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昭和49年5月

日仏海洋学会

La Société franco-japonaise
d'océanographie
Tokyo, Japon
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The Food Effects of Three Unicellular Algae for Larval
Oyster Ostrea edulis L. in the Laboratory*

Keiji Takeda**

Abstract: The author carried out investigation to know about the growth of European flat oyster (Ostrea edulis L.) fed with three species of unicellular algae and the spat growth in open sea from July 7 to November 4, 1966.

Chaetoceros calcitrans f. pumilus of a marine centric diatom and Monochrysis lutheri of a marine Chrysophyta as foods for the oyster larvae were produced with Umebayashi’s modified PI solution, and Chlorella ellipsoidea of a freshwater green algae was produced with a simple medium containing some nutrients per one liter of freshwater (spring water) as follows: 50 mg-Na2HPO4, 12H2O, 100 mg-KNO₃, 6.5 mg-MnSO₄·6H₂O, 0.6 mg-MgSO₄·7H₂O, 5 mg-FeCl₃·6H₂O, 4 mg-Na₂EDTA, 2 ml of 5% Tris buffer solution of 7.4-7.5 in pH value.

Chaetoceros and Monochrysis cells were suitable as single food for larvae, but it seemed that the food effect of Chaetoceros cells for the increasing of shell length of larvae was a little better than that of Monochrysis cells. On the other hand, the larvae fed with Monochrysis cells attached on collectors in the smaller stage in shell length than those fed with Chaetoceros cells. And, in addition, the setting force (setting function) just after the larvae fed with Monochrysis cells attached on collectors was stronger than that of those fed with Chaetoceros cells.

Chlorella cells were eaten well by larvae, but could not be digested in the digestive organs. Therefore, the growth effect of larvae was not observed at all.

The survival rate of larvae in all vessels was 88.89% and more just before attaching on collectors. Perhaps this good survival rate might be brought about by the complete exchange of rearing water, test vessels and the washing of larvae with filtered seawater on cleaning just before feeding every morning.

After the larvae attached on collectors were kept quiet for several days in a big tank filled with seawater containing several ten-thousand cells per milliliter of mixed phytoplankton cells (Monochrysis and Chaetoceros), they were replaced from the tank to the shallow sea in Ashizaki Inlet for culture on July 24, 1966. And they grew to the oysters of 3 to 5 cm shell height on November 4 in the same year.

1. Introduction

There are many studies on the artificial spawning and collection of sea bivalves in Japan as shown in Table 1. The author also devoted himself exclusively to the studies on the artificial collection of a scallop and a European flat oyster, etc. in the laboratory. An European flat oyster (Ostrea edulis) is a well-known sea bivalve a lavigarous shell, and the new-born planktonic larvae are very big (185-190 μ shell height). Therefore, the mass rearing and collection of them in the commercial scale are not difficult.

This time, the author wishes to report on the growth of the oyster larvae fed with three unicellular algae in the laboratory.

2. Materials and methods

1. Species of phytoplanktons as food for larvae
   1) Chaetoceros calcitrans f. pumilus (a marine centric diatom)
   2) Monochrysis lutheri (a marine flagellata:
Table 1. Marine shells used for artificial spawning, rearing or collection of planktonic larvae in Japan.

<table>
<thead>
<tr>
<th>Species of marine shells</th>
<th>Names of workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crassostrea gigas</td>
<td>SATO et al. (1943)</td>
</tr>
<tr>
<td>Ostrea edulis</td>
<td>SATO et al. (1970-b, 1970-c)</td>
</tr>
<tr>
<td>Mysitis edulis</td>
<td>IWATA (1949)</td>
</tr>
<tr>
<td>Pinctada martensi</td>
<td>KOBAYASHI et al. (1952)</td>
</tr>
<tr>
<td>P. maxima</td>
<td>WADA (1942)</td>
</tr>
<tr>
<td>Pteria penguin</td>
<td>FUJITA et al. (1966, 1967), SHIOMITSU et al. (1968), YAMAGUCHI et al. (1960), YAMANAKA et al. (1970)</td>
</tr>
<tr>
<td>Patinopecten yessoensis</td>
<td>YAMAMOTO et al. (1943, 1950), SATO et al. (1970-d), TAKEDA (1970), TAKEDA et al. (1966)</td>
</tr>
<tr>
<td>Scapharca broughtonii</td>
<td>KANNO (1963), KANNO et al. (1963), ITO et al. (1967)</td>
</tr>
<tr>
<td>Tapes (Amygdalina) philippinarum</td>
<td>HATANAKA et al. (1943), IWATA (1948), SAGARA (1958)</td>
</tr>
<tr>
<td>Macrura sulcataria</td>
<td>IWATA (1948), SAGARA (1958)</td>
</tr>
<tr>
<td>Spisura s. s. chalinensis</td>
<td>KANNO (1965)</td>
</tr>
<tr>
<td>Halicopsis discus</td>
<td>SAGARA (1963), KANNO et al. (1963), KIKUCHI (1964)</td>
</tr>
<tr>
<td>Turbo cornutus</td>
<td>SATO et al. (1970-a), AYAMA et al. (1972-a, 1972-b)</td>
</tr>
<tr>
<td>Chrysophyta)</td>
<td></td>
</tr>
<tr>
<td>3) Chlorella ellipsoidea</td>
<td>(a freshwater green alga)</td>
</tr>
</tbody>
</table>

2. Food phytoplankton productions

Three species of phytoplanktons mentioned above were grown with globular flasks of 2.0 l in capacity under the conditions of 20.0–23.0°C of room temperature, 1.0 l/l/min in aeration volume and 3.0 klux in light intensity (National Hi-light 40 W white fluorescent lamp).

The culture medium for production of Chaetoceros and Monochrysis cells was Umebayashi’s modified PI solution (UMEBA YASHI, 1961), and that for production of Chlorella cells was the simple freshwater medium as follows:

- a) KNO₃ 100.0 mg
- b) Na₂HPO₄, 12H₂O 50.0 mg
- c) MnSO₄, 7H₂O 6.5 mg
- d) MgSO₄, 7H₂O 6.0 mg
- e) Na₂EDTA 4.0 mg
- f) FeCl₃, 6H₂O 5.0 mg

* Spring freshwater (1,000 ml) + (a, c, d, e) → (b, f) → heating (100°C) → cooling

3. Larvae rearing

Four round-shaped styrof vessels of 10 l in capacity used for the trial were filled with 5-liter of filtered seawater with 1,000 larvae per liter, and set under the light intensity of 80–200 lux in the culture room (19.0–23.0°C in temperature). For the rearing of larvae, about 100-bubble in aeration volume were sent to each vessel with a glass pipe of 3 mm in inside diameter. Also the larvae for these trials were individually hatched out in water of about 17°C in temperature.

The quantities (cells/ml) of phytoplankton cells per day as a single food fed to larvae were as follows:

1) Chaetoceros cells of 10,000 cells/ml/day were fed to the larvae in Vessel A, and Monochrysis cells of 10,000 cells/ml/day were fed to the larvae in Vessels B from the first to the last day of the trial.

2) Chlorella cells of 40,000 cells/ml/day were fed to the larvae in Vessels C and D from the first to the 4th day of the trial. But the author did not have the growth effect of Chlorella cells at all, therefore the cells were exchanged to Chaetoceros cells in Vessel C or Monochrysis cells in Vessel D from the 5th day of the trial.

But 10,000 or 40,000 cells/ml/day of each species of phytoplankton as food for larvae were equally divided in two and fed twice a day.

The seawater and each vessel for larvae rearing were completely renewed and the larvae
Table 2. Survival rate of planktonic larvae in each vessel till just before attaching on collectors.

<table>
<thead>
<tr>
<th>Test vessel</th>
<th>7th</th>
<th>14th</th>
<th>17th</th>
<th>19th</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100 %</td>
<td>100 %</td>
<td>94.84 %</td>
<td>—</td>
</tr>
<tr>
<td>B</td>
<td>100 %</td>
<td>100 %</td>
<td>93.07 %</td>
<td>—</td>
</tr>
<tr>
<td>C</td>
<td>100 %</td>
<td>100 %</td>
<td>—</td>
<td>88.89 %</td>
</tr>
<tr>
<td>D</td>
<td>100 %</td>
<td>100 %</td>
<td>—</td>
<td>90.65 %</td>
</tr>
</tbody>
</table>

The author found that the shell length of the larvae fed with Monochrysis cells in Vessel B was about 315 μ (262 ± 45.4 μ in mean shell length) and those fed with Chaetoceros cells in Vessel A was about 325 μ (276 ± 49.8 μ in mean shell length) just before settling on the collectors. The same difference was obtained in the trials of Vessels C and D.

3. Survival rate for planktonic larval stage (Table 2)

The survival rate of larvae in all vessels was 100 % from the beginning to the 14th day. But it dropped to 94.84 % in Vessel A, 93.07 % in Vessel B, 88.89 % in Vessel C and 90.65 % in Vessel D just before their setting on the collectors.

4. Discussion

Loosanoff et al. (1963) showed that Mono-
chrysis lutheri, Isochrysis galbana, Platymonas sp. and Dunaliella sp. are useful foods, and Monochrysis or Isochrysis is good as a single food for many kinds of sea bivalve larvae. They also said that the mixed food of these phytoplanktons has an excellent effect for the larvae growth in shell height. Davis et al. (1958) also attained the same results from their trials. And Walne (1965) reared oyster larvae (Ostrea edulis) using Isochrysis. On the other hand, Sato et al. (1970) reported that the food effect of Chaetoceros f. pumilus is better than that of Paeodactylum tricornutum for the growth in shell length in the planktonic stage of European flat oyster. The author also obtained that Chaetoceros cells are eaten well by small scallop larvae (110–150 μ in shell length) and Paeodactylum cells are effective as food for the larvae of about 160 μ and more shell length (Takeda, unpublished MS in 1966).

Today, the results from the present rearing trials using Chaetoceros f. pumilus, M. lutheri and C. ellipsoides cells cultured in the media as shown in "Materials and methods" are discussed as follows:

It seemed that the food effect (Vessel A) of Chaetoceros cells for the growth in shell length of larvae is a little better than that (Vessel B) of Monochrysis cells in the later half of the rearing. Namely, the shell length of the larvae fed with Monochrysis cells was about 315 μ (but 262 ± 45.4 μ in mean shell length) and that of those fed with Chaetoceros cells was about 325 μ (but 276 ± 49.8 μ in mean shell length) just before setting on the collectors (Fig. 1), and the same difference was observed in the rearing in Vessels C and D.

The feet of larvae fed with Monochrysis cells began to develop from the growing stage of about 270 μ in shell length, but those of larvae fed with chaetoceros cells began to develop from the growing stage of 285 μ in shell length. In addition, the force of setting on the collectors of the larvae fed with Chaetoceros cells was a little weaker than that of larvae fed with Monochrysis cells just after the setting on the collectors. Therefore, it was necessary to keep quiet the collectors for the larvae fed with Chaetoceros cells for several days after setting.

![Diagram](image)

Fig. 2. Growth of ark-shell larvae fed with 10^6 cells/ml/day of different phytoplanktons for the first seven days and fed with 2×10^4 cells/ml/day from the 8th day of rearing.

- 1: Mean shell length
- 2: Maximum shell length
- 3: Minimum shell length
- A: Growth of larvae fed with Monochrysis cells
- B: Those fed with Chaetoceros cells
- C: Those fed with Paeodactylum cells
- D: Those fed with Chlorella cells

The author could not find out the reason why such difference was brought about in the growing stage, for there was nothing about the analytical data on the nutritive value of phytoplanktons used in the present trials. But Chaetoceros was one of the useful foods like Monochrysis for the growth of oyster larvae from the view point of the increase of shell length.

On the other hand, Chlorella cells were not effective for the growth of larvae, for they could not digest these in their digestive organs, and the same fact was obtained in the author's recent trial on the growth of ark-shell larvae (Scapharca braughtonii) (Fig. 2) or scallop larvae (P. yessoensis) (Takeda, unpublished MS) fed with Chlorella cells. The author shows some results of the trial on the food effect of some kinds of phytoplanktons for ark-shell larvae as follows:

The ark-shell larvae of 93.6 μ in mean shell length fed with Chaetoceros cells showed growth of 143 μ in mean shell length (103 μ in minimum and 203 μ in maximum) (Fig. 2, A), and those fed with Monochrysis cells showed growth of
The Food Effects of Three Unicellular Algae for Larval Oyster

Fig. 3. Temperature and specific gravity of surface water at the culture place in Ashizaki Inlet for the hanging culture from the end of July to the end of October in 1966.

\*: specific gravity, \#: water temperature.

133 \( \mu \) in mean shell length (but 125 \( \mu \) in minimum and 176 \( \mu \) in maximum) (Fig. 2, B). But the food effects of Phaeodactylum and Chlorella for them were not obtained at all. Because Phaeodactylum cells were too big as food for ark-shell larvae of 93.6 \( \mu \) to 105 \( \mu \) in shell length, and Chlorella cells were not digested in their digestive organs (Fig. 2, C and D). However, it was seen that Chlorella cells (Lewin's or Gilliard's isolate) used in Davis et al.'s work (1958) were slightly effective as food for Venus Mercenaria larvae and not effective for Curassostrea virginica larvae. Therefore, we cannot use the sorts of Chlorella cells as food for the rearing of Ostrea edulis and Scapharca broughtonii larvae.

The survival rate of the larvae in the present rearing trials was 88.89 \% and more just before setting on the collectors in all vessels as shown in Table 2. Perhaps, such good survival rate might be brought about by the effect of the complete renewal of rearing water and rearing vessels or the effect of the washing of larvae with filtered seawater on the net of 110 x 110 \( \mu \) in mesh before feeding to them every day.

Lastly, the author explains about the treatments of the collectors with spats set in the vessels as follows:

After keeping the collectors of about 15 cm in diameter with 30 to 40 of spats set in a tank (about 6 tons in capacity) filled with seawater containing several ten-thousand cells per milliliter mixed food of Chaetoceros and Monochrysis cells until the spats set well on the collectors (for several days), these were hung from a raft in Ashizaki Inlet of Mutsu Bay on July 24, 1966. This culture was continued till next year. But hereupon the author reports on specific gravity, temperature of the surface seawater from the end of July to the end of October in 1966 and rough shell size in November 4 in the same year. Namely, the specific gravity sometimes dropped from 25 to 18, 16, 14 or 13 (\( \sigma_4 \)) by rain fall, but usually the values under the layer (culturing depth) of one meter or more in depth were 20 or more and the maximum value was about 25.1 (\( \sigma_4 \)). The seawater temperature was ranged from 15\(^\circ\)C to 24\(^\circ\)C (Fig. 3).

Small oysters of 30 to 40 per sheet of collector were lessened to about 10 at once on the first of September (after a month and a half from the beginning of hanging culture in the sea). And these small oysters on the collectors grew from 3 to 5 cm in shell height on November 4 in the same year.

Acknowledgments

The author is most grateful to Mr. Chales-Aimé Bolduc of Hachinohe Technical College for his revision, to Dr. Yutaka Uno of Tokyo University of Fisheries for his heartfelt advice on this manuscript. And thanks are also due to Mr. Atsushi Satô of Aquicultural Research Centre of Aomori Prefecture for his technical help on the rearing of oyster larvae in the present trials.

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KANNO, H. and S. KIKUCHI (1963): On the rearing of *Anadara broughtonii* (SCHRENCK) and *Haliotis discus* HANNAK INO. *ibid.*, XI (3), 71-76.


ヨーロッパヒラガマの幼生に対する3種の単細胞藻類の飼料効果

武田 恵二

要旨：著者は孵化直後の幼生に、梅林改変PI液で生産したChaetoceros calcitrans f.pumilusやMonochrysis lutheriおよび著者が調査の淡水培養液で生産したChlorella ellipsosoidaを単種飼料として与えて飼料効果試験を行った。投与量は3階の投与量をP.C.V.で定めると、また異なった結果が得られるであろうが、今回は一定投与量を細胞数で取扱い次とおりの結果を得た。

1) 800〜200 luxのもとで10ℓ容量スチロール円型水槽を用い、幼生数を1,000/mlとし、毎朝水槽と飼育水の全交換、幼生の洗浄を行った後、朝7〜8時ChaetocerosやMonochrysisを5,000cells/ml、あるいはChlorellaを20,000cell/ml投与した。

2) 同期間での浮遊幼生の成長増加効果はMonochrysisよりもChaetocerosの方が幾分優れていた。

3) 適に対Monochrysisを与えた方の幼生の足の発達はChaetocerosによる幼生より早い小型（270μ）の時期に始った。

4) Monochrysisを与えた幼生は、当初から強く採食器に固着する傾向が認められた。

5) Chaetocerosを与えた幼生の付着力が弱い傾向があるので、付着後は飼料生物を加えた海水タンクで数日間安静養生後、野外養殖場に移することが必要である。

6) Chlorellaはよく摂取されるが、全く消化されずに排泄されて成長効果は著しく少量であった。

7) 付着直後でも88.89%以上の高い生存率を得たのは、毎朝の飼

8) 実験で得た付着稚児を6月下旬に海面に移して養殖したところ、同年の11月4日に最長は約3〜5cmに達した。
Halophilism of Microorganisms in the Eutrophied Bay of Tokyo at the End of Summer Stagnation Period

Hunitake Seki**, Jun-ichi Matsuo***, Mitsuij Yamashita*** and Haruo Numanoi***

Abstract: The halophilism spectrum of the natural microflora in seawater of Tokyo Bay was shown to be one by the mixed microbial florae of the freshwater (non-halophiles) and the oceanic (slight halophiles) environments, although precise shapes of the spectra were various in different samples collected from different watermasses at different collection times. From statistical analyses it was shown that non-halophilic heterotrophic bacteria could inhabit predominantly in water of Tokyo Bay having up to such a high salinity as 30.96 %, whereas non-halophilic yeasts inhabited predominantly in most water samples (salinities: 26.609-33.340 %) throughout the watercolumn.

1. Introduction

We have reported status quo of the eutrophication in Tokyo Bay (Tsuji et al., 1974) and the possible main mechanism of the formation of microaerobic zone in the bottom layer of the bay (Fig. 1) during summer stagnation period, i.e., phytodetritus and fecal pellets produced by copepod grazing on flagellates of the red tide in the surface layer were shown to form major fraction of organic debris which was used by microorganisms for the consumption of dissolved oxygen in the bottom layer (Seki et al., 1974a and b). Thus, the destruction of natural environment of Tokyo Bay is most serious during summer stagnation period.

During this period the microorganisms associated with the phytodetritus and the fecal pellets in the surface layer might be composed of freshwater microorganisms (non-halophiles) as well as marine microorganisms (slight halophiles), as seawater of the surface layer was less saline as strongly influenced by the freshwater inflow of sewage and industrial wastes. On the other hand, the microorganisms in seawater of the bottom layer must be chiefly composed of marine microorganisms because the layer was then affected little by the freshwater inflow but greatly by the seawater inflow along the bottom from the outside of the bay, as was indicated by high salinity of seawater of the bottom layer (Fig. 2). From microbial halophilism point of view, therefore, predominant microorganisms responsible for the decomposition of phytodetritus and fecal pellets might interchange while they are sedimenting through the watermasses.

Rapid self-purification process for the organic matter was observed within a few months from summer stagnation to fall overturn (Tsuji et al., 1974), when microorganisms in every watermass were exposed to salinity change of the ambient water. From microbial halophilism point of view, again, predominant microorganisms responsible for this self-purification process should be studied.

2. Materials and methods

Hydrographic observations and water sampling were made from August 9 to September 28, 1973, at Station 1 (Fig. 1).

Water temperature, salinity, dissolved oxygen, pH, Eh, light intensity, microbial respiration, particulate organic carbon, particulate organic nitrogen, chlorophyll a, carotenoids and total number of bacteria were determined by the methods described in Seki et al. (1974b).

Numbers of heterotrophic bacteria and yeasts
Fig. 1. Station location and general hydrography in Tokyo Bay.
Station 1 (35°31.6′N, 139°53.9′E)

were counted by the agar poured plate method. The media used for the colony count had the following composition:

Freshwater medium for heterotrophic bacteria
Bacto-peptone: 1 g
Bacto-agar: 15 g
Distilled water: 1,000 ml
pH adjusted to 7.0

Seawater medium for heterotrophic bacteria
Bacto-peptone: 1 g
Bacto-agar: 15 g
NaCl: 35 g
Distilled water: 1,000 ml
pH adjusted to 7.8.

Freshwater medium for yeasts
Glucose: 10 g
Bacto-peptone: 1 g
Bacto-yeast extract: 1 g
Bacto-agar: 15 g
Distilled water: 1,000 ml
pH adjusted to 4.5 with lactic acid.

Seawater medium for yeasts
Glucose: 10 g
Bacto-peptone: 1 g
Bacto-yeast extract: 1 g
Bacto-agar: 15 g
NaCl: 35 g
Distilled water: 1,000 ml
pH adjusted to 4.5 with lactic acid.

The halophilism spectrum of the natural microflora was measured as the relative activity of glucose uptake by the method described in SEKI et al. (1969).

3. Results
1. Summer stagnation and its degradation
On August 9, watermasses at Station 1 were completely stratified (Fig. 2) as have been observed every summer. Transition from summer stagnation to fall overturn started before August 27, and fall overturn was completely established on September 28 (Fig. 3). The degradation of the stagnation seemed to be accelerated especially with vertical mixing being set up by

Fig. 2. Vertical distribution of some environmental factors on August 9, 1973.
violent wind which blew for approximately one week until August 26.

2. Halophilism spectrum of natural microflora

The halophilism spectrum of the natural microflora, as indicated by the heterotrophic potentiality of microorganisms, from summer stagnation to fall overturn is shown in Fig. 4.

At the typical summer stagnation period, as observed on August 9, the spectrum in each watermass was different each other. In the surface layer, the maximum microbial activity was measured at 2% NaCl, and more than 60% of the maximum activity were observed in the salinity range of 0.5 to 3%. In the intermediate layer, the microbial activity had two maxima at 0.5 and 3% NaCl. In the bottom layer, the maximum activity was measured at 3% NaCl. The microbial activity in deeper layer had more stenohaline characteristics.

During the transition from summer stagnation to fall overturn, the microbial activity had the maximum at 0.5 or 3% NaCl and the optimum salinity for the activity had no special relation with the depth. At an early stage of the transition, on August 28, the spectrum from every depth had rough shape, whereas at a final stage of the transition, on September 12, the spectrum had very smooth shape: This difference in shapes of the spectra at the different stages must indicate the progress of microbial acclimatization to new salinity environment.

Finally at the fall overturn, on September 28, the microbial activity at every depth had the maximum at 1% NaCl and more than 80% of the maximum activity were observed in the salinity range of 0.5 to 2% NaCl.

3. Halophilism of heterotrophic bacteria and yeasts

The ratio of colonies growing on a freshwater medium to colonies growing on a seawater medium for samples collected from every depth during the observation is shown in Fig. 5 for heterotrophic bacteria and in Fig. 6 for yeasts.

The ratio for heterotrophic bacteria was always higher than 1 for the seawater samples
Fig. 5. Relationship between salinity of a water sample and the ratio of the number of bacterial colonies growing on a freshwater medium to the number growing on a saltwater medium.

○: seawater samples collected from Tokyo Bay
□: seawater sample collected from the coast of Misaki city at the open sea
×: freshwater sample collected from the Tama river at Mitake city in a mountain free from pollution

Table 1. Regression analysis of fresh and salt water colony ratio to salinity of original sample (data from Fig. 5).

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Sum of square</th>
<th>Degree of freedom</th>
<th>Mean square</th>
<th>Fo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear regression</td>
<td>3.479</td>
<td>1</td>
<td>3.479</td>
<td>31.333*</td>
</tr>
<tr>
<td>Residual</td>
<td>3.357</td>
<td>32</td>
<td>0.111</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7.017</td>
<td>33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Probability level F(1, 32; 0.01): 7.50

from 4 to 8 m, whereas the ratio was between 0.1 and 1 for the seawater samples from other depths. The regression line between the ratio of colonies (y) and the salinity (x) was determined to be

\[ y = -0.369x + 12.426 \]

with an unbiased variance \( \sqrt{V_{yx}} = 0.333 \) from a statistical analysis of the data (Table 1). From this analysis, it was shown that in situ salinity affects the bacterial halophilism and that the bacteria which grow best in a freshwater medium predominantly inhabited water with salinities of less than 30.96%.

On the other hand, it was impossible to determine the regression line between the ratio of yeast colonies (y) and the salinity (x) from a statistical analysis of the data (Table 2). The ratio was higher than 1 for most seawater samples, which indicates that non-halophilic yeasts were predominant at the investigated region.
4. Discussion

The halophilism spectrum of the natural microflora in seawater of Tokyo Bay at summer stagnation period has shown that the microflora in the surface layer has euryhaline characteristics with the maximum activity at 2% NaCl, and that the microflora in deeper layer has rather stenohaline characteristics with the maximum activity at 3%. The spectrum seems to be affected by salinity characteristics of watermasses where the microorganisms inhabit. During transition from summer stagnation to fall overturn, the spectrum changed its shape from rough to smooth as the result of the acclimatization of microorganisms to the degree of mixing of freshwater and seawater throughout the whole watercolumn. Except for the spectrum in the seawater sample from the bottom layer at summer stagnation period, all the spectra showed that non-halophilic microorganisms were responsible to some extent for the heterotrophic potentiality of microorganisms at in situ salinity (Fig. 4). It was also shown by the halophilism of heterotrophic bacteria (Fig. 5) and yeasts (Fig. 6) that non-halophilic yeasts were predominant in most samples and that non-halophilic bacteria predominantly inhabit water with salinities of less than 30.96%. These results must indicate that the formation of microaerobic zone in the bottom layer is chiefly carried out by slight halophilic microorganisms and that the self-purification process for the organic matter produced chiefly by red tide during summer (Tsuji et al., 1974) is rapidly carried out by both halophilic and non-halophilic microorganisms at the transition from summer stagnation to fall overturn when in situ salinity was from 31.4 to 32.7% throughout the watercolumn.

The observed fact that the bacteria which grow best in a freshwater medium predominantly inhabit water with salinities of less than 30.96% in Tokyo Bay, showed a little difference with Larsen’s definition (Larsen, 1962) of nonhalophiles being microorganisms which grow best on a medium with less than 2% NaCl and with our former observation (Seki et al., 1969) that heterotrophic bacteria which grow best in a freshwater medium inhabit water with a salinity of less than 1.9% in a non-polluted region. However, the difference can be explained partly by the work of other authors (e.g., Jones, 1964) that the survival of terrestrial bacteria in the marine environment may be enhanced by the presence of organic materials. As a matter of fact, both dissolved and particulate organic materials in seawater at the station have been measured during this period more than 10 times greater than those in seawater at the coastal region in the open sea (Tsuji et al., 1974; Seki et al., 1974b; Fig. 2 in this paper).

Acknowledgments

This work was partly supported as special projects “Environment and Human Survival” and “Studies on the Petroleum Pollution of Marine Environments” by the Ministry of Education of Japan. This investigation was impossible but for the kind help of Fisheries Experiment Station of Chiba Prefecture.

References


夏季停滞期から秋季循環期の東京湾における微生物の好塩性に関する研究

関 文威　松尾潤一　山下光司　沼野井春雄

要旨：東京湾における、有機物の自己浄化作用が最も重要な時期である夏季停滞期から秋季循環期において、有機物分解過程に最も重要な役割を果たしている微生物が示す好塩性反応を調査研究した。

海水中の微生物相が示した好塩性反応は、淡水及び海水起源に典型的な微生物による反応の中間的なものであり、それらが生息していた水域における淡水と海水との混合跡をよく反映しているものと考えられる。

また、非好塩性の有機栄養細菌や酵母の耐塩度は、実験室内環境や自然環境で示される値よりやや高く、東京湾の栄養塩化の実体を示しているものと考えられる。
Salinités de surface caractéristiques du courant équatorial et du contre-courant équatorial nord à 150°-160°E

J. R. DONGUY** et C. HENIN**

Abstract: Since August 1969, four Japanese merchant ships are making regularly, every 60 nautical miles, between New Caledonia and 10°N, surface observations of temperature and salinity. A complete voyage lasts 40 days. The ships cross the equator between 150°E and 160°E.

Contrary to former data, the new observations show high surface salinities (35.0-35.5%) from 1°N to 3°S and between 150°E and 160°E. This high salinity is associated with East wind and the mean monthly surface temperature is lower at the equator than north and south; the T-S diagrams show also evidence of upwelling near the equator.

Low surface salinities (less than 34.0%) are observed from 5°N to 10°N at 150°E mainly between August and October, though in summer, the North Equatorial Counter-current is supplied at the same time by waters from the northern hemisphere and by high salinity waters from the southern hemisphere. The maximum rainfall in the Philippines occurs in January; to reach 150°E in August, the diluted water should have a speed of 0.2 knot instead of 1.2 as observed. The low salinities occur with SW winds or in the presence of the Trade Wind Convergence Zone, both bringing rainfalls. The surface salinity charts drawn during EQUIPAC in August 1956 and during a VITYAZ cruise in August 1957 are pointing out several isolated minima between 5°N and 7°N. Thus there are strong evidences for the in situ formation of low salinities in the North Equatorial Counter-Current.

1. Introduction

De nombreux minéraliers viennent charger du minerai de nickel en Nouvelle-Calédonie et le transportent au Japon. Plusieurs d'entre eux ont bien voulu apporter leur concours à un programme d'échantillonnage superficiel entre la Nouvelle-Calédonie et 10°N. Depuis août 1969, quatre navires en moyenne font régulièrement, tous les 60 milles, des mesures de température et des prélèvements d'eau de mer de surface. Un voyage complet dure 40 jours; les navires, suivant le port de destination, coupent l'équateur entre 150°E et 160°E.

La température a été lue au demi degré près sur un thermomètre placé à l'entrée de la conduite de refroidissement des moteurs, à une profondeur de 5 mètres en moyenne. Un échantillon d'eau prélevé au même moment sur le même circuit, était conservé en bouteille étanche; sa salinité a été mesurée au salinomètre à induction avec une précision de ±0,01 %.

2. Salinités de surface du courant équatorial

L'upwelling équatorial, caractérisé en surface par une salinité élevée et une température basse, n'est généralement pas signalé à l'ouest de 160°E. Si la carte produite par Reid (1969) pour l'été boréal (mai-octobre) présente des salinités de surface (35,0% à 35,5%) compatibles avec l'existence d'un upwelling, celle de l'hiver boréal (novembre avril) (fig. 1) montre que, de 150°E à 160°E, la salinité est inférieure à 35,0%. Or, les observations des navires marchands pendant cette période présentent des salinités superficielles élevées (de 35,0% à 35,5%) de 1°N à 3°S entre 150°E et 160°E (fig. 2).

Sur la figure 2 ont été groupées:
- la salinité superficielle maximum généralement située entre 1°S et 2°S à 150°E de août 1969 à décembre 1971.
Fig. 1. Salinité de surface pendant l’hiver boréal dans le Pacifique ouest d’après REID (1969).

-les composantes zonale et méridienne du vent moyen à l’île Manus (02°S 147°E) pendant la même période extraites des “Tropical Strip Surface Charts” (National Climatic Center, Asheville, USA).

Les salinités élevées se rencontrent par vent de sud-est capable d’induire un upwelling. D’après CROMWELL (1953), la divergence produite par un tel vent est décalée au sud de l’équateur. Comme, de plus, l’eau subsurface est plus salée au sud de l’équateur qu’à l’équateur lui-même, cela explique les salinités superficielles élevées observées entre 1°S et 2°S pendant la période d’alizés de sud-est, c’est-à-dire de juin à décembre environ.

L’upwelling équatorial peut aussi être mis en évidence par un abaissement de la température de surface. Les moyennes mensuelles de température superficielle entre 20°S et 10°N le long de la route des navires (fig. 3) montrent des variations saisonnières au sud de 5°S et au nord de 5°N. En revanche, les variations de température sur l’équateur semblent moins régulières ; à des périodes variées on observe un refroidissement s’étendant sur quelques degrés de latitude qui pourrait être dû à un upwelling. Il convient de remarquer que, malgré la faible amplitude des variations, le refroidissement est significatif puisqu’il ressort de la moyenne des observations de plusieurs navires.

Plusieurs diagrammes T-S de surface (fig. 4) confirment la présence d’un upwelling à l’équateur tant à 151°E qu’à 159°E ; à l’équateur l’eau est à la fois plus salée et plus froide qu’au nord et au sud.

3. Salinités de surface du contre-courant équatorial nord

En hiver, le contre-courant équatorial nord ne reçoit de l’eau que de l’hémisphère nord. En été, il est alimenté à la fois par des eaux venant de l’hémisphère nord et par des eaux de salinité relativement élevée venant de l’hémisphère sud (HISARD et al., 1969) ; c’est donc à cette époque qu’il devrait être le plus salé. Or c’est principalement entre août et octobre que les navires marchands ont observé de basses salinités (inférieures à 34,0 %) à sa surface, c’est-à-dire entre 5°N et 10°N à 147°E.

Le maximum de précipitation aux Philippines est en janvier (fig. 5) ; pour arriver en août à 150°E, l’eau dessalée devrait avoir une vitesse de 0,2 nœud au lieu des 1,2 nœuds observés. L’arrivée d’une eau dessalée par advection est donc peu probable et c’est ce que confirme l’étude de la salinité à 7°N et de ses variations en fonction de la situation météorologique.
Fig. 2. Maximum superficiel de salinité dans le courant équatorial (trait continu) et composantes zonale et méridienne du vent moyen à l’île Manus (02°S, 147°E).

Fig. 6. Minimum superficiel de salinité (trait continu) dans le contre-courant équatorial nord et composantes zonale et méridienne du vent moyen à l’île Woleai (07°N, 143°E).
Sur la figure 6 ont été groupées :
- la salinité superficielle à 7°N, 147°E de août 1969 à décembre 1971,
- les composantes zonale et méridienne du vent moyen à l'île Woleaï (7°N, 143°E) pendant la même période extraites des "Tropical Strip Surface Charts" (National Climatic Center, Asheville, USA).

Les basses salinités superficielles coïncident généralement avec un vent venant du sud-ouest ou encore une absence de vent due à la présence de la zone de convergence des vents. Ces deux phénomènes amènent des précipitations. En 1969 et 1970, les vents de sud-ouest sont apparus d'août à novembre, mais, en 1971, ils ont soufflé d'avril à novembre. La formation de cette eau dessalée serait donc due aux précipitations locales. La salinité de surface (fig. 7) des croisières
EQUAPAC (août 1956) et VITYAZ 25 (août 1957) le confirme. On y distingue en effet plusieurs minima isolés (S<34,0 %) entre 5°N et 7°N, c’est-à-dire à l’emplacement du contre-courant équatorial nord.

4. Conclusion
Dans le Pacifique occidental, les phénomènes d’advection ne peuvent pas expliquer certaines salinités superficielles observées dans le courant équatorial et dans le contre-courant équatorial nord. Elles sont formées sur place par upwelling dans le courant équatorial, par précipitation dans le contre-courant équatorial nord.

Remerciements
Les auteurs adressent leurs remerciements au commandant et à l’équipage des navires Gokureyu maru, Horyu maru, Koryu maru de la Compagnie TAIHEIYO KISEN KAISHA, Koyo maru de la Compagnie SHINWA KAIUN KAISHA, Hashin maru et Nanyo maru de la Compagnie NIPPON YUSEN KAISHA, Hisasshima maru de la Compagnie KOKUYO KAIUN KAISHA ainsi qu’aux Etablissements BALLANDE, au Groupe P. PENTECOST et à la Société JOHNSTON, consignataires de ces navires. Leur collaboration efficace et sympathique a permis de mener à bien cette étude.
Fig. 7. Salinité de surface pendant
a) la croisière Equapac (août 1956),  b) la croisière 25 du Vityaz (août 1957).

Bibliographie


東経 150°～160° 線での赤道海流、北赤道反流を特徴づける表面塩分

J. R. DONGUY et C. HENIN

要旨：1969年夏から東経 150°～160° 線に沿ってニューカレドニアから北緯 10° まで日本の商船によっって表面水温と表面塩分とが観測されてきた。これ以前のデータと違って、南緯 3° から北緯 1° の間に高い塩分（35.0～35.5 ‰）が見出される。もとより 8 月から 10 月まで、北緯 3° と 10° の間
に低い塩分（34.0 ‰以下）がある。フィリピン諸島での最大降水は 1 月におよびから、この降水で
うすめられた海水が 8 月に 150° 線に達するとすれば、その速度は 0.2 ノットとなり、この海域で
の観測値 1.2 ノットよりもずっと遅い。この低塩分水は、南西風または貿易風がもたらす降水によ
るものと思われる。1956年 8 月の EQUAPAC、1957年 8 月の VITYAZ の観測結果に、北赤道反
流海域内で低塩分水が生ずることを示しているようである。

なお、太平洋沿岸の玉裏丸、宝裏丸、興裏丸、新和海運の光洋丸、大日海運の八新丸、大阪旭海
運、東京船便の南洋丸、国洋海運の久島丸の乗組の方々に感謝する。
Natural Stable Sea Foam and its Meteorological Significances*

Tomosaburo ABE** and Naoki FUKUCHI**

Abstract: In the season of prevailing westerly north winds, enormous amounts of stable sea foam are produced at a breaker zone or a certain shoreline of Japan Sea. The examination of the liquid which was obtained when the stable sea foam had decayed showed that it contained enormous amounts of coastal phytoplankton and small fragments of sea weed, then these substances are surface active materials. The foam powder is obtained as residual substance after drying above liquid. By adding of the powder into a seawater, its value of the foaming factor, $FF$ is increased, but $k_b$ increases little, on the contrary, $\tau$ increases very large.

When the FF value of a seawater in situ becomes 125 mm•sec, stable sea foam is produced. It seems that the concentration of the foam powder contained in a natural seawater is only 0.03 %.

The frequency of occurrence of the foam transport are 3 days every 10 days in the period from November to the next February.

It is most probable that the diameter of the scattered foam masses is 6 cm and its frequency about 21 % at Fukura, Yamagata Prefecture.

And also meteorological consideration are done when the stable sea foam masses are transported there. Practically, 75 % of the number of the foam transport take place at winter monsoon situation. In winter, the foam transport seems to occur when traveling cyclone arrives on the Kuriles, and this cyclone track has northern component after pass through Japan.

1. Introduction

In the season of prevailing westerly north winds, enormous amounts of stable sea foam \textit{i.e.},\textit{longlived and tenacious ones} are produced at a breaker zone or a certain shoreline of the Japan Sea, and some of accumulated sea foams are scattered in inland direction by wind turbulences. These salty masses become attached many things nearby, and various kinds of disasters are happened (for example, electric current leakage, corrosion of metal, and so on.).

Such phenomena often occurred at the Pacific coastal lines of Japan on the season of the Typhoon and high wind.

It was found by one of the authors (ABE) that the important attribute of the stabilization of a seawater is due to surfactants which extracted from native coastal phytoplankton (mainly a certain kinds of diatom at the Fukura shore, Yamagata Prefecture), sea weeds, etc.

When seawater is disturbed violently with wind and wave actions (ABE, 1962, '63).

The various features of stable sea form \textit{in situ} are shown in Figs. 1~5.

2. Effects of the foam powder on the foaming of seawater

What is designated the foam liquid is the one obtained after natural stable sea foam disappeared, its appearance is an opalescent dark brown one (Fukura), and the foam powder (the residual substances obtained after drying above liquid), it appears an opaque, brownish white powder. Then various substances diffused from the powder have apparently the properties for surface active substances which stabilized a sea foam, that is, a sea foam becomes long-lived and tenacious one.

When a certain amount of the powder is put into a filtered ordinary seawater and the mixture is shaken, it become stable foaming characteristics as shown in Fig. 6.
Fig. 1. Production of stable sea foam.

Fig. 2. Accumulation of stable sea foam.

Fig. 3. Flying of stable sea foam by winds. Distance between two black arrows is one meter.

Fig. 4. Flying of stable sea foam by winds.

Fig. 5. Transport of stable sea foam by winds. (Photo by Mr. N. SAKAGUCHI)

Fig. 6. Effects of the foam powder on the foaming of a seawater.

(Figs. 1~4, photo at Fukura shore, Yamagata Prefecture)
Natural Stable Sea Foam and its Meteorological Significances

Therefore, values of the foaming factor, FF are increased by addition of the powder, where FF is a certain physical constant which has been previously introduced of one of the authors (Abe, 1953, '55, '62). Therefore, we investigate the mechanism of it in detail; by addition of the powder, the FF increases little, on the contrary, FF increases very larger, that is, it shows that the foam producing power is almost constant according to the experimental results of the former case (h_o), but the life of foam becomes longer due to be strengthened the membrane of foam according to the experimental results of the latter one (τ).

From Table 1, it can be seen that the foam liquid is about 60 times more viscous than an ordinary seawater, moreover, the membrane of stable sea foam is sufficiently able to resist external forces, and then the membrane is able to become so thinner that pretty interference colors may be appeared momentarily.

Wilson and Collier (1972) discussed experimentally on the production of surfactants by various marine phytoplankton cultures.

Amounts of the foam liquid contained in a stable foam mass is substantially calculated using the ratio of the specific volume of foam mass itself to that of the foam liquid, which is roughly 87 : 1 by our calculation (see Table 1), and then it is seen, volume of 87 times of the stable foam mass as much as that of the foam liquid reduced substantially only one part of the foam liquid. Southward (1953) reported that 500 ml of stable sea foam reduced to 5 ml of an opalescent yellow-brown liquid (Isle of Man, England), that is, it is about the same order in both cases, the Fukura and the Isle Man, though the reduction rate of the case of the former is somewhat less than the latter, and moreover, his microscopic examination of the foam liquid showed the presence of particulate matter of various sizes, some were of obvious planktonic origin, for example, part of copepod cuticle, diatom frustules and green flagellates, however, the majority of the particles were recognizable, varying from 0.5 to 1.0 μ in diameter, but mostly about 1 μ (that is, of just colloidal dimensions), and showed a strong tendency to form a layer at air/water interfaces.

How many values are the concentration of surfactants contained in a natural seawater when stable foam is produce? When the FF value of a seawater at the Fukura becomes 125 mm·sec, stable foam is gradually produced, it means that the concentration of surfactants contained in a natural seawater is only 0.03 %, because it is roughly estimated using the value in Fig. 1 (see the place of p_w).

3. The transport of stable foam mass

By means of our observations, the transport of sea foam mass begins to occur and transport in small scale since the middle of November, and then it becomes to increase gradually in the frequency and scale, then it reaches at maximum stage in the end of January, and then decreases gradually since the middle of February. It is rare case that the transport

<table>
<thead>
<tr>
<th>Substance</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g·m⁻¹)</td>
<td>foam liquid</td>
<td>0.977</td>
</tr>
<tr>
<td></td>
<td>foam mass</td>
<td>0.0113</td>
</tr>
<tr>
<td>Surface tension (dyn·cm⁻¹)</td>
<td>foam liquid</td>
<td>27.34</td>
</tr>
<tr>
<td></td>
<td>seawater⁺</td>
<td>74.7</td>
</tr>
<tr>
<td></td>
<td>ordinary</td>
<td></td>
</tr>
<tr>
<td>Coefficient of viscosity (cm²·sec⁻¹)</td>
<td>foam liquid</td>
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<td></td>
<td>seawater⁺</td>
<td>0.0137</td>
</tr>
<tr>
<td></td>
<td>ordinary</td>
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</tr>
<tr>
<td>Thermal conductivity (cal·cm⁻¹·sec⁻¹·deg⁻¹)</td>
<td>foam liquid</td>
<td>0.0076</td>
</tr>
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<td></td>
<td>foam mass</td>
<td>0.0061</td>
</tr>
<tr>
<td></td>
<td>seawater⁺</td>
<td>0.00135</td>
</tr>
<tr>
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<td>foam mass</td>
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</tr>
<tr>
<td></td>
<td>foam mass</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>one hour later</td>
<td></td>
</tr>
<tr>
<td></td>
<td>foam liquid</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>seawater⁺</td>
<td>3.8</td>
</tr>
</tbody>
</table>

*: see references
occurs in August (that is a case accompanied with the typhoon) or in April as shown in Fig. 7. (ABE and FUKUCHI, 1968).

The frequency of occurrence of the transport are 3 days every 10 days, or about every 3 days in the period from November to the next February.

Some of the stable foam masses accumulated at a shore are scattered by gusty winds (mean speed is more than 7 m/sec). Scattered mass is of irregular shape, and so the size of it is represented by the diameter of an ideal sphere of the same volume, then Fig. 8 shows the frequency distribution of the size of stable sea foam which are scattered. It is most probable that the diameter is 6 cm, its frequency about 27 %, and almost sea foams are smaller than 22 cm, and larger ones are few. As previously mentioned, the specific volume ratio of the foam mass to the foam liquid is 87 : 1, then the foam liquid contained in the sphere (6 cm in diameter) of foam mass is 1.30 ml roughly. The characteristics of the foam liquid are shown in Table 1.

Winds are blowing with the speed more than 7 m/sec, their direction are north north westerly ones, and almost parallel to the Fukura shoreline when many small stable foam masses

Table 2. Plankton observation of the foam liquid.

<table>
<thead>
<tr>
<th>Date</th>
<th>Feb. 6, 1962</th>
<th>Feb. 7, 1962</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diatoms</td>
<td>No. per 10 ml %</td>
<td>No. per 10 ml %</td>
</tr>
<tr>
<td>Asterolinella japonica</td>
<td>+</td>
<td>150 0.3</td>
</tr>
<tr>
<td>Biddulphia auraita</td>
<td>2,880 0.3</td>
<td>—</td>
</tr>
<tr>
<td>Cocconeis spp.</td>
<td>960 0.1</td>
<td>1,600 2.5</td>
</tr>
<tr>
<td>Gramatophora marina</td>
<td>—</td>
<td>320 0.5</td>
</tr>
<tr>
<td>Licmophora lingbyei</td>
<td>2,240 0.2</td>
<td>320 0.5</td>
</tr>
<tr>
<td>Melosira boreri</td>
<td>134,400 14.0</td>
<td>37,440 59.0</td>
</tr>
<tr>
<td>Navicula spp.</td>
<td>3,200 0.3</td>
<td>1,600 2.5</td>
</tr>
<tr>
<td>N. long. v. reversa</td>
<td>640 0.1</td>
<td>160 0.3</td>
</tr>
<tr>
<td>Pleurosigma affine</td>
<td>1,230 0.2</td>
<td>160 0.3</td>
</tr>
<tr>
<td>Thalassiosira hyalina</td>
<td>2,560 0.3</td>
<td>160 0.3</td>
</tr>
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<td>T. Subtilis</td>
<td>800,000 83.0</td>
<td>20,160 32.0</td>
</tr>
<tr>
<td>Pennatae misc.</td>
<td>1,280 0.1</td>
<td>640 1.0</td>
</tr>
<tr>
<td>the others</td>
<td>1.4</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Date: Feb. 6-7 1962

<table>
<thead>
<tr>
<th>Diatoms</th>
<th>No. per 10 ml %</th>
<th>No. per 10 ml %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asterolinella japonica</td>
<td>—</td>
<td>2,400 0.4</td>
</tr>
<tr>
<td>Cocconeis spp.</td>
<td>4 0.2</td>
<td>52,800 8.7</td>
</tr>
<tr>
<td>Denticula marina</td>
<td>16 0.7</td>
<td>4,800 0.8</td>
</tr>
<tr>
<td>Eucampia zoodeecers</td>
<td>16 0.4</td>
<td>—</td>
</tr>
<tr>
<td>Grammatophora marina</td>
<td>—</td>
<td>9,600 1.6</td>
</tr>
<tr>
<td>Licmophora lingbyei</td>
<td>322 11</td>
<td>57,600 9.4</td>
</tr>
<tr>
<td>Frugiaria Islandica</td>
<td>388 18</td>
<td>—</td>
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<td>Melosira boreri</td>
<td>240 11</td>
<td>283,200 46</td>
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<tr>
<td>Navicula spp.</td>
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<td>105,600 17</td>
</tr>
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<td>Nitocha longissima</td>
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<td>—</td>
</tr>
<tr>
<td>Skeletonema costatum</td>
<td>8 0.4</td>
<td>—</td>
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<tr>
<td>Thalassionema nitzschioides</td>
<td>12 0.6</td>
<td>—</td>
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<td>Thalassiosira decipiens</td>
<td>8 0.4</td>
<td>26,400 4.3</td>
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<tr>
<td>T. hyalina</td>
<td>60 2.8</td>
<td>—</td>
</tr>
<tr>
<td>T. subtilis</td>
<td>896 42</td>
<td>67,200 11</td>
</tr>
<tr>
<td>Pennatae misc.</td>
<td>4 0.2</td>
<td>—</td>
</tr>
</tbody>
</table>

Total: 2,140 609,600

Fig. 7. Monthly mean change of transported stable sea foam masses, 1965–1967 (Fukura).

Fig. 8. Size distribution of transported stable sea foam masses (Fukura).
are scattered hard. Then it may be considered
that the upwelling produced by the wind in a
shore water during the period may be accompa-
nied with movements of certain surfactant
particles nearby, but the details on their
features and mechanism have to be studied on
the basis of may accurate observations \textit{in situ}
and in laboratory in the near future.

4. Relation between the foam transports and
the meteorological conditions

The transport of the stable sea foam is the
result that it is produced due to the turbulence
of seawater made by wave action at breaker
zone, and the accumulation of it is caused by
blowing wind at craggy shore and then the
shearing force of wind acts on the foam accu-

cumulation. Therefore, it is seemed to be the
first cause of the formation how wind blows.
This is investigated in respect to weather map
and transport during the period from 1965 to
1967. In relating to it when foam transport
occur, wind is mainly blowing in the direction
of NW–N at Fukura. This atmospheric situ-

ation is just satisfied by the winter time mon-
soon situation. Practically, 75\% of the number
of the foam transport take place at this situa-
tion. In this situation, the fetch and duration
seems to satisfy to stimulate the wind wave
at the Japan Sea.

1. Pressure system

As stated above, the foam transport is oc-
curred mainly when atmospheric situation is
winter type, that is, this situation is frequent
in Japan during winter season, a cyclone is
located at the Kuriles and north-westerly mon-
soon is prevailing in the northern part of
Japan. The winter type situation is classified
to 3 types relating to atmospheric pressure,
that is, A situation is one that the difference
of pressure is over 15 mb, A' situation is 10–
15 mb, and B situation is under 10 mb at the
area of 130° to 140°E on 35°N line. Both A
and A' situations are strong monsoon cases
and B is rather weak one.

Fig. 9 shows a pressure system of A' situ-
tation. Table 3 shows the frequency of occu-
rence of each pressure system (α) and that of
foam transport (β) at Fukura. It is obviously

\begin{table}
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
Situation & Number of day (α) & Number of transport day (β) & Ratio (β/α) & \% \\
\hline
A & 26 & 20 & 77 & \\
A' & 80 & 26 & 52 & \\
B & 61 & 23 & 38 & \\
\hline
\end{tabular}
\end{table}

that the ratio β/α is much at strong winter
monsoon situation. However, when the press-
ure system is A' situation, the ratio is rather
little than A situation. The cause of this
reduction is seemed to be due to the \textit{satoyaki}
situation (snow-fall in the train), and its fre-
quence are 8 times in A' situation. This
pressure system is that northern part of Japan
is covered by the atmosphere of which gradient
of pressure is slight or by closed isobar. At
this situation wind is very slight in the northern
part of Japan, and it is snow in the train of
a mountain, and the foam transport do not
occur at Fukura.

2. Cyclone tracks

The foam formation occur mainly in winter
pressure system in Japan. However, at this
winter system, the foam transport is not oc-
curred occasionally. Then, examining a wea-
ther map, there are some distinction in cyclone
tracks. In winter, there are remarkable 4
Type II: Occurrence; after pass through Japan, a cyclone arrives on the Kuriles, and then travels to the north.
None; a cyclone travels to the east alone.

Type III: Occurrence; a cyclone track has the northern component on the Kuriles.
None; a cyclone travels to the east alone.

Type IV: The distinction is little.
Therefore, the foam transport seems to occur, when each traveling cyclone arrives on the Kuriles, and above each cyclone track has northern component after pass through Japan.
It is obviously that the distinction of the cyclone track is mainly related to track after pass through Japan.

Acknowledgments
The authors wish to express their sincere thanks to the staff of the laboratory, Science University of Tokyo, Mr. Satoru Takechi, Japan Meteorological Agency, for his meteorological analysis, and thanks are also due to Dr. E. C. Lafort, USN Undersea Center, for his interest and encouragement throughout the present study and thanks are extended to Mrs. M. Fukuchi for typing the manuscript.

References
安定海水泡沫の生成飛散と気象要素との関係

岡 部 友 三 郎 福 平 直 樹

要旨：冬期、季節風を卓越時、日本海沿岸において多量の安定な海水泡沫が発生し、飛散するのがしばしば見られる。この泡沫は、沿岸のプランクトン及び海藻類等を源とする表面活性有機物質が海水に溶着入して発生するものと考えられる。この泡沫より乾燥して得られる粉末を一般の海水に溶かし、ることで、Foaming Factor (F.F.) が指数的に増大する。しかし、海水の実測はほとんどなく、foam の増大が主である。これは、現場海水の F.F. の傾向とも一致している。現場海水の F.F. の値が 125 mm・sec 以上となら、沿岸に安定泡沫が発生することから、現場海水には、0.007 重の泡沫粉末量で安定泡沫が発生しやすいと考えられる。

安定泡沫飛散の現象は、冬季 11 月から翌年の 2 月にかけては約 3 日に一度の頻度で見られ、その飛散量は直径 6 cm が最も多く、27 % を占めている。

また、気象と泡沫飛散の関係を調べたところ、飛散回数の 75 % は、日本が冬型気圧配置の時に起こっていることがわかった。これは、大気で発生した移動性低気圧が日本を通過後、北に向かい千島に到達する場合に、最も泡沫飛散の可能性が強いと考えられる。
相模湾沿岸における異常高潮位と湾の温度場及び塩分場との関係
松山 優治** 寺本 俊彦** 前田 明夫**

Abnormal Variations of Sea Level at the Sagami Bay Coast and their Relation to Variations in Offshore Fields of Water Temperature and Salinity

Masaji MATSUYAMA, Teshihiko TERAMOTO and Akio MAEDA

Abstract: Abnormal variations of sea level recorded at Aburatsubo during 1964 to 1971 are analysed in relation to variations of water temperatures measured regularly once a day at the sea surface, 25 m depth and 50 m depth off Iwae and variations of temperature- and salinity-sections between Manazuru and Miasaki occupied regularly once a month by Kanagawa Fisheries Experimental Station. The term abnormal variations are used when rises and falls of sea level from its annual mean amount to 10 cm in magnitude and last for more than a week. The sea-level variations are also analysed in reference to variations of daily-mean atmospheric-pressure difference between Oshima and Hachijojima. Most of the abnormal rises of sea level are accompanied with baroclinic variations in the field of water temperature. Abnormal sea-level variations which are of the time scale of a week to two are especially in close correlation to the east-west component of geostrophic wind over the adjacent region. Abnormal, transient sea-level variations magnitudes of which amount to 7 to 15 cm within a day sometimes take place at the coast of the Sagami Bay. Among those variations that occurred during 22nd to 24th of October in 1971 is studied in relation to hydrographic observations which were just conducted before and after the period. This sea-level variation which reaches 15 cm in magnitude is associated with the variation of density field that is suspected to have been caused by upwelling.

1. 序 文
1964年以降1970年末までに日本沿海の潮位資料を解析した磯崎（1972）は、日平均潮位偏差から考えて、1971年9月の異常高潮位と同程度の顕著な異常高潮位は1966年8月と1968年7月の2回、1971年9月に起こることは6回起こっていることを指摘している。彼は異常高潮位と浮遊粒子10 cm以上と1週間以上継続し、数百km以上の水平スケールを持つものを定義している。又、彼は異常高潮位は日本南岸を西向きに伝播したことを指摘した。異常高潮位とその伝播方向と位相速度の大きさから考えて、内部ケルビン波（Internal Kelvin Wave）又は陸棚波（Continental Shelf Wave）が沿海を伝わったことはほぼ間違いないといわれている（吉野，1972）。

われわれは異常潮位変動に関連して、海岸の内部で密度場がどのように変動したかに特に注目して研究を進めた。変動が一週間以上にわたることはから内部モードの現象が起こっている可能性があると考えられるからである。実際には、われわれが取得しようとした時間スケールの変動の解析に利用しうる海洋内部の変動に関する情報は極めて少なく、わずかに相模湾の一測点における水温記録が存在するに過ぎない。この論文の前半
では、この資料に基づいて得られた相模湾における海の内部の変動と層位変動との関係が論じられている。同時に、層位変動と陸岸に平行に吹く風との関係も調べられている。著者ら（1973）によると、異常層位に伴い非常に短時間に急激な層位変化（8～15 cm/day）が起こる。後半ではこの間に、海水がどのような運動をした可能性があるかについて推測がなされている。

2. データ及びデータ処理

1. 潮位
Fig. 1に示す油壺（35°09.4'N, 139°37.1'E）の日平均層位が使用された。層位の気圧補正は横浜の日平均気圧により行われた（潮代でも気圧が測定されているが、日平均気圧は両者ではほとんど変わらない）。

層位変位は、8年間（1964～1971年）の平均層位178 cmと気圧1,012 mbを基準にして次のように定義される。

日平均層位変位 = （実測層位 - 178 cm） + α（日平均気圧 - 1012 mb）

ただし、気圧1 mbの変化は層位1 cmの変化に対応するとし、α = 1 cm/mbarとされた。以後の層位変動の議論には、この日平均層位変位が用いられる。

2. 地観風東西成分
陸岸に平行なほぼ東西方向の風を代表するものの

Fig. 2.1. From the top to the bottom, variations of water temperature at the surface (thine line), 25 m depth (dotted line) and 50 m depth (thick line) at Iwae, variations of daily-mean sea-level at Aburatsubo, variations of daily-mean atmospheric-pressure at Yokohama, variations of Aburatsubo daily-mean sea-level from which an atmospheric-pressure effect is eliminated and variations of daily-mean atmospheric-pressure difference between Oshima and Hachijo-jima are illustrated for the period from March to June, 1964.
1965

1966

1967

Fig. 2-2. From the top to the bottom, variations of water temperature at the surface (thine line), 25 m depth (dotted line) and 50 m depth (thick line) at Iwae, variations of daily-mean sea-level at Aburatsubo, variations of daily-mean atmospheric-pressure at Yokohama, variations of Aburatsubo daily-mean sea-level from which an atmospheric-pressure effect is eliminated and variations of daily-mean atmospheric-pressure difference between Oshima and Hachijo-Island are illustrated for the period from April to July, 1965.

として、大島と百八島との気圧差から次式により求められた地衡風速が用いられた。

\[ u = -\frac{1}{\rho \omega f} \frac{\partial P}{\partial y} \]

ここに、\( \rho \) は空気の密度、\( P \) は気圧、\( f = 2\omega \sin \varphi \) はコリオリ・パラメーター（\( \varphi \) は地球自転の角速度、\( \varphi \) は大島と百八島の平均緯度）である。又、百八島と大島を結ぶ直線を \( y \) 軸とし（百八島から大島に向う向きをその正方向とする）、これに直交して \( x \) 軸をとる右手系直角座標が用いられている。この方法で推算すると気圧差 1 mb は地衡風速約 5 m/sec に相当する。一般には、海面上の風は摩擦のため、地衡風から角度にして 10° 前後ずれるが、本文の議論にはそれほど大きな影響を与えないと考え、海面上の風を地衡風として近似的に扱った。

3. 一定点における水温

神奈川県真鶴沖、岩江定殖網漁場（Fig. 1）では、毎朝揚網時に、表面、25 m 深、50 m 深の三層の水温が 1954 年から約 20 年間継続してとられている。これで用いられたのはこのデータである。

(30)
4. 相模湾及び相模灘の水温、塩分
神奈川県水産試験場が真鶴と三崎を結ぶ定線（Fig. 1）上で1964年より毎月1回行って來ている海洋観測の結果が用いられている。

3. 異常高潮位の解析とその結果
1964年～1971年に起こった10回の異常高潮位の際の水温（細線、点線、太線はそれぞれ表面、25 m深、50 m深の水温）、日平均実測潮位、日平均気圧、日平均潮位差、日平均気圧差をFig. 2-4、1968年6月～10月の水深25 m、50 mの水温をFig. 2-5に示す。各図の下に示す矢印は、神奈川県水産試験場による実測観測の時期を示す。

1. 潮位変化と水温変化との関係
磯崎（1972）は波高の変化と潮位変化とを比較し、両者の間に正の相関があると述べている。ところがFig. 2-1よりFig. 2-7によると、表面水温の変化と潮位変化については、1968年8月の例において正の相関がみられる程度で、その他の例ではそれはほとんど明確な関係は見られない。

ここで重要なことは、25 m深と50 m深の水温変化が潮位変化との間に一般に正の相関関係
Fig. 2-6. From the top to the bottom, variations of water temperature at the surface (thick line), 25 m depth (dotted line) and 50 m depth (thin line) at Iwae, variations of daily-mean sea-level at Aburatsubo, variations of daily-mean atmospheric-pressure at Yokohama, variations of Aburatsubo daily-mean sea-level from which an atmospheric-pressure effect is eliminated and variations of daily-mean atmospheric-pressure difference between Oshima and Hachijojoima are illustrated for the period from August, 1970 to January, 1971.

Fig. 2-7. From the top to the bottom, variations of water temperature at the surface (thick line), 25 m depth (dotted line) and 50 m depth (thin line) at Iwae, variations of daily-mean sea-level at Aburatsubo, variations of daily-mean atmospheric-pressure at Yokohama, variations of Aburatsubo daily-mean sea-level from which an atmospheric-pressure effect is eliminated and variations of daily-mean atmospheric-pressure difference between Oshima and Hachijojoima are illustrated for the period from July to October, 1971.

をもっていることである。この二層の水温変化と日平均潮位偏差の変化との関係をもう少し詳しくみるために、1968年8月の例を取上げ、それを拡大してFig. 3に示す。図の上部には水温、下部には潮位偏差が示されている。50 m 潮の水温については、その上昇過程で欠測を生じているので、二層の水温間の位相差は明らかではないが、たたか2〜3日程度である。異常高潮位10例のうち、7例において潮位変化に対応してこれら二層の水温が変化している。

1965年3月、1966年10月、1966年12月の3例については、このような潮位と二層水温間の対応関係がみられない。しかしこのことから、これら3例の異常高潮位の力学的機構が他の場合と異なり、その影響が明確に現れるわけではない。何とならば、潮位変化の上下運動に伴うある構造のような水温変化の著しさは、その近傍における水温鉛直分布に依存する。この理由がこの影響の大きさ、特に高潮の水温変化の場合にあるか否かによって、水温変化の著しさは大きく異なる。全図に示されている25 m 潮、50 m 潮
の二層が水温垂直分布の上でどのような位置を占めるかを調べるために，定線観測の資料が用いられた。100 m, 150 m, 200 m のおのおのの深さについて定線上7測点にわたってとった空間平均水温と，100 m の深さについて7測点にわたってとった空間平均塩分を Fig. 4 に示す。図中の下向きの矢印は，この時に異常高潮位が観測されたことを示す。異常高潮位に伴う25 m 深，50 m 深の水温変化がみられなかった前述の3例についても，1966年10月，12月の2例では100 m 深，150 m深の水温は上昇している。これら2例の起こった時期は表層混合層が厚くなる対流期にあたるため，25 m 深と50 m 深は水温一様な表層混合層の中であり，異常高潮位が起きてもこれらの深さの水温は上昇しなかったと考えられる。

以上のように異常高潮位10例のうち9例において高潮時に伴って，垂直方向の水温構造，従って密度構造が変化し，潮位が上昇したのに対して水温躍層が下降したと言うパラクリティックな変化であったことを示している。

2. 大島と八丈島の気圧差の変化と波浪の潮位変化との関係

Mean temperature and salinity along 35°07'N

Fig. 4. Temporal variations of spatial-mean water-temperatures over isobars of 100 db, 150 db and 200 db and a spatial-mean salinity over an isobar of 100 db along a hydrographic section at 35°07'N occupied regularly once a month by Kanagawa Fisheries Experimental Station.
ぶ断面に直交する方向の地衡風速に比例する。大島と八丈島を結ぶ繊がほぼ南北方向にあることを考えれば、気圧差が正の時、東風成分を示し、負の時、西風成分を示すことが知られる。

今、この関係を更に詳しく調べるために、1971年8月～10月、1968年8月～10月における異常高潮位を例として取上げ、拡大してそれぞれ、Fig.

Fig. 5. Correspondence of daily-mean sea-level variations at Aburatsubo (atmospheric-pressure effect being eliminated) to variations of daily-mean atmospheric-pressure difference between Oshima and Hachijo-jima, for the period from August to October, 1971.

Fig. 6. Correspondence of daily-mean sea-level variations at Aburatsubo (atmospheric-pressure effect being eliminated) to variations of daily-mean atmospheric-pressure difference between Oshima and Hachijo-jima, for the period from August to October, 1968.

5. Fig. 6 に図った。前者では、長期間変動（1か月以上）に関しては潮位と気圧差との間の相関は見られない。しかし、一週間から十数日周期の変動については、図中に銘線で結びついているように、潮位変化と気圧差の変化は非常によく対応している。すなわち、潮位変化にみられる6～8日間の変動の山はほとんどすべての場合、気圧差にもみられる。両者の位相を比較すると、位相ずれがZeroか、あるいは気圧差の方が潮位よりわずかに進んでいる。これより短かい周期の変動については、気圧差の変動に潮位変動は追随していない。例えば、10月14日における+6.2 mb、10月23日における-3.5 mbのように、気圧差の短期間の変化に対しては、その値が大きくても潮位は対応して变化しない。後者についても、前者について成立の関係は一般に成立っている。しかし、後者に示される1968年8月の異常高潮位においては、例外的に気圧差との対応がみられない。この場合、8月10日以前の数日を除けば気圧差は大体負の値、従って西風が吹いていたことを示す。


Table 1. The relationships between the abnormal rises of sea-level and the surface layer temperatures (0.50 m depth), the upper layer temperatures (100-200 m depth), the difference of atmospheric-pressure between Oshima and Hachijo-jima.

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Surface layer temperatures</th>
<th>Upper layer temperatures</th>
<th>Difference of atmospheric-pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>May</td>
<td>○</td>
<td>○</td>
<td>×</td>
</tr>
<tr>
<td>1965</td>
<td>June</td>
<td>×</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>1966</td>
<td>August</td>
<td>○</td>
<td>○</td>
<td>×</td>
</tr>
<tr>
<td>1966</td>
<td>October</td>
<td>×</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>1966</td>
<td>December</td>
<td>×</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>1967</td>
<td>September</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>1968</td>
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○: Close correlation  ×: No correlation
相模湾沿岸における異常高潮位と波の密度場及び塩分場との関係

月の3例である。一般には、Fig. 2-1よりFig. 2-7にみられるとおり、異常高潮位時に潮位変化と気圧差の変化とがかなりよく対応している。

3. まとめ
異常高潮位10例について、各々の変化の特徴をまとめたのがTable 1である。この結果から、異常高潮位は東風と関係していることが多く、且つ、パーキャリック・モードの現象を伴うことが極めて多いことがわかる。

4. 急激な潮位上昇及び下降と波の密度場の変動との関係
上に述べた異常高潮位では、一般に水位は比較的急激に上昇したり、下降したりすることが多い。その程度は、例えば、月平均潮位が1971年9月1日～2日の1日間に15cm上昇し、又、1971年10月22日～24日の2日間に15cm下降している。このような比較的短期間に起こる水位の変動に、海洋の水温場あるいは密度場の鉛直構造がどのように対応するであろうか。次に述べる観測の結果は、この問題に対し示唆を与える。

1971年10月、相模湾、相模湾付近の海況変化を知る目的で、東大海洋研究所の「淡青丸」と神奈川水試の「うしゅお」が共同で前述した相模湾の沿線断面を2回に行なび観測した。これらの時期はそれぞれ10月21日と10月28日であり、2日間で水位が15cm下降した10月22日～24日の前後にあたる。この期間の波浪中央に当る測点（St. 9）の鉛直方向の水温及び塩分分布をFig. 7に示した。21日の高潮位時に比べて28日の低潮位時には、水温は50m～500m深で低下し塩分は表層から150m深までに高くなり、それより300m深付近までは低くなっている。

Fig. 8に定線上のSt. 7とSt. 9における10月21日と10月28日の測定結果に基づいて描かれたT-S曲線を示す。表層100m深以浅を除けば、両曲線はほぼ同一曲線上にある。例えば、高潮位

Fig. 7. Variations in vertical profiles to temperature and salinity observed at St. 9 before and after the abnormal sea level variation at Aburatsubo which occurred during 22nd to 24th of October, 1971.

Fig. 9. T-S diagrams for St. 19 and St. 25 which were occupied before the abnormal variation occurred during 22nd to 24th of October, 1971 along with T-S diagram for St. 7 which was occupied after the abnormal variation.
時の150m深の水温及び塩分値は低潮位時の100m深の水温及び塩分値にはほぼ一致するように、低潮時のある層の水温、塩分は高潮位時におけるより浅いある層の水温、塩分に等しい。

Fig. 9 は、St. 7 の低潮位時の T-S 曲線と相模湾外の 2 測点（St. 19、St. 25）における潮位変化前の T-S 曲線を比較したものです。三つの T-S 曲線は、かなり似かよっているが、任意の深さに対する T-S の値はそれぞれの観点で異なっている。以上を要するに、潮位変化に伴った水温場や塩分場の鉛直構造の変化は、海水の水平運動に直接結びついて生ずるのではなく、表層水の水平運動に伴う下層水の浮昇によって生じた可能性があることを示唆している。

5. 結論
過去の異常高潮位の資料を整理し、潮位変化と水温変化、気圧差（風向、風速）変化との関係を調査した。その結果、
1. 潮位変化と水温変化の関係から大半の場合、異常高潮位はパーキャリック・モードを伴う現象であることがわかった。
2. 一週間から十数日程度の周期については、多くの場合気圧差の変動と潮位変動とは一対一に対応する。両者の間の位相差はほとんどないか、あるいは気圧差の方が位相が進んでいる。しかし、1〜2 日程度と言う短周期について、気圧差変化のピークはその振幅の大小にかかわらず、潮位変化に影響しない。

謝辞
この解析のためにデータを提供して下さった神奈川県水産試験場の木村組、田村組、岩田静夫の他各位に厚く感謝致します。又、解析に当りいろいろ御指導下さった東京大学理学部の吉田耕造教授、杉ノ原伸夫博士に厚く感謝致します。

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Compte rendu

Microbiological Aspects of Petroleum Degradation in the Aquatic Environment*

S. A. CROW**, S. P. MEYERS** and D. G. AHEARN***

1. Introduction

In this decade, increasing attention is being given to the effects and fates of the vast quantities of oil, estimated between 6 and 12 million metric tons annually, that enter the world oceans (M itchell, 1972; F reegarde, 1972; Heyerdahl, 1972; Blumer, 1971). A complete review of the extensive literature dealing with oil spills and microbial degradation of spilled oil is beyond the scope of the current presentation. The excellent reviews of Nelson-Smith (1968, 1970, 1973), Cowell (1971), ZoBell (1964, 1969), Atlas and Barth (1973) and the study of Hepple (1971) are recommended for complete coverage of the topic. Further, the toxicity of crude oil and its derivatives to animal life has been extensively reported in the literature. Alterations of littoral and sublittoral ecosystems have been well demonstrated, (Smith, 1968), noting various degrees of toxicity of crude oil as a function of type and quantity, amount of weathering and species of biota involved (Carthy and Arthur, 1968).

Recently, sub-lethal effects of spilled oil have been given serious consideration. Mironov (1968) pointed out that the sensitivity of eggs and larval forms was much greater than the adult counterparts, on which most toxicity studies are performed. Davis (1971) reported the deleterious effects of pollutants on the reproduction of marine animals. Blumer (1973) illustrated another subtle implication of the toxicity of crude oil in that, at concentrations of 1:100,000, it could significantly modify the feeding habits and behavior of the lobster, Homarus americanus. It has been further suggested that crude oil might interfere with the chemotactic feeding and mating responses of many organisms (Takahashi and Kittredge, 1973). Another subtle effect of crude oil is its carcinogenic potential (Dean, 1968). Blumer (1971) cited alkylbenzanthracene and 1,2 benzanthracene as significant carcinogens contained in crude oil. In addition, the multi-nuclear aromatic content of the fraction of crude oil boiling over 300°C suggests potential dangers. Ehrhardt (1971) and Blumer et al., (1970) have also demonstrated that these high-boiling compounds are part of the fraction which is readily absorbed and incorporated into the body fats of oysters. Freegarde (1972) presented evidence that copepod members of the plankton ingest and expel fine oil globules. The effects of oil on plankton, however, are largely undetermined.

Increasing attention is being paid to salt marsh ecosystems and its composite vegetation especially the importance of chronic pollution. Cowell (1971a) discussed two types of chronic pollution. In both, recovery of the ecosystem may occur only after the source of pollution is removed. The need to examine oil impact on marshland microbial ecosystems, notably micro-
cially-induced processes of chitin and cellulose turnover and detrital input into the complex estuarine food web has been stressed (MEYERS et al., 1973). This is all the more important in areas of localized oil production, where danger from spills and blow-outs exists, such as along the upper Gulf of Mexico Coast.

The effect of crude oil on ecosystems is a perplexing problem in view of its being a complex mixture of hydrocarbons and non-hydrocarbon entities containing oxygen, sulfur, nitrogen and many trace metals (DAVIS, 1967; DEAN, 1968). The hydrocarbons in crude oil may be paraffins, alkanes or saturated hydrocarbons, or aromatic hydrocarbons. As a class, crude oil does not usually contain olefins or alkenes, but these compounds may be found in other petroleum products (BLUMER, 1973). The non-hydrocarbon constituents are usually referred to simply as asphaltic material.

ZOBELL (1973a) listed the composition of crude oils as: aliphatics, 15-35%; cycloparaffins, 30-50%; aromatics, 5-20%; and asphaltene, 2-15%. Oils from different geographic regions can be very dissimilar chemically and therefore toxicologically. Numerous compounds found in crude oils i.e., benzene, hexane, etc., have well-established toxicities at low concentrations (VAN OVERBEK and BLONDEAU, 1954). HAVIS (1950) reported that aromatic hydrocarbons are most toxic to plants, with olefins and naphthenes ranked next, and alkanes being least toxic. While considerations of actual modes of toxicity is beyond the range of this review, it is well known that most toxic hydrocarbons exhibit narcotic properties in low concentrations. At higher concentrations certain hydrocarbons become markedly toxic due to their being cytoytic, thus bringing about a disruption of cellular organization.

2. Effect of crude oil on the microbial ecosystem

The ability of microorganisms to degrade petroleum and petroleum products has been well known for over 50 years. However, the effect of crude oil intrusion on microbial ecology, or the microbial ecosystem, has received only slight attention.

BALDWIN (1922) noted increases in total heterotrophic bacterial populations in soil from a corn field treated with petroleum. The production of nitrate was decreased in proportion to the amount of oil. A decrease in species diversity was also observed with the addition of crude petroleum, although petroleum application seemed to have little effect on the numbers of anaerobes. Nitrogen fixation was also inhibited by crude oil, but the retardation appeared to be overcome after a period of sixty days. Ammonia production was lowered only slightly. The mineralization activity was a reflection of fungal activity. Mold growth was little affected by crude oil, and the types of bacteria favored by crude oil were not able to form ammonia from organic compounds.

In a study of the yeast ecology of an asphalt refinery and its watershed, TURNER and AHEARN (1970) detected several oil-induced changes. An increase in total microbial biomass was noted over control or unaffected areas. In addition, localities with visible hydrocarbon contamination had yeast populations largely composed of Candida tropicalis, C. lipolytica, C. guilliermondii, and Trichosporon capitatum. In areas where hydrocarbons had been considerably diluted, Aureobasidium pullulans and Rhodosporidium-Rhodotorula spp. predominated.

AHEARN and MEYERS (1972) noted a slow increase in yeast populations of marsh plots following oil treatment. There was a concurrent shift in species density from a sporogenous population, dominated by Pichia and Kluyveromyces, to an asporogenous population with Rhodotorula and Trichosporon being dominant. CROW (1971), in studies of a large offshore oil spill, noted a similar enrichment of total yeast populations and a shift toward Rhodotorula-Rhodosporidium complex.

KINCANNON (1972) reported only slight changes in microbial populations over an 8 month period when crude oil was added to soil. Flavobacterium, Nocardia, Pseudomonas, and Arthrobacter were the prominent microbial genera found. Some evidence of ecolog-
ichal succession was seen. During the last nine months of the study, *Corynebacterium* increased noticeably, while *Arthrobacter* was seldom prominent. During this time yeasts were predominant in several samples. In laboratory studies, the addition of oil to nutrient agar lowered the total developing populations.

**Meyers et al.** (1973) observed a microbial succession in experimentally oil-treated plots toward species of hydrocarbonoclastic yeasts. The indigenous yeast flora of the marsh was unable to degrade crude oil to any significant extent. A similar phenomenon was reported by **LePetit et al.** (1970) who found hydrocarbon-utilizing yeasts only in littoral waters chronically polluted with refinery pollutants.

**Cobe** and **Guard** (1973), in examining beach microflora following contamination by bunker fuel, found no great change in the microbial communities after oil intrusion. There was no significant change in diversity of bacterial genera with time or depth, with major populations of *Achromobacter, Alcaligenes, Moraxella,* and *Pseudomonas* noted throughout the study.

In addition to the above environmental response, crude oil has been shown to be toxic, or at least inhibitory to a number of microorganisms (Beerschotch, 1954). **Walsh** and **Mitchell** (1973) and **Young and Mitchell** (1973) showed an inhibition of bacterial chemoreception by a number of purified hydrocarbons and crude oil. Motile bacteria are capable of moving in a non-random fashion to suitable growth substrates. Various hydrocarbons and haloacetylated hydrocarbons induced random motion even in the presence of intense attractants. The importance of chemoreception in the microbial chemistry of the ecosphere is not clearly established at present.

3. Microbiological aspects of Hydrocarbon degradation

The ability of microorganisms to grow on hydrocarbons was first established by **Miyoshi** (1895) who observed growth of the fungus, *Botrytis cinerea,* on paraffin. In a series of articles beginning in 1906, **Soehngen** firmly established the field of hydrocarbon microbiology by exploring the ability of microorganisms to utilize various hydrocarbons including kerosene, gasoline, and Russian and American crude oil.

Moreover, the ability to utilize hydrocarbons appears to be widespread among microorganisms. More than 200 species of bacteria, yeasts, and filamentous fungi are able to degrade or metabolize a diversity of hydrocarbons. Seventy genera of organisms comprising 28 bacteria, 30 filamentous fungi, and 12 yeasts have been shown to utilize hydrocarbons (Zobell, 1973). To simplify the following review, initial references will be grouped as to type of organism, *i.e.,* bacteria, yeast, filamentous fungi, described by the author.

**Yeast**

**Tausson** (1938) reported utilization of hydrocarbons by a number of yeast and yeast-like fungi including those of genera *Debaryomyces, Endomycetes, Hansenula, Torulopsis,* and *Monilia.*

**Komagata et al.** (1964) showed that 56 of 498 yeasts could use kerosene as a sole source of carbon and energy. Most of the yeasts were members of the genus *Candida* but representative isolates of *Rhodotorula* and *Hansenula* also exhibited hydrocarbonoclastic activity.

**Markovetz and Kallio** (1964) demonstrated that several isolates of *Rhodotorula, Trichosporon* and *Candida* were able to assimilate various hydrocarbons of chain length C_{14}-C_{16}. *Candida lipolytica* and *C. pulcherrima* utilized all even-numbered chain 1-alkenes C_{16}-C_{18} as well as all even-numbered alkanes. **Miller et al.** (1964) showed that growth of an isolate similar to *Candida intermedia* was greater with increased chain length from C_{14}-C_{16}.

**Scheda and Bos** (1966) tested 1,200 yeasts for growth on *n*-hexadecane, *n*-decanes and kerosene. Some *Rhodotorula* species utilized all hydrocarbons tested, but growth was comparatively slow. Many isolates of *Pichia, Debaryomyces, Candida* and *Torulopsis* grew well on all hydrocarbon substrates. **Otsuka et al.** (1966) examined growth of 10 hydrocarbonoclastic isolates of *Candida.* An isolate of *C. tropicalis* grew better on kerosene than
others studied. Both *C. tropicalis* and *C. cloacae* isolates assimilated numerous pure hydrocarbons from C₁₀-C₁₆. Cell yields increased to a maximum at 15% light oil.

**KLUG and MARKOVETZ** (1967a) investigated hydrocarbon assimilation by a number of species of *Candida*. A high percentage of the organisms oxidized many of the n-alkanes in the C₉-C₁₈ series. Growth on even-chained l-alkene series C₁₀-C₁₈ was restricted to a much lower percentage of the yeasts. **KLUG and MARKOVETZ** (1967b) extensively studied the growth of *Candida lipolytica* (ATCC 8661) in mineral salts-hydrocarbon medium. The conversion of n-alkanes and corresponding l-alkenes to fatty acid and alcohols of the same chain length (C₁₄-C₁₈) was observed.

Hydrocarbon assimilation by 66 yeasts within 16 genera was tested by **LOWERY et al.** (1968). Only 11 organisms grew on n-alkanes, mostly members of *Candida, Rhodotorula* and *Debaromyces*. None of the yeasts tested were able to assimilate alkanes with less than nine carbons. Several yeasts developed on 2-hexanone and 2-heptanone but none grew on ketones of chain length greater than C₁₁.

**AIDA and YAMAGUCHI** (1969) noted that growth of *Mycotorula japonica* was improved by dialysis culture. A vessel with two compartments separated by a cellulose dialysis membrane permitted replenishment of nutrients and removal of toxic products from the growth compartment. The dialyzable material depressed the growth of the organism on kerosene medium but not on glucose. The free fatty acid, lauric acid, was responsible for inhibition on n-hexadecane.

The oxidation of p-cresol, a phenolic substrate, by yeast was demonstrated by **HASHMOTO** (1970). The enzyme system for p-cresol oxidation was formed when the fungus was incubated with phenol. The organism produced a C₅H₄OH product, the structure of which could not be completely elucidated, from the cleavage of the benzene ring.

**IDA and ITIUKA** (1970) studied the anaerobic conversion of 1-decene to n-decyl alcohol and decanoic acid. Resting cells of *Candida rugosa* formed 2-3 times as much decyl alcohol under anaerobic conditions, strongly suggesting an initial hydrogenation rather than a direct incorporation of molecular oxygen in this anaerobic hydrocarbon degradation scheme.

**BARUA et al.** (1970) noted utilization of paraffins by *Trichosporon pullulans*. Assimilation of shorter alkanes (C₁₆, C₁₈, C₂₀) was more rapid than longer chain assimilation on mixed hydrocarbon substrates. Larger chains, however, showed increased breakdown rates, suggesting that inducible enzymes may function in this conversion. *T. pullulans* exhibited no growth on the isoalkane fraction of gas oil.

**Filamentous fungi**

Initial observation of hydrocarbonolytic activity occurred with filamentous fungi (MIYOSHI, 1895). **TAUSSON** (1925) demonstrated the ability of *Aspergillus niger* to maintain itself on paraffin wax. **HOPKINS and CHIBNALL** (1932) described growth of an organism resembling *Aspergillus versicolor* which was able to use both odd and even numbered paraffins to C₄₀H₈₀.

**PRINCE** (1961) reported that representatives of the filamentous fungus, *Cladosporium*, could grow on jet fuel. **KRNYTSKY and McLAREN** (1962) noted similar observations with the fungus, *Hormodendrum*.

**KESTER** (1961) used n-tridecane as a sole source of carbon for growth of *Aspergillus albiaceus, Cephalosporium roseum, Colletotrichum altramentarium, Acremonium patronii, Fusarium balbigenum* and *Monila bonordenii*. Elsewhere **KRAUSE and LANGE** (1965) found three species of *Fusarium* were able to grow on various n-alkanes C₁₁, C₁₈, C₂₀, C₂₃, C₂₅, C₂₇. In addition, it was noted that 1-octadecene and squalene also could be utilized by the three organisms.

**NYNS et al.** (1968) stated that utilization of hydrocarbons was a property found mainly in the two orders, Mucorales and Moniliales. Genera involved included those of *Fusarium, Penicillium, Paecilomyces, Chloridium, Oidiodendron*, and *Scolecosadidium*. Several isolates of *Penicillium* grew well in the presence of numerous pure hydrocarbons, petroleum fractions, and toluene.

**LOWERY et al.** (1968) reported utilization of hydrocarbons, by species of *Aspergillus, Cepha*
losporium, Dematium, Epicoccum, Fusarium, Gliocladium, Graphium, Macor, Paecilomyces, Penicillium, and Trichoderma. The majority of these organisms grew well on C₁₀-C₁₅ normal hydrocarbons, with only a few isolates showing growth on C₄ or shorter chained hydrocarbons. Gaseous alkanes, i.e., ethane, propane and butane, have been found to support the growth of a few hyphomycetes and bacteria (Zajic et al., 1969; McLee et al., 1972; Davies et al., 1973).

Markovetz et al., (1968) described growth of a group of filamentous fungi on selected n-alkanes and t-alkenes. Isolates of Cunninghamella grew well on all even alkanes C₁₀-C₁₅ and on even t-alkenes of 12 carbons and greater. Representatives of Fusarium, Cephalosporium, and Spicaria exhibited good growth on many of the pure compounds tested.

Cerniglia and Perry (1972) demonstrated growth of Cunninghamella elegans and a Penicillium sp. on a wide range of hydrocarbons. A paraffinic crude appeared much more susceptible to fungal attack than an asphaltic crude.

Cofone et al. (1973) examined an isolate of Cladosporium resinae for its hydrocarbons-clastic activity. n-Alkanes from C₉-C₁₉ gave good growth, followed by a decrease in pH. No growth was observed on gaseous hydrocarbons or on paraffin oil containing n-alkanes from C₉-C₁₉. Alkenes supported lower growth rates than did corresponding alkanes. Shaking cultures gave variable results.

Bacteria

ZoBell (1946) lists the following bacteria as known hydrocarbon-utilizers: 14 species Actinomyces, 13 Pseudomonas, 10 Proactinomyces, 10 Mycobacterium, 5 Corynebacterium, 3 Vibrio, 2 Achomobacterium, and one or more species or isolates of Desulfovibrio, Escherichia, Geikyella, Serratia, and Spirillum. The accumulation of data on hydrocarbon-utilizing bacteria is extensive. Most of this material will be reviewed in the ecology of hydrocarbon utilizers and only the references considered most pertinent to further discussion have been included.

Sohngen (1913) demonstrated that several mycobacteria and pseudomonads utilized various hydrocarbons, such as paraffin, gasoline, and petroleum as a sole source of carbon and energy. The substrates were oxidized to carbon dioxide and water (mineralization) and traces of organic acids.

Tausz and Peter (1919) described several organisms capable of attacking paraffinic hydrocarbons, including n-hexane, n-octane, di-methyl-octane, n-hexadecane, triacontane and tetracontane. These bacteria, probably pseudomonads, were inactive on cyclic hydrocarbons such as cyclohexane and dimethylycyclohexane.

Gray and Thornton (1928) isolated organisms of the genera Micrococcus, Mycobacterium, Bacterium, Bacillus and Spirillum capable of degrading various aromatic compounds. Isolates were able to utilize naphthalene, toluene, cresol, and phenol.

Bushnell and Haas (1941) demonstrated growth of cultures of Corynebacterium simplex, and three unidentified species of the genus in a mineral salt medium with solid paraffin or light oil as a carbon source. C. simplex also was able to utilize kerosene for growth. Stock cultures of various Pseudomonas species also were tested for their ability to utilize kerosene. The majority of the cultures exhibited good growth on kerosene. Mycobacterium phlei, M. lepra and M. smegmatis grew in mineral salts medium with paraffin or kerosene as substrates. Cultures of Proteus, however, failed to grow under similar conditions.

Stone et al. (1942) tested oxidation of various oils by a mixed microbial population. In examining organisms growing on crude oil, a preponderance of pseudomonads was noted. Pure culture studies of 250 representative isolates failed to show correlation between particular biochemical morphological traits and growth on any oil or oil fraction. Uniconical cultures indicated a change in biochemical reactions when placed on hydrocarbons. Oils of very high molecular weight, paraffinic nature and low molecular weight, aromatic composition were most resistant to dissimilation.

Webley (1954) observed good growth of Nocardia opaca on n-dodecane, n-tetradecane, n-hexadecane, and n-octadecane while heptane, octane and nonane supported little or no
growth.

TRECCANI et al. (1955) tested three organisms, an achromobacter, nocardia, and a mycobacterium, for their ability to utilize hydrocarbons. Cultures of nocardia and the mycobacterium utilized numerous compounds from C₅-C₈. Hydrocarbons of 3-12 carbon chain length were assimilated by the achromobacter.

4. Ecology of hydrocarbon utilizers

Although the ability of microorganisms to degrade hydrocarbons has been well established, the ecological activity and importance of these organisms has only recently attracted considerable interest due to the incidence of major oil accidents. KNEBEL (1946) calculated that the annual production of hydrocarbons through photosynthesis was approximately eighty million barrels of hydrocarbons. This large amount, coupled with the estimated one to two million metric tons added by oil transportation, sewage, and natural seeps, suggests the magnitude of hydrocarbon degradation.

Yeasts

In extensive studies of the microflora of oil fields in Japan, IZUKA and GOTO (1965) isolated several cultures of red yeasts from oil brines. All yeasts belonged to the genus Rhodotorula, except for one strain of Sporobolomyces japonica. Organisms were significantly different physiologically from those found in undisturbed soil. The yeasts studied were unable to utilize kerosene. Growth temperatures of 20-30°C also suggested an adaptation to the oil well environment.

VADALKAR et al. (1969) isolated yeasts from soil and water samples from natural lakes, oilfields, and oil seeps in India. Of the ten strains that grew well on hydrocarbons, seven were Candida species with one each of Trichosporon, Saccharomyces, and Pichia. Candida lipolytica, C. tropicalis, and Trichosporon pululans grew quite rapidly on gas-oil with generation times as low as 1.14 hours.

LEPETIT et al. (1970) isolated yeasts from two littoral areas near Marseille, France. A difference in species composition was noted between polluted and non-polluted areas. Seven species able to utilize gas-oil were isolated, all being representatives of Candida or Torulopsis, species with known hydrocarbonoclastic ability.

AHEARN et al. (1971) isolated yeasts from marine, estuarine, and freshwater environments and tested these for hydrocarbon utilization. Species of Candida, Trichosporon, Rhodotorula, Rhodosporidium, Endomyces, Pichia and Debaryomyces were able to utilize hydrocarbons. Most rapid hydrocarbon degradation occurred with species of Candida. Isolates from non-polluted areas gave less growth on hydrocarbon substrates than similar isolates from polluted areas. Increased concentration of yeasts, particularly hydrocarbon utilizers, was noted in the vicinity of an offshore oil fire, suggesting possible association with in situ degradation.

MEYERS and AHEARN (1971) noted rapid growth of Endomyces (Candida) lipolytica on most fractions of petroleum. Growth was slightly better in media with seawater as the diluent. Several isolates grow better on yeast nitrogen base and heavy gas oil than on yeast nitrogen base and glucose. Mixed cultures of organisms were able to utilize substrates not used by monotypic cultures. Yeasts were observed growing on the periphery of oil globules with an effect on the surface tension.

AHEARN and MEYERS (1972) discussed the microbiology of artificially oil-treated marsh plots. Yeasts of non-oiled areas were unable to rapidly or extensively degrade Louisiana crude oil. Populations resulting from microbial succession, primarily Trichosporon sp. and Rhodotorula, exhibited greater hydrocarbonoclastic activity. Examination of yeast biomass in the area of Shell Platform B offshore oil well fire, again showed extensive enrichment of total population in general, and particularly in hydrocarbon utilizers at sites within one-half mile of the fire.

Fungi

PERRY and CERIGNIA (1973) found that strains of Cunninghamamella elegans and Penicillium zonatum were most effective in degrading crude oil. Strains of Aspergillus versicolor, Cephalosporium acremonium, and Penicillium ochro-chlorens also grew well on hydrocarbons. Reportedly, up to 92% of a paraffinic crude
oil was degraded by selected fungi. Optimum growth temperature for *C. elegans* was 30°C and 37°C for *P. zonatum*. Organisms grew better in seawater which had been enriched with nitrogen and phosphate-containing compounds than in natural seawater.

**Walker et al.** (1973) studied hydrocarbon-utilization by *Cladosporium resinae*, a prevalent hydrocarbon-degrading fungus. Studies showed that rapid degradation of hydrocarbons was due to mineralization of most of the hydrocarbons rather than assimilation into cellular carbon. Hydrocarbon oxidation was found to proceed in most instances via a constitutive enzyme system in *C. resinae*. Growth on hydrocarbons brought about a decrease in pH in most cases. Data also indicate that *C. resinae* transports alkanes into the cell and then oxidizes these compounds. All these factors suggest a major role for the fungus in the degradation of petroleum in natural environments.

**Bacteria**

**Ekzertsev** (1968) noted formation of gaseous products when crude oil samples were incubated anaerobically. Degradation seems to be enhanced by the natural microflora of the crude oil. Increased oil breakdown was observed when crushed cores from oil-producing zones were added to the oil. Anaerobic breakdown represented the major source of methane in oil deposits.

**Polyakova** (1963) examined the heavily oil-polluted Neva Bay and estuary for hydrocarbon-utilizers. Microorganisms which could oxidize Solar oil, a Russian crude, were found in large numbers. Organisms capable of degrading benzene, toluene or anthracene were not isolated during the sampling period. Seasonal distribution studies revealed that oil-oxidizers reached a peak during the July-August sampling. Hydrocarbon-utilizing organisms were more numerous at the surface, probably in association with oil slicks. The predominant organisms found were species of *Pseudomonas*, *Myobacterium* and *Bacterium*.

**Iizuka and Komagata** (1964) isolated hydrocarbon-utilizers from oil-brines and soils of Japanese oil fields. Growth on nutrient agar brought about a rapid loss in ability of most pseudomonads to utilize hydrocarbons. Species of *Corynebacterium* and *Brevibacterium*, however, did not lose their ability to degrade hydrocarbons. Loss of enzymatic capacity suggests some essential difference in the mechanism of hydrocarbon utilization between gram-negative and gram-positive microorganisms.

**Zobell and Prokop** (1966) noted that the oil content (total unsaponifiable, carbon tetrachloride extract) of mud samples from Barataria Bay was generally from 0.001% to 0.1% of wet weight of samples. Areas of recent pollution gave oil contents of greater than 1% of the mud. Disappearance of crude oil from water surface was noted with an inoculum of 10 oil-oxidizing bacteria/ml. Illumination by sunlight compared with incubation in the dark had no observable effect on the appearance of oil after several months. Disappearance of 0.1 ml of crude oil from inoculated containers (141 liter) was observed within a period of one week, and as much as 10 ml was removed within 18 weeks with several crude oil chemical types. Field studies illustrated the removal of 100 ml of oil from the surface of a 200 liter vessel within 9 weeks. The ability of organisms to quantitatively reduce crude oil under cultured conditions were calculated by gravimetric methods and population measurements. Reduction by as much as 16.3-97.9% was noted with various crude. Oil-oxidizers were present in densities as high as 10^6 cells/gram of mud. The ability of sulfate reducers to grow, using mineral oil as sole carbon source, was also demonstrated in laboratory cultures.

**Gunkel** (1968), in bacteriological studies of polluted sediments, found increased numbers of hydrocarbon-utilizing organisms in all samples containing oil. The occurrence of proteolytic organisms was not deleteriously affected by the presence of oil in any samples. **Jones and Edington** (1968) examined the microflora of an upland moorland soil and underlying shale for organisms capable of oxidizing hydrocarbons. Samples taken at 20 cm gave the highest proportion of hydrocarbon-utilizers in all samples collected. The addition of hydrocarbons stimulated respiration. Long chain n-aliphatics were more rapidly degraded than short-chain n-
aliphatics, aromatics, and alicyclic hydrocarbons. In each sample, it was noted that fungi played an important role in degradation of hydrocarbons.

PERRY and SCHILD (1968) reported large numbers of microorganisms in soil were capable of utilizing hydrocarbons as a sole source of carbon and energy. Organisms isolated on an oxygenase requiring substrate, such as catechol or resorcinol, showed a much higher frequency of hydrocarbon utilization than those isolated on a substrate not requiring an oxygenase. Hydrocarbonoclasts represented from 1-3% of those organisms capable of growing on nutrient agar. Much greater proportions were found in areas around oil wells.

JONES (1969) studied the effects of adding various hydrocarbons to soil. Increase in microbial activity was noted with addition of n-eicosane by buried slide techniques. Further, rates of n-eicosane assimilation were lower at environmental temperature (10°C) than at experimental temperatures.

MIRONOV (1969) isolated hydrocarbon utilizers from the Black Sea. It was observed that occurrence of microorganisms was dependent on the content of petroleum products. Organisms isolated were members of the genera Bacterium, Pseudobacterium, Vibrio, Achromobacter, Micrococcus, Bacillus, Spirillum and Sarcina. In addition, different species diversities were noted for all four stations. Three near-shore sites, subject to continual petroleum input, gave diversity values of 14, 19 and 24, while a station 10 miles from shore with only slight petroleum contamination had only 11 species. MIRONOV also suggested that self-purification, i.e., autochthonous biodegradation of petroleum products, may be inhibited by the introduction of other organic compounds into the system.

MIGET et al. (1969) isolated actively oil-degrading cultures from soil and water extensively exposed to hydrocarbons. Two types of growth were noted: 1) that within the oil phase (oil positive) and 2) that within the aqueous phase. Cultures readily oxidized hydrocarbons (paraffins) up to C28. Oxidation of 30-35% of the crude oil occurred within 60 hours in enriched seawater. In an examination of Cook Inlet, Alaska, KINNEY et al. (1969) demonstrated that unoptimized inlet water could induce crude oil degradation. Approximately 100 organisms per liter were found to be able to degrade oil. It was estimated that biodegradation of crude oil was essentially complete within 1-2 months in Cook Inlet, with almost complete degradation of oil concentrations of 20 mg/l within this period.

JOHNSTON (1970) investigated crude oil decomposition in sand columns. Oxygen concentrations throughout the column decreased, with the deepest level becoming anaerobic soon after addition of oil. Slow recovery was noted beginning immediately below the oiled layer, however, recovery was not complete after four months. Removal rates of crude oil in heavily oilied (1.1 kg/m3) sand was estimated at 0.09 g oil/m2/day and 0.04 g/m2/day with a light oiling (12 mg oil/m3). Amounts of oil greater than 100 g/m3 would initiate the onset of anaerobic conditions. When normal oxygen profiles were established, crude oil was decreased only 10% suggesting that large amounts of crude were resistant to degradation in the sand column environment.

MIRONOV (1970) noted that most species of hydrocarbon utilizers were isolated when water temperatures were rather high, e.g., above 20°C. Studies showed that concentrations of organisms capable of growing in mineral media with oil as a carbon source were similar to the normal heterotrophic standing crop. The mere isolation of large numbers of hydrocarbon-utilizing microorganisms only suggests that oil can be degraded in that environment; this in not de facto evidence that degradation occurs. An isolate Pseudomonas sinosa, however, was capable of growing well on several crude oils, but only poorly on peptone. Correlations of oil degraders and ability to degrade oil pollutants would seem valid only for areas where “pure” oil pollution occurs without the addition of other organic material.

BRIDIE and BOS (1971) compared rates of oil degradation by natural seawater populations with degradation of a model substrate, e.g., mineral oil. Biodegradation of crude in seawater could be increased significantly by introduction of nitrogen and phosphorus compounds,
suggesting that the limiting factors in crude oil degradation are the availability of nitrogen and phosphorus compounds. The normally low concentrations of nitrogen and phosphorus in seawater limits extensive bacterial reproduction. Areas with large initial populations of oil degraders therefore have rapid degradation rates.

KATOR et al. (1971) demonstrated a preferential metabolism of saturated paraffins in Louisiana crude oil. Cells were found predominantly at the oil-water interface after introduction of the microbial culture. Oil “stickiness” was observed to decrease in simulated field studies. In laboratory studies, utilization of C _{16}-C _{30} n-paraffins were observed. Indications of a diauxic response i.e. two phases of exponential growth, were also detected in the laboratory.

ATLAS and BARTHA (1972a) examined degradation and mineralization of petroleum by two bacterial isolates, *Brevibacterium* sp. and *Flavobacterium* sp. Maximum degradation of crude oil and a model petroleum (C _{16}, C _{18}, C _{20}) occurred within 2 weeks. Crude oil degradation was as much as 60% with model petroleum degradation as great as 75%. Compounds to C _{14} disappeared primarily by volatilization; C _{14}-C _{22} were extensively degraded. Degradation appeared to proceed continuously without any diauxic responses.

ATLAS and BARTHA (1972b) demonstrated that the simultaneous addition of nitrate to 10^{-2} M and phosphate to 3.5×10^{-4} M significantly increased the degradation and mineralization of crude oil by natural seawater populations. Mineralization, however, appeared to be much more dependent on concentrations of nitrogen and phosphorus compounds, while degradation appeared to be constant over a range of concentrations. It was therefore suggested that deficiencies of either nitrogen or phosphorus would produce cells with abnormally high lipid stores and low metabolic activity.

SOLI and BENS (1972) isolated strains of *Corynebacterium*, *Arthrobacter*, and *Achromobacter* capable of oxidizing normal paraffins, and aromatic hydrocarbons in a synthetic seawater medium. Mixed bacterial cultures utilized as much as 50% of a Louisiana crude oil within 48 hours. Normal paraffins were more easily attacked.

JOBSON et al. (1972) observed degradation of two crude oils at 4 and 30°C by mixed bacterial cultures obtained by enrichment procedures. The initial response was emulsification, followed by an increase in density of the crude oil. Chemically, this was accompanied by a utilization of n-alkanes, with longer chains appearing to be slightly more resistant. Degradation of aromatics in crude oil mixtures but not as sole carbon sources suggested that co-oxidation may be the principal mechanism for the rapid removal of those compounds from the environment.

REISELDER et al. (1972) isolated a mixed culture capable of emulsifying crude oil in 2–4 days. In studies of dispersal of oil at 32°C by a mixed culture, a decrease in pH from 7.5 to 5.0 was noted during the first 2 days. Populations rapidly increased to maximum levels during the initial 24 hours, and then steadily declined. The mixed culture was found to be composed of several different organisms, only one of which would emulsify oil in pure culture even though all produced colonies on crude oil media and nutrient agar. RAG–1, an *Arthrobacter* isolated from the mixed culture, was capable of dispersing oil in only one day, if grown on oil prior to inoculation. Supernate fluid from cultures of RAG–1 grown on hexadecane was also able to produce dispersion of oil.

SEKI (1973) reported use of a silica gel medium for enumeration of petroleum-degrading microorganisms. Populations of petroleum utilizers were found to be less than 100/100 ml of water at several stations in Tokyo Bay.

WALKER and COLWELL (1973) recorded population levels of petroleum degraders in Chesapeake Bay ranging from 5×10^{4} to 9×10^{4} cells per sample. A decrease in pH of hydrocarbon media was noted concurrent with growth of organisms. Microorganisms grew on representative aliphatic and aromatic hydrocarbons. In laboratory studies, culture yield of organisms exposed to oil in the environment was greater than yield of organisms not exposed to oil.

ATLAS and BARTHA (1973a) enumerated hy-
drocarbon utilizers in Raritan Bay, New Jersey, with populations ranging from a low of 24 cells/l to a high of 3,400/l. Greater numbers of oil-degraders were found when Sweden crude was used in place of South Louisiana crude in the media. Sweden crude oil is more paraffinic than Louisiana crude. Mineralization of both Louisiana and Sweden crudes by natural populations in seawater collected at several stations was noted. However, it was necessary to add nitrogen and phosphorus compounds to achieve 30-40% mineralization in 18 days. Populations of oil degraders in a volume of seawater were not useful in predicting rate of disappearance of oil. Populations of all 100 ml water samples were able to reduce 1 ml of crude oil by 70% in 18 days.

BLUMER et al. (1973) reported the natural history of two oil spills in diverse environments. Light paraffinic crudes spilled near Massachusetts, U.S.A. and Bermuda showed marked persistence over more than a year of sampling. The rates and extent of oil degradation appeared to reflect the presence of nutrients, but even in the presence of decaying seaweed, the degradation of aromatics was insignificant until nearly complete removal of the n-alkanes.

5. Pathways and considerations in hydrocarbon degradation

In discussing the mechanisms of hydrocarbon degradation it is simpler to first examine the mechanism of n-alkane degradation, since these pathways are well established and are found in a greater number of organisms. Numerous workers (SENEZ and KONOVALTSCHIKOFF-MAZOYER, 1956; THIJSSSE and VAN DER LINDEN, 1958; STEWART et al., 1959; KESTER and FOSTER, 1963; LEBAULT et al., 1970; and COONEY and WALKER, 1973), have reported the formation of fatty acids from metabolized hydrocarbons. The intermediates are presumably alcohols together with several other complex metabolites. Terminal (mono-terminal) oxidation appears to be the major pathway for microorganisms, however, evidence for di-terminal oxidation has been presented by KESTER and FOSTER (1963), ALLEN et al. (1971) and MARKOVETZ (1971) have given evidence for subterminal oxidation via formation of the corresponding alcohol, ketone, and ester.

Cycloparaffin metabolism has not been as extensively studied as has paraffin metabolism, and data on the exact mechanism are scarce. The most extensive work, that of OYAMA and FOSTER (1965), deals with oxidation of cycloparaffins incapable of supporting growth as a sole source of carbon and energy. Studies showed that cycloalkanes were converted to ketonic substances, usually cyclomonoacetones. VAN DER LINDEN and THIJSSSE (1965) reported that cycloalkanes with long side chains were degraded. It was not demonstrated whether the cyclic part of the cycloalkane was metabolized.

The mechanisms of degradation of aromatic hydrocarbons have been reviewed by HIBBON (1972). Apparently, initial reactions result in the formation of dioxygenes by ill-defined processes. However, the complexity of polycyclic hydrocarbons and their constituents found in crude oil makes any generalization of degradation pathways difficult. Benzene, a representative aromatic, undergoes conversion to o xoacidic acid via catechol and muconic acid (VAN DER LINDEN and THIJSSSE, 1965).

Hydrocarbons incapable of being utilized as a sole source of carbon or energy may be degraded by another mechanism, i.e., co-metabolism; this occurs when an organism oxidizes a substrate only concomitantly with the oxidation of a utilizable substrate. LEADBETTER and FOSTER (1960) observed the phenomenon with ethane, propane, and butane during growth of Pseudomonas methane on methane. Davis and RAYMOND (1961) demonstrated that Nocardia sp. could oxidize substituted alkyl-aromatic hydrocarbons (such as p-isopropyltoluene) in the presence of n-hexadecane, but not in its absence. A variety of mono- and dicyclic hydrocarbons which themselves failed to support growth were found to be co-oxidized by pre-grown cells of Nocardia (RAYMOND et al., 1967). HORVATH and KOF (1972) explained the breakdown of alkyl-benzene sulfonates by mixed microbial species as co-metabolism. HORVATH (1972) indicated that co-metabolism is an important degradation mechanism for some complex molecules.
ever, the relationship between specific compounds and the co-metabolites of these non-growth hydrocarbons has not yet been established conclusively. Many common compounds, *i.e.*, chitin, cellulose, protein, and their breakdown products may prove suitable co-substrates for many compounds now regarded as recal-
citrant.

Among the more important factors in the rapid degradation of crude oil are oxygen, temperature, availability of nutrients, and surface area.

**Oxygen.**—Established pathways of hydrocarbon metabolism involve the initial action of an oxygenase system. BUSHNELL and HAAS (1941) suggested that organisms might also be able to use combined forms of oxygen such as nitrates or sulfates in oxidation of crude oil. They stated, however, that these alternate oxygen sources were used only when natural free $O_2$ was in low concentration. The work of NOVELLI and ZOBELL (1944) supported this hypothesis in part. The ability of species of *Desulfovibrio* to assimilate various hydrocarbons from decane to hentriacontane under anaerobic conditions was reported. HANSEN and KALLIO (1957), however, were unable to demonstrate use of nitrate as a terminal oxidant for hydrocarbons. Using oxygenated-homologous substrates it was easily demonstrated that once oxygen was incor-
porated into the hydrocarbon structure, it could easily be degraded with nitrate and presumably sulfate as the electron acceptor.

LEADBETTER and FOSTER (1959) clearly estab-
lished the incorporation of molecular oxygen by bacteria utilizing hydrocarbons. Organisms cultured on hydrocarbons in an atmosphere containing oxygen-18 showed an increase in $^{18}O$ concentrations over organisms grown on non-
hydrocarbon substrates. ISHIKURA and FOSTER (1961) noted incorporation of $^{18}O$ into cells of *Candida lipolytica* grown on hydrocarbons.

Anaerobic hydrocarbon metabolism is still an enigma. EKZERTSEV (1958) indicated that apparent anaerobic decomposition of oil occurred in the presence of fragmented cores from oil productive horizons. Gas formation was ob-
served and the principal gases were identified as methane and carbon dioxide. The microbial agents were not identified, but this activity probably was the result of mixed populations rather than a single organism. The scattered reports which suggest anaerobic biodegradation of hydrocarbons may in fact be attributed to degradation of oil constituents containing mo-
lecular oxygen.

ZOBELL and PROKOP (1966) presented evidence that mud samples from Barnatia Bay contained organisms capable of anaerobically oxidizing mineral oil. The production of sulfides sug-
gested that sulfates were being reduced in the oxygenation of hydrocarbons, and that *Desulfo-
vibrio* played some role in this anaerobic oxidation of hydrocarbons. Elsewhere, POST-
GATE (1959) suggested the inability of most *Desulfovibrio* spp. in pure culture to degrade specific hydrocarbon compounds with sulfate as the electron acceptor. Thus, ZOBELL and Prokop's observation might be attributed to the action of a mixed anaerobic microbial flora rather than to a single organism (ZOBELL, 1969).

More recently, IIDA and IIZUKA (1970) demonstrated anaerobic formation of $n$-decyl alcohol from $n$-decene-1 by resting cells of *Candida rugosa*. This and previous observations (IZUKA et al., 1969; IIZUKA et al., 1968) of $n$-decane-1 as an intermediate in the breakdown of $n$-decane suggests an alternative to aerobic oxidation. A pathway involving dehydrogenation to the alkene and anaerobic oxidation to decyl alcohol was postulated.

**Temperature.**—Hydrocarbon degradation may occur over a wide range of temperatures. En-
vironmental biodegradation, however, is com-
licated by a number of non-biological factors, such as evaporation, dispersion, solubility, spreading, and emulsification, all of which may be temperature dependent. Most laboratory studies, however, have been conducted in the 20-30°C range, where rapid degradation does occur. KLUG and MARKOVETZ (1967a) and MATELES et al. (1967) have observed the growth of thermotolerant species of *Candida* and *Bacillus* on hydrocarbons at temperatures above 40°C. ZOBELL and AGOSTI (1972) and ZOBELL (1973b) have reported the degradation of hydrocarbons below 0°C. GUNKEL (1967) showed reduced degradation rates at low tem-
peratures.

Kinney et al. (1969) concluded that biodegradation was the major agent in the Cook Inlet, where temperatures rarely reached 5°C. Rates of degradation at 5°C were seven times lower than rates at 10°C. Atlas and Bartha (1972c) noted longer lag phases in addition to reduced growth rates at lower temperatures. Kator et al. (1971) found that paraffin oxidation rates doubled with a 10°C rise in temperature.

Nutrients.—Nitrogen and phosphorus seem to be the limiting elements in environmental biodegradation of crude oil. Most other elements K, Mg, Fe, Ca, which might be required are in adequate concentrations in most environments. Imelik (1948) reported that phosphorus enrichment was necessary for growth of Pseudomonas aeruginosa on hydrocarbons. The addition of magnesium also gave beneficial effects.

Gunkel (1967) reported enhanced biodegradation when cultures were supplemented with phosphates and ammonium chloride. Lepetit and Barthelemy (1968) found similar effects with nitrogen and phosphorus supplementation, with rapid utilization of nitrogen between the second and fifth days, corresponding to the period of maximal oil loss. Atlas and Bartha (1972b) extensively studied limitation of oil degradation by nitrogen and phosphorus. Addition of $10^{-2}$M nitrate and $3.5 \times 10^{-4}$ phosphate increased biodegradation from 3 to 70% and mineralization from 1 to 42%.

Gunkel (1967) observed that addition of peptone inhibited degradation of crude oil. When peptone or peptone and yeast extract was added, the initial rate of oil degradation was affected. However, after 8 weeks, the total amount of oil degraded was comparable to that lost in unsupplemented media. Lepetit and Barthelemy (1968) also observed inhibition by peptone. In contrast, Gill and Ratledge (1973) found that the addition of alkanes to a culture of Candida sp. growing exponentially on glucose resulted in a novel diauxic effect, namely, the inhibition of glucose transport and assimilation. Yet the growth of certain yeasts may be inhibited by aromatic compounds and other constituents of crude oils (Ahearn et al., 1971).

Surface Area.—Water appears to be essential to the degradation of crude oil. Hill (1968) has demonstrated that dry kerosene was lethal to species of Nocardia and Pseudomonas within a few hours. Cladosporium resinae, however, survived well in low water concentrations. Cooney et al. (1968) noted that isolates of Pseudomonas aeruginosa and a Hormodendrum sp. were not able to grow without a water phase. Pilpel (1968) observed that oil in water emulsions and a thin layer of oil on water were more rapidly degraded than water in oil emulsions. Increasing the surface area of oil-water interface can have many beneficial effects, among which are the following:

1) increases leaching of soluble (usually toxic) hydrocarbons
2) increases the availability of nutrients
3) aids penetration of oxygen
4) increases area available for microbial attack
5) increases the removal of toxic or inhibitory metabolic products.

Several studies (Ahearn et al., 1971; Severance and LARock, 1973) have reported oleophilic microorganisms which either penetrate into the oil phase or selectively grow in the oil of a water-oil system. The physicochemical factors governing this type of growth are as yet unknown.

Artificial enhancement of biodegradation.—ZoBell (1969) suggested that microorganisms might be used to enhance degradation of polluting oils in areas where conventional methods of removal were not feasible. Miget et al. (1969) studied the feasibility of seeding microbial cultures on oil-polluted waters. The limiting factors, as previously mentioned, appeared to be nitrogen and phosphorus concentrations. Most schemes of “seeding” oil spills have provided for some additional sources of these elements. Rorichaux and Myrick (1972) demonstrated that, in addition to mixed microbial inocula, various chemical dispersants could hasten the destruction of oil pollutants. Atlas and Bartha (1973b) established the effectiveness of oleophilic nitrogen and phosphorus sources in enhancing biodegradation of 

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oil. Paraffinized urea and octylphosphates gave greater degradation of oil in environmental simulation tests. It was anticipated that the oleophilic nature of these compounds would not simulate algal blooms; such blooms are a serious problem with water-soluble nitrogen and phosphorus sources.

The effectiveness of oleophilic fertilizers in stimulating oil slick biodegradation is yet to be established in field experiments. Several investigators (JOBS, et al., 1974; ANDERES, 1973) have indicated that sites remote from oil pollution lacked significant populations of hydrocarbonlastic flora. Fertilization of such sites may be ineffective unless a seed inoculum is added. The application of microbial seed systems to facilitate oil biodegradation may be best suited for specialized environments such as marshes or refinery water treatment systems. Marshes are unsuitable for the use of standard oil spill clean-up procedures and their importance as productivity centers should preclude the use of toxic dispersants or burning procedures. Water treatment systems or shipboard bunkers may be most amenable to seed culture use, since environmental conditions for such facilities may be partially controlled. At present, maximal oil utilization is achieved with mixed culture systems. Factors governing successional development of diverse microorganisms on crude oil are ill defined. Understanding of this complex area will need to be attained before practical application of seed culture systems can be realized.

References


ALLEN, J. E., F. W. FORNEY and A. J. MARKO


BLUMER, M., M. EHRLHARDT and J. H. JONES (1973):


HILL, E. C. (1968): Biochemical degradation of


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203.


学会記事

1. 昭和49年5月24日、東京水産大学において評議員会が開かれた。
1) 会務報告、発表報告が行われた。
2) 昭和48年度の収支決算及び昭和49年度の予算案が審議された。
3) 学会賞受賞候補者推進委員会の森田委員長から松生氏を受賞候補者として推薦した経過について報告があり、松生氏が受賞者に決定した経過が佐々木会長から報告された。
4) 昭和49年度学会賞受賞候補者推進委員14名を下記のとおり選出した。
有賀裕雄、石野雄、今村謙、宇野健、草下孝也、久保田博、高谷泰一、佐藤正弘、杉浦吉雄、多賀信夫、高野健三、松生裕、森田良美、山路勇（五十音順）

2. 昭和49年5月30日、日仏会館講演室において第2回総会が開かれ、佐々木会長の挨拶に引き続き次の報告、審議が行われた。
1) 昭和48年度の会務並びに学会報告が行われた。なお、昭和48年度の収支決算（別表）は監事の監査を受け承認された。
会員数：48年度の新入会員は正会員12名、賛助会員4名、個人会員5名（内死亡1名）、賛助会員2社である。昭和49年3月31日現在の会員数は名簿会員11名、正会員416名、賛助会員56社である。
2) 今村編集委員長から学会誌第11巻の編集経過報告が行われた。
第11巻第1〜4号は総ページ数232ページで、その内容は論文14編（和文5、英文9）、寄稿１編（和文）、総説2編（和文1、英文1）、資料1編（和文）、シンポジウム10編、記念講演1編、その他学会記事などである。
なお、第12巻より表紙に色紙を使用せず白色とすることにした。
3) 森田委員長並びに佐々木会長から学会賞受賞候補者選考並びに賛助者決定までの経過報告があった。
4) 正会員費の値上げについて審議の結果、現在の1,500円を2,500円に値上げすることが承認された。
5) 昭和48年度の収支決算並びに昭和49年度の予算案について審議の結果。別表のとおり承認された。

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6) 昭和49, 50年度の評議員選出された。（日仏海洋学会役員, 本誌(38)ページ参照）
7) 昭和49年度学会賞受賞指名者推薦委員の選出について報告された。
3) 総会終了後, 引き続き学会賞の授与が行われた。
昭和49年日本海洋学会賞受賞者：松生浩史（東京大学水産大学）
受賞講演：大洋における光学的特性に関する研究（別項「推薦理由」参照）
佐々木会長から松生浩史博士に賞状、メダル及び賞金が授与され、続いて受賞記念講演が行われた。
4) 講演終了後, 講演会を開催し、多数の参加者が集まり、盛況であった。
5) 昭和49年5月30日、2日目の日仏海洋学会に於いて、昭和49年度「日仏海洋学会学術研究発表会」が次の通り開催された。

第1日（5月30日）
午前の部
座長： 前川次三郎（東京大学）
1) 最近の沿岸海流の潮流調査方法と利用方法

午後の部
座長： 前川次三郎（東京大学）
2) 1984年小樽海浜の流れ調査

第2日（5月31日）
午前の部
座長： 石野誠（東京大学）
9) 沿岸水系の汚濁負荷と海水交換についての考察

午後の部
座長： 高野弘幸（東京大学）
14) 冬期の西太平洋におけるクロロフィルaとフェオフィチンの分布特性について（佐野昭（気象庁）
15) 生物による内湾環境の指標性

特別講演
座長： 松生浩史（東京大学）
西之島新島の地形物理・化学と海洋学的災害調査結果について（城戸卓夫（東京大学）
映画： 西之島新島の記録（16ミリ カラー）
<table>
<thead>
<tr>
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<td>船の科学館</td>
<td>佐々木光義</td>
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<td>Samuel P. Meyers</td>
<td>Louisiana State</td>
<td>関 文雄</td>
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<td>University, U.S.A.</td>
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7. 会員の住所、所属の変更。

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<tr>
<th>氏名</th>
<th>新住所又は新所属</th>
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8. 交流及び寄呈図書。
1) 研究実用化報告 22(1), 23(1,2), (電通研) |
2) Science et Pêche, No. 8, 239-231. |
4) 東京海洋大学学術研究  | 270, 271 |
5) 神戸海洋気象台紀要  | 32, 1974年 |
6) 海洋研究資料  | 6(2,5), |
7) 港湾技術研究所報告  | 12(4), |
8) 港湾技術資料 No. 171-175. |
9) Ocean Age  | 6(4,5) |
10) 国立科学博物館研究報告  | 17(1). |

12) 海洋機器開発  | 6(3,4), |
13) 広島県水产試験場研究報告  | 第5号, |
14) 広島県水产試験場事業報告  | 昭和47年度, |

日仏海洋学会賞受賞候補者推薦理由書

氏名： 松田 洋（東京海洋大学）

題目： 大洋における光学的性質に関する研究

推薦理由： 松田氏は1961年頃から東京海洋大学に所属する

ことで、太平洋、東部インド洋及び南極洋にわたる広範な

光学的観測を行い、従来資料が極めて少なかった大洋の

光学的性質に関する多くの新しい事実を発見した。松田

氏の研究は、太陽エネルギー分布について天空から海面

までの一貫して観測していること、及びその結果を地球全

体にわたってグローバルに応用していること、この二点

で特に高く評価されており、その成果の主なものを要約

すれば次の通りである。

(1) 従来の大洋では海域の違いや水深構造によってあ

まり大きな差がないと考えられていた海水の光学的性質

について、実事例に基づく大きな差があることを広範

な観測によって明らかにした。例えば、南極海域、東

北極海域、南極収束線域、黒潮海域、東部インド洋海

域は、波高の影響が大きいため、放射透度比、波長間強度比の

各面から、それぞれ異なる光学的性質をもっているこ

や、水深と水温の関係においては光学的性質にも著

しい特異性があることなど、多くの新事実を見いだし

た。

(2) 従来主に海上の観測に基づいて研究されてきた日射

量の分布について、大洋上的観測から検証を加え、可

能日射量及び面積日射量を広範囲にわたって算出し、

可能日射量は各渡程ともKRAITKINSの10%%小さいことなどの結果を得た。

(3) これらから海洋生物にに関する概念海洋エネルギー

フラックスの分布を計算し、例えば、10 m 深さでの

間の量値の比は、インド洋沿海岸域：黒潮：東北極洋：

南極：北極収束線域：100：54：44：13：6 である

こと等を示した。

以上の成果は海洋物理学者の進歩に寄与する所が顕著で

あるのみならず、海洋の基礎科学や生態学の研究者を輝

著する所も大であり、本賞を受けるに十分である。

学会賞受賞候補者推薦委員会

委員長：森 田 良 美

1967: Study on the optical characteristics of the waters in the three oceans. Part 1. Optical structure of the Kuroshio (Japan Current) from Lat. 20° N to Lat. 31° N along the meridian of 142°E. J. Tokyo Univ. Fish., 53(1-2).


1973: A study on optical nature in oceanic waters. La mer, 11(1).

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（59）
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第15回総会で、昭和49年度から下記のように会費（年額）の改正が承認されましたのでお知らせ致します。

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