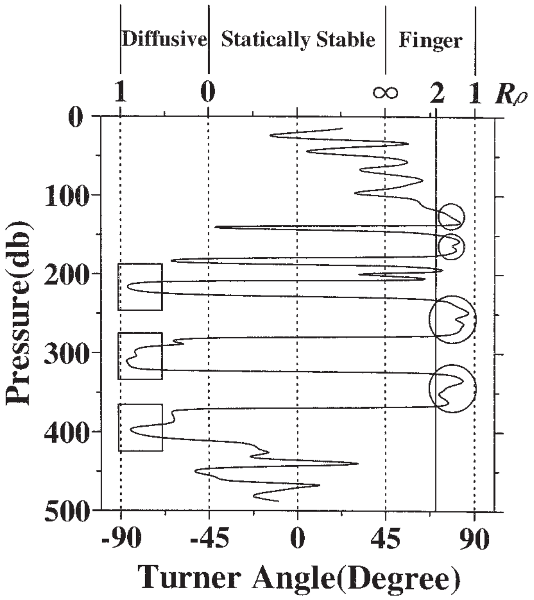


Fig. 1 Vertical profile of TURNER Angle in October 1998. TURNER Angle is shown at a lower horizontal coordinate, and corresponding density ratio R_ρ is at upper one. Diffusive ($-90° < Tu < -45°$, $0 < R_\rho < 1$), statically stable($-45° < Tu < 45°$, R_ρ : negative) and salt finger($45° < Tu < 90°$, $1 < R_\rho < \infty$) regimes are shown on top. A vertical solid line shows the boundary where $R_\rho = 2$ which separates the higher activity salt finger region($1 < R_\rho < 2$) from the lower one. Circled areas show the region for active salt finger, and squared ones for active diffusive convection.

Tu which falls into each one degree bin is counted, and is divided by the total data number to obtain the occurrence frequency.

3. Histogram and T-S diagram analysis

Histograms of $R_\rho(Tu)$ obtained from each observation are shown in Fig. 2 together with station plots. In each year, more than 60% water columns are unstably stratified to double diffusive convection, and in 1996, 1997 and 1999, modes of occurrence frequencies of R_ρ are found in the salt finger convection regime, but the value is about 4 suggesting that salt finger convection should occurs but is weak. On the other hand, in 1998 and 2000, we can found modes in both salt finger and diffusive convection regimes. The modes in salt finger regime are less than 2 in both years, and especially in 2000, a sharp peak exists near R_ρ is unity. This suggests that salt finger convection is so active in both years. The modes in diffusive regime are also near R_ρ unity suggesting diffusive convection is also active in these years.

Thus, the activity of double diffusive convection differs in each year. Then, we compare the histograms in 1997 and 1998 in more detail by plotting histograms at each σ_θ layer from $\sigma_\theta = 26.0$ to 27.0 at 0.1 σ_θ interval (Fig. 3a and 3b). Note that the occurrence frequency is calculated by dividing the total data number of each *Tu* within each layer (this number usually

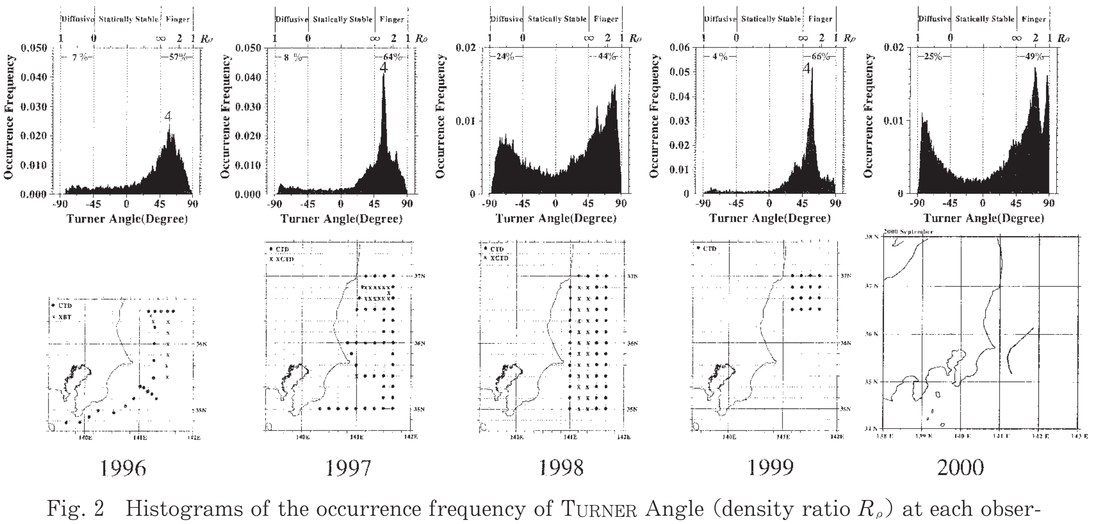


Fig. 2 Histograms of the occurrence frequency of TURNER Angle (density ratio R_ρ) at each observation with occupied stations plotted underneath.

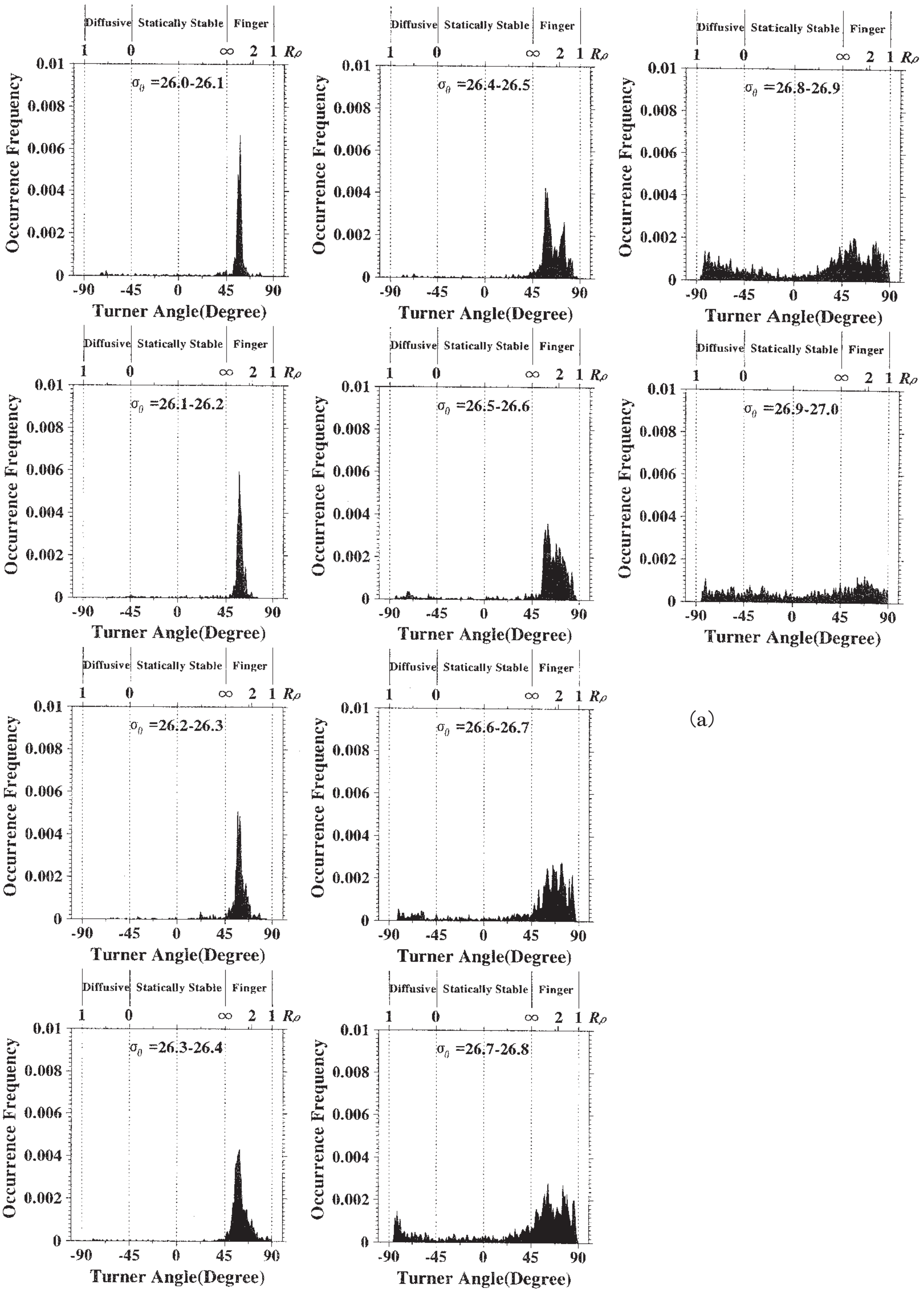
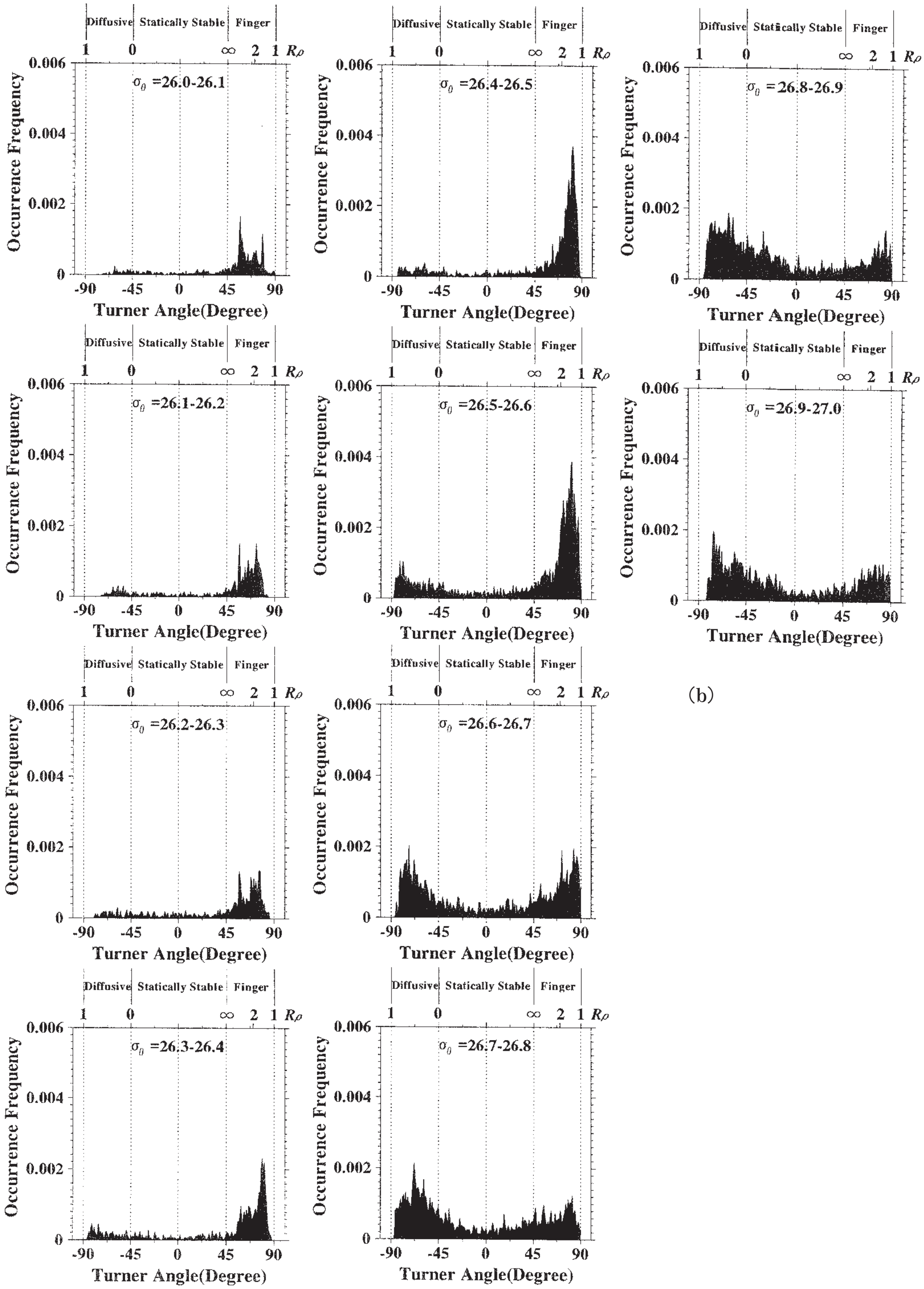


Fig. 3 Histograms of the occurrence frequency of TURNER Angle (density ratio R_ρ) at each potential density surface in (a) 1997 and (b) 1998.


Diffusive
Statically Stable
Finger
1
0
∞
2
1
R_ρ
Occurrence Frequency
0.006
0.004
0.002
0
-90
-45
0
45
90
Turner Angle(Degree)
σ_θ =26.0-26.1
σ_θ =26.1-26.2
σ_θ =26.2-26.3
σ_θ =26.3-26.4
σ_θ =26.4-26.5
σ_θ =26.5-26.6
σ_θ =26.6-26.7
σ_θ =26.7-26.8
σ_θ =26.8-26.9
σ_θ =26.9-27.0

(b)

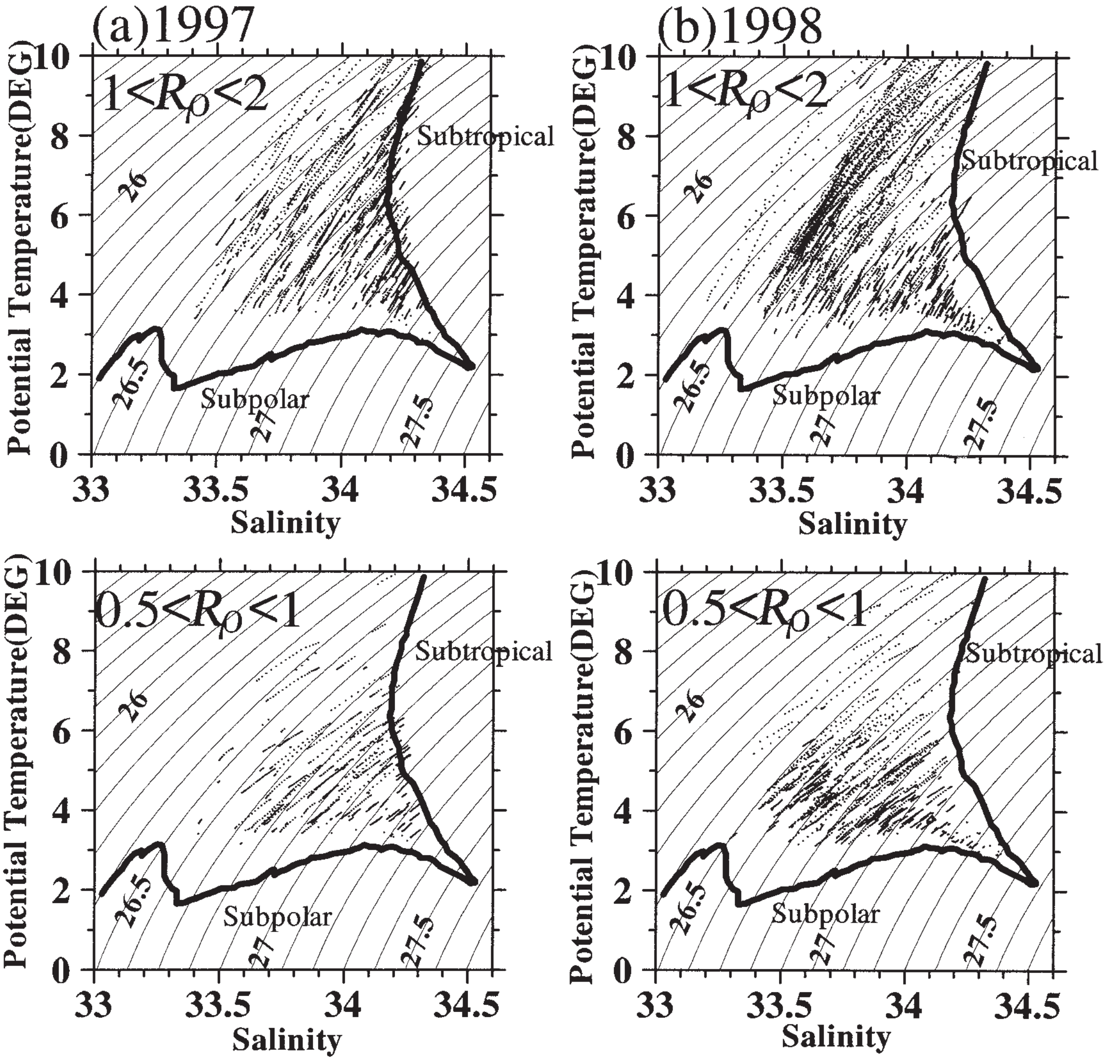


Fig. 4 T-S diagrams in (a) 1997 and (b) 1998. In upper two panels, conditionally sampled data which R_ρ distributed between 1 and 2 are plotted, and that between 0.5 and 2 in lower two panels.

differs between each layer) with the total data number of each observation. In 1997, a mode is clearly defined between $\sigma_\theta=26.0$ and 26.6 layers in the salt finger regime. $R_\rho(Tu)$ of this mode is 4.3(58 degree) and is almost kept constant down to $\sigma_\theta=26.9$ surface, but its height diminishes. On the other hand, in the layer between $\sigma_\theta=26.4$ and 26.5, there appears another mode at $R_\rho=1.7(Tu=75\text{degree})$. This mode is not clearly defined in the layers below, but exists down to $\sigma_\theta=26.9$ surface without changing its height. The heights of these two modes are almost comparable down to $\sigma_\theta=26.9$ surface. Therefore, in 1997, salt finger convection should exist, but is weak in the whole water columns as was seen in Fig. 2. The mode in the diffusive regime is not clearly defined, but exists in the layers below $\sigma_\theta=26.6$ surface.

In 1998, in the layers between $\sigma_\theta=26.0$ and 26.1, two modes exist at $R_\rho=5$ ($Tu=57$degree) and $R_\rho=1.5$ ($Tu=78$degree). The mode at a large value of R_ρ becomes not clear as σ_θ increases, but not so for that at smaller value of R_ρ. This latter mode forms a sharp pointed peak in the layers between $\sigma_\theta=26.3$ and 26.6, and R_ρ decreases its value slightly from $R_\rho=1.48$(Tu=79degree) to $R_\rho=1.27$(Tu=81 degree). Below this layer, the mode in the salt finger regime becomes less distinct, but that in the diffusive regime becomes clearly defined. The mode value in the layers between $\sigma_\theta=26.6$ and 26.7 is $R_\rho=0.42$ (Tu=−68degree) and that $\sigma_\theta=26.9$ and 27.0 is $R_\rho=0.6$ (Tu=−76degree), respectively. Therefore, salt finger convection should be active in the upper layers above $\sigma_\theta=26.7$ and 26.8 layers, and diffusive convection should be active below this layer. The same histogram plots were also done in 2000 observation (not shown here), and results support this conclusion.

We can see the same features in the T-S diagrams obtained in 1997 and 1998 in Fig. 4. In these figures, conditionally sampled data ($1<R_\rho<2$: active salt finger, $0.5<R_\rho<1$: active diffusive convection) are plotted together with typical water masses observed off Joban-Kashima and Sanriku Coast defined by TALLEY and YUN (2001). In 1997, the active salt finger layers are equally distributed over the wide range of σ_θ, and the active diffusive convection layers distribute mainly below $\sigma_\theta=26.5$. In 1998, however, the active salt finger layers also distribute in the same manner as in 1997, but, concentrates above $\sigma_\theta=26.7$ layer. The distribution pattern of active diffusive convection layers are almost same as in 1997, but are shifted towards the subtropical water mass.

4. Summary and discussion

We have investigated the activity of double diffusive convection in Mixed Water Region (MWR) off Joban-Kashima and Sanriku Coast where double diffusive convection should play a role in modification of the source water of North Pacific Intermediate Water (NPIW). CTD data obtained from 1996 to 2000 in September or October are analyzed by histogram plotting of occurrence frequency of density ratio R_ρ which can indicate the activity of double diffusive convection. We can summarize the main results as follows:

(1) More than 60% fluid column down to 500db (σ_θ is almost above 27.0) unstably stratified to double diffusive convection. The activity of double diffusive convection differs year by year. In 1996, 1997 and 1999, the mode value of R_ρ is greater than 4 suggesting salt finger convection is not active. We did not find the modes in diffusive convection regime in these years. In 1998, and 2000, however, the distinct modes were found in both salt finger and diffusive convection regimes. The mode values of R_ρ in salt finger convection in both years are less than 2, and those in diffusive convection regime is near unity suggesting salt finger and diffusive convections are active in these years.

(2) In years when double diffusive convection is active, salt finger convection prevails above $\sigma_\theta=26.7$ and 26.8 layers, and diffusive convection does below this layers.

The first result only indicates the year-to-year variation in the activity of double diffusive convection at the same season. There is a possibility that relatively short-term variation should exists in the activity of double diffusive convection. In fact, NAGASAKA *et al.* (1995) observed 2–3 days variation in the intensity of interleaving layers (several kilometer scales) possibly caused by double diffusive convection. Unfortunately, their observations were done by XBT, and no histogram analysis was made. However, the density ratio may change drastically according as the disappearance of interleaving layers. This point should be checked by the intense XCTD observation or long-term CTD Yo-yo/Tow-yo observation in future.

The latter result was also obtained by TALLEY and YUN (2001). As was mentioned in the introduction, they concluded that the half of density increment needed for the formation of NPIW is achieved by the efficient transports of density by double diffusive convection. Our results will partly support their result, but also indicate that this efficient mixing process by double diffusive convection should occur intermittently in MWR year by year. In fact, T-S diagram in 1998 shifted towards subtropical waters, but not so in 1997. This may indicate the intensification of southward intrusion of subarctic water into NPIW in 1998 and 2000 and the possibility of the efficient formation of NPIW in these years. The reason for this intermittency is not clear at present, but may be due to the southward extension of subarctic gyre relating to the wintertime wind condition in the Subarctic Region.

The existence of double diffusive convection in MWR has been anticipated by some authors (e.g. NAGASAKA *et al.*, 1995, YOSHIDA *et al.*, 1985), and may be confirmed by the present analysis. This convection should play a role in the modification of NPIW, but some other authors (e.g., YASUDA 1997) proposed a model in which isopycnal mixing is essential to the formation of NPIW. In their model, a source water of NPIW has already acquired its density at its formation site, and then achieves its minimum salinity through the mixing along isopycnal surface in MWR. Our results, however, also suggest that even if active double diffusive convection does not exist, slow vertical mixing due to salt finger would be present to transport salt and heat form overlying Kuroshio (Subtropic) Water to underneath Oyashio (maybe a source of NPIW or Subarctic) Water, and as a result, sufficient salt is acquired to form NPIW. In this case, the density increment due to salt finger should be negligible. This last discussion is so speculative and controversial one, and should be investigated in further detail in future.

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資　料

第 41 巻第 1 号掲載欧文論文要旨

荒川　久幸　小西　晶子　山崎　紗衣子　森永　勤：三宅島雄山噴火後の周辺海域の濁りの分布

　三宅島の雄山火山噴火活動に伴う漁場環境への影響調査の一環として，島周辺海域の濁りの分布について濁度，SS，強熱減量および粒径分布を，東京水産大学研究練習船海鷹丸へ乗船して調べた。調査期間は雄山噴火から 3－4 ヵ月経過後の2000年10月17–20日および11月17–19日である。その結果，10月では島の東で，11月では北西において濁度（光束消散係数）0.35–0.54 m^{-1}の高濁度層がそれぞれ60–90m深の密度躍層付近に観測された。また，高濁度水のSS濃度は10月および11月でそれぞれ0.82mg/lおよび0.71mg/lの最大値を示した。濁度（Y）とSS（X）との関係は，Y＝0.32X＋0.14,（r^2＝0.42)である。さらに，高濁度水の懸濁態無機濃度は10月で0.52mg/l, 11月で0.41mg/lと著しく高く，これらを懸濁態無機物の割合から見ると，前者は63.4%，後者は57.7%にそれぞれ相当する。高濁度水（11月Stn.3，75m深）の粒径分布は同測点の表層水に比べ，粒径8–14（mの範囲で卓越した。以上のように高濁度水は密度躍層付近に見られ，主に無機懸濁粒子を多量に含有することから，三宅島に由来するものと考えられる。(*Department of Ocean Sciences, Tokyo University of Fisheries, Konan 4–5–7, Minato-Ku, Tokyo, 108–8477 Japan）

G. Cotonnec[1*], L. Seuront[2], G. Thoumelin[3], L. Fraga-Lago[4]：*Phaeocystis* sp. の春季ブルーム期におけるイギリス海峡東部の*Acartia clausi, Psudocalanus elongatus*および*Temora longicornis*の脂肪酸組成と餌との関係

　イギリス海峡東部において1998年の春季ブルーム開始時と終了時に各 1 回実施された 3 時間毎のラグランジ的調査に基づき，粒状有機物（POM）およびカイアシ類の優占種（*Acartia clausi, Temora longicornis, Pseudocalanus elongatus*）の脂肪酸組成を調べた。植物プランクトンの現存量は，初めの調査時の方が後よりも高かった。そのとき，*Phaeocystis* sp. が優先しており（全多様度の約90%）珪藻は低い割合であった。クリプト藻類と渦鞭毛藻類は常に低いレベル（＜１%）であった。三種の脂肪酸（14：0，16：0，18：0）がPOMの中で卓越し全脂肪酸の75%ないし96%を占めていた。不飽和脂肪酸は主として必須脂肪酸（ω 3 およびω 6 脂肪酸）で構成されていた。本研究における主たる発見は，不飽和脂肪酸，とくに20：5ω 3（EPA）および22：6ω 3（DHA）がPOMに比較してカイアシ類に非常に高い割合で含まれていたことである。詳しくいうと，18：1ω 9 の割合が高いという特徴を持つ*P. elongatus*と比べて*T. longicornis*と*A. clausi*では脂肪の組成が類似していて20：5ω 3 および22：6ω 3 の含量が高かった。これは，*P. elongatus*の肉食性および*T. longicornis*と*A. clausi*の雑食性を示唆する。POMでは脂肪酸組成の変化が全脂肪酸含量の減少をもたらしていたが，調査した 3 種の生物では脂肪酸組成の変化は見いだされなかった。しかし，*T. longicornis*は餌の脂肪酸組成の変化に他の 2 種に比べるとより敏感であった。最後に，産生されるEPA-DHA比の種特異性は，脂肪酸の動員がそれぞれの種で異なる様式で起こっていたことを示唆することを強調する。([1]MREN, Université de Littoral-Côte d'Opale, CNRS UMR 8013 ELICO, 32 avenue Foch, Wimereux F–62930, France. [2]Ecosystem Complexity Research Group, Station Marine de Wimereux, CNRS UMR 8013 Elico, Universite des Sciences et Technologies de Lille, 28 avenue Foch, F–62930 Wimereux, France. [3]LCAM, Université de Lille I, UMR 8013 ELICO, Bât C8, Villeneuve d'Ascq 59655, France. [4]MREN, Université de Littoral-Cote d'Opale, UMR 8013 Elico, 32 avenue Foch, Wimereux F–62930, France. ＊Corresponding author:Tel:33–321996432/Fax:33–321996401/E-mail:gwen@mren2.univ-littoral.fr）

吉田　次郎：密度比分布を通して調べた，常磐鹿島沖合いから三陸沖合にかけての二重拡散対流の活発度

　常磐鹿島灘から三陸沖合海域の混合海域において，1996年から2000年にかけてCTDを用いた観測を行い，二重拡散対流のアクティビティを調べた。その結果，500db（σ_θ＜27.0)深以浅では，60%以上の高い割合で二重拡散対流が活発であることが示されたが，その度合いは年によってかなりの違いがあることが示された。このことは，二重拡散対流が間欠的に起こっていることを示唆するものである。二重拡散対流が活発な年には，北太平洋中層水（NPIW）を特徴づけるσ_θ＝26.8層は，ソルトフィンガー（上部)，diffusive型対流（下部）によって挟まれており，二重拡散対流がNPIWの変質過程を担っている可能性が示唆された。(*Department of Ocean Sciences, Tokyo University of Fisheries, Konan 4–5–7, Minato-Ku, Tokyo, 108–8477, Japan）

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Société franco-japonaise d'océanographie, Tokyo

学 会 記 事

1. 2003年3月4日(火)幹事会開催　東京水産大学海洋環境棟会議室において第1回幹事会が開かれた。総会，学術研究発表会および評議員会などの日程を決めた。

2. 2003年3月5日〜3月20日　Eメールにより，評議員から推薦のあった学会賞及び論文賞受賞候補者について審議の結果　前田昌調会員(宮崎大学)を学会賞受賞候補者，堀本奈穂会員(東京水産大学)を論文賞受賞候補者と決定し，会長に報告した。

3. 19期学術会議会員の候補者及び推薦人，推薦予備者について谷口　旭会員(候補者)山口征矢会員(推薦人)長島秀樹会員(推薦予備者)をそれぞれ選出した。

4. 新入会員

氏　名	所属・住所等	紹介者
大澤高浩	千葉大学環境リモートセンシング研究センター 〒236-0022　千葉市稲毛区弥生町1-33	森永　勤

5. 退会(逝去者含)
久保田　穣

6. 受贈図書
広島日仏協会報　No. 157，158
養殖研ニュース　No. 51，52
なつしま　No. 205，207，208
東海大学紀要　28輯
農業工学研究所ニュース(24，25)
NII News　No. 15，16
NTT R&D　Vol. 51(10，11，12)　52(1，2，3)
養殖研ニュース　No. 52
勇魚　No.27
水産総合研究センター　No. 6
Journal of Ocean University of Qingdao Vol. 2(1)
Journal of the Korean Society of Oceanography Vol. 38(1)
Ocean and Polar Research Vol. 37(3, 4)
青島海洋大学学報(自然科学報)　第32巻(5，6)
海洋水産研究　Vol. 23(3，4)，24(1)

日仏海洋学会会則

昭和35年４月７日　制定
昭和60年４月27日　改正
平成４年６月１日　改正

第１条　本会は日仏海洋学会と称する。

第２条　本会の目的は日仏海洋および水産学者の連絡を密にし，両国のこの分野の科学の協力を促進するものとする。

第３条　上記の目的を実現するため本会は次の事業を行なう。

⑴　講演会の開催
⑵　両国の海洋学および水産学に関する著書，論文等の相互の翻訳，出版および普及
⑶　両国の海洋，水産機器の技術の導入および普及
⑷　日仏海洋，水産学者共同の研究およびその成果の論文，映画などによる発表
⑸　両国間の学者の交流促進
⑹　日仏海洋，水産学者の相互の親睦のために集会を開くこと
⑺　会報の発行および出版
⑻　その他本会の目的を達するために必要な事業

第４条　本会には，海洋，水産学の分野に応じて分科会を設けることができる。

分科会は評議員会の決議によって作るものとする。

第５条　本会の事務所は日仏会館（〒150　東京都渋谷区恵比寿３丁目９番25号）に置く。

第６条　本会に地方支部を置くことができる。

第７条　本会会員は本会の目的に賛成し，所定の会費を納めるものとする。

会員は正会員，学生会員および賛助会員とする。

第８条　正会員会費は年額6,000円，学生会員会費は年額4,000円，賛助会員会費は一口年額10,000円とする。

第９条　本会は評議員会によって運営される。

評議員の定数は50名とし，正会員の投票によって選出される。選挙事務は別に定める選出規定による。

会長は評議員会の同意を得て５名までの評議員を追加することができる。

評議員の任期は２年とする。ただし，重任を妨げない。

第10条　評議員はその内より次の役員を選ぶ。ただし，監事は評議員以外からも選ぶことができる。

会長　１名，副会長　２名，幹事　10名，
監事　２名

役員の任期は２年とする。ただし，重任を妨げない。

役員の選出方法は別に定める選出規定による。

第11条　本会に名誉会長，顧問および名誉会員を置くことができる。名誉会長，顧問および名誉会員は評議員会の決議により会長これを委嘱または推薦する。

日仏会館フランス人学長を本会の名誉会長に推薦する。

第12条　会長は本会を代表し，総会および評議員会の議長となる。会長事故あるときは副会長がこれに代わる。

会長，副会長および幹事は幹事会を構成し，本会の庶務，会計，編集，研究発表，渉外などの会務を行う。

監事は本会の会計を監督する。

第13条　年に１回総会を開く。総会では評議員会の報告を聞き，会の重要問題を審議する。会員は委任状または通信によって決議に参加することができる。

会長は必要に応じて評議員会の決議を経て臨時総会を招集することができる。

第14条　本会則の変更は総会の決議による。

日仏海洋学会評議員・役員選出規定

1．本規定は日仏海洋学会会則第９条および第10条に基づき本会の評議員および役員の選出方法について規定するものである。

2．評議員は正会員の50名連記無記名投票により選出する。

評議員の選挙事務は庶務幹事が行う。ただし，開票にあたっては本会役員以外の会員２名に立会人を委嘱するものとする。

3．会長は評議員の単記無記名投票により選出する。

会員選挙の事務は庶務幹事が行う。ただし，開票にあたっては本会役員以外の会員２名に立会人を委嘱するものとする。

4．副会長，幹事，および監事は，会長の推薦に基づき評議員会で決定する。

5．本規定の改正は評議員会の議を経て行う。

日仏海洋学会賞規定

1． 日仏海洋学会賞（以下「学会賞」という）および日仏海洋学会論文賞（以下「論文賞」という）を本学会に設ける。学会賞は本学会員で，海洋学および水産学において顕著な学術業績を挙げた者のなかから，以下に述べる選考を経て選ばれた者に授ける。

論文賞は若手研究者や大学院生を筆頭著者とする論文を対象とする。原則として選考年度を含む３年（暦年）の間に，本学会誌に発表された論文のなかから，優秀な論文２編以内を選び，その著者（共著者を含む）に，以下に述べる選考を経て授ける。

2． 学会賞および論文賞候補者を選考するため学会賞および論文賞受賞候補者推薦委員会（以下「委員会」という）を設ける。

3． 委員会の委員は13名とする。

委員は毎年春の評議員会で選出し，委員長は委員の互選により定める。

会長は委員会が必要と認めた場合，評議員の同意を得て２名まで委員を追加委嘱することができる。

4． 委員会は学会賞受賞候補者１件および論文賞受賞候補者２件以内を選び，12月末までに選定理由書をつけて会長に報告する。

5． 会長は委員会が推薦した各候補者につき無記名投票の形式により評議員会にはかる。

投票数は評議員総数の３分の２以上を必要とし，有効投票のうち４分の３以上の賛成がある場合，これらを各賞受賞者として決定する。

6． 授賞式は翌年春の総会において行い，学会賞受賞者には賞状およびメダルを，論文賞受賞者には賞状をそれぞれ贈呈する。

7． 本規定の改正は評議員会の議を経て行う。

覚書

1　委員は各専門分野から選出されるように十分配慮すること。

2　受賞者は原則として順次各専門分野にわたるよう十分配慮すること。

3　平成14年度より適用する。

日仏海洋学会誌「うみ」投稿規定

1. 「うみ」（欧文誌名 La mer）は日仏海洋学会の機関誌として，和文または欧文により，海洋学および水産学ならびにそれらの関連分野の研究成果を発表する学術雑誌であり，同時に研究者間の情報交換の役割をもつことを目的としている。

2. 「うみ」は，原則として年4回発行され，投稿（依頼原稿を含む）による原著論文，原著短報，総説，学術資料，書評その他を，編集委員会の審査により掲載する。これらの著作権は日仏海洋学会に帰属する。

3. 投稿は，日仏海洋学会会員，および日仏海洋学会正会員に準ずる非会員からとする。共著者に会員を含む場合は会員からの投稿とみなす。

4. 用語は日，仏，英3か国語のいずれかとする。ただし，表および図説明の用語は仏文または英文に限る。原著論文には約200語の英文または仏文の要旨を別紙として必ず添える。なお，欧文論文には約500字の和文要旨も添える。ただし，日本語圏外からの投稿の和文要旨については編集委員会の責任とする。

5. 原稿はすべてワードプロセッサを用いて作成し，本文・原図とも2通（正，副各1通）ずつとする。副本は複写でよい。本文原稿はすべてA4判とし，白紙にダブル・スペース（和文ワープロでは相当間隔）で記入する。表原稿および図の説明原稿は本文原稿とは別紙とする。

6. 投稿原稿の体裁形式は「うみ」最近号掲載論文のそれに従う。著者名は略記しない。記号略号の表記は編集委員会の基準に従う。引用文献の表示形式は，雑誌論文，単行本分載論文（単行本の一部引用も含む），単行本などの別による基準に従う。

7. 原図は版下用として鮮明で，縮尺（版幅または1/2版幅）に耐えられるものとする。

8. 初校に限り著者の校正を受ける。

9. 会員に対しては7印刷ページまでの掲載を無料とする。会員の投稿で上記限度を超える分および非会員投稿（依頼原稿を除く）の印刷実費はすべて著者負担（10,000円/ページ）とする。ただし，カラー印刷を含む場合などには，別に所定の費用を著者（会員，非会員とも）負担とする。

10. すべての投稿原稿について，1編あたり別刷り50部を無料で請求できる。50部を超える分は請求により50部単位で有料で作製される。別刷り請求用紙は初稿校正と同時に送付される。

11. 原稿の送り先は下記の通りとする。なお著者（共著の場合は代表者）連絡先のe-mailアドレス並びにFAX番号を付けることとする。

〒108-8477　港区港南4-5-7　東京水産大学海洋環境学科（吉田　次郎気付）
日仏海洋学会編集委員会
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執筆要領

1. 原稿

⑴ 和文原稿の場合：ワードプロセッサを使用し，A4判の用紙におよそ横30字，縦25行を目安に作成すること。

⑵ 欧文原稿の場合：ワードプロセッサを使用し，A4判の用紙にダブルスペース25行でタイプし，十分な英文添削または仏文添削を経て提出すること。

⑶ 和文原稿，欧文原稿いずれの場合も，要旨，表原稿および図版説明原稿はそれぞれ本文原稿とは別紙とする。

⑷ 最終原稿提出の際に，印刷原稿とともに原稿，表，図版が保存されたフロッピーディスク，CD-R/RW，MO等での提出を依頼する。この場合，原稿はMicrosoft WORD，Just System一太郎，PDFの原稿のみに限る。また，表，図版はこれら原稿ファイルの中に取り込むか，bmp，jpg等の一般的な画像ファイルに保存したものに限る。なお，電子媒体は返却しない。

2. 論文記載の順序

⑴ 原著（和文原稿）：原稿の第1ページ目に表題，著者名，研究の行われた所属機関，所在地，郵便番号を和文と欧文で記載する。研究終了後所属機関が変わった場合は現所属機関も記載する。連絡先（共著の場合は連絡先

とする著者を明示する）の住所，電話番号，ファックス番号，E-mailアドレスも記す。最後にキーワード（4語以内），ランニングヘッドを英文で記載すること。第2ページ目に欧文要旨（欧文表題，著者名を含む）を200語以内で記す。本文は第3ページ目から，「緒言」「資料」「結果」「考察」「謝辞」「文献」「図版の説明」などの章立てあるいは項目順に記載する。基本的には最近号掲載論文の体裁形式を参考にして投稿原稿を作成すること。原稿には通しのページ番号を記入すること。

⑵　原著（欧文原稿）：原稿の第1ページ目に表題，著者名，研究の行われた所属機関，所在地，郵便番号を記載する。研究終了後所属機関が変わった場合は現所属機関も記載する。最後にキーワード（4語以内），ランニングヘッドを記載すること。第2ページ目に欧文要旨（欧文表題，著者名を含む）を200語以内で記す。本文は第3ページ目からとする。「Introduction」「Data」「Results」「Discussion」「Acknowledgement」「References」「Figure Caption」などの章立てで順に記載する。基本的には投稿原稿の体裁形式は最近号掲載論文を参考にして作成すること。最終ページに和文の表題，著者名，連絡先著者住所，電話番号，ファックス番号，E-mailアドレスおよび約500字以内の和文要旨を添える。原稿には通しのページ番号を記入すること。

⑶　原著短報，総説：和文ならびに欧文原稿とも原著論文に準ずる。

⑷　学術資料，書評：特に記載に関する規定はないが，すでに掲載されたものを参考にすること。

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原稿での活字は10.5pt～12ptを目安に設定し，英数字は半角フォントを用いること。学名はイタリック，和文原稿での動植物名はカタカナとすること。句読点は（。）および（，）とするが。文献リストでは（.）および（,）を用いること。章節の題目，謝辞，文献などの項目はボールドまたはゴシックとする。

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文献は本文および図表に引用されたものの全てを記載しなければならない。和文論文，欧文論文共に筆頭著者のアルファベット順（同一著者については，単著，共著の順とし，それぞれ発表年の古い順）にまとめ，以下の例に従って記載する。

⑴　論文の場合

有賀祐勝，前川行幸，横浜康継（1996）：下田湾におけるアラメ群落構造の経年変化.　うみ，**34**，45–52.

YANAGI, T., T. TAKAO and A. MORIMOTO (1997): Co-tidal and co-range charts in the South China Sea delived from satellite altimetry data. La mer, **35**, 85–93.

⑵　単行本分載論文（単行本の一部引用）の場合

村野正昭（1974）：あみ類と近低層プランクトン．海洋学講座10　海洋プランクトン（丸茂隆三編），東京大学出版会，東京，p. 111–128.

WYNNE, M. J. (1981): Phaeophyta: Morphology and classification. *In* The Biology of Seeweeds. LOBBAN, C. S. and M. J. WYNNE (eds.), Blackwell Science, Oxford, p. 52–85.

⑶　単行本の場合

柳　哲雄（1989）：沿岸海洋学―海の中でものはどう動くか―.　恒星社厚生閣，東京，154pp.

SVERDRUP, H. U., M. W. JOHNSON and R. H. FLEMING (1942): The Oceans: Their Physics, Chemistry and General Biology. Prentice-Hall, Englewood Cliffs, New York, 1087pp.

⑷　本文中での文献の引用

本文中での文献の引用方法はすでに発行された雑誌を参考にするが，基本的には次の形式に従う。

①Greve and Parsons(1977)
②(Avian and Sandrin, 1988),
③Yanagi *et al.*(1997)は……（3名以上の共著の場合）
④……示している（例えば，Yanagi *et al.*, 1997)（3名以上の共著の場合）

5.　図，表および写真

⑴　図，表および写真とその説明はすべて英文または仏文を用いる。

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原則としてSI単位を用いること。塩分は実用塩分単位（Practical Salinity Unit:psu またはPSU）を用いる場合は単位なしとする。

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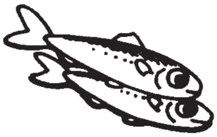

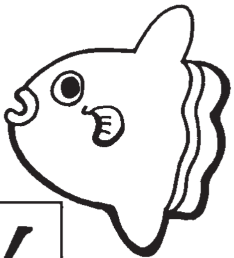

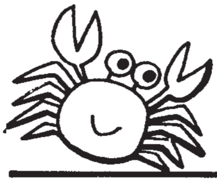

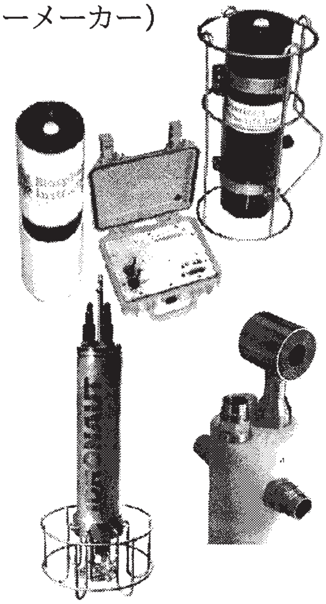

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