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The role of cryptozoology in achieving an exhaustive inventory of the marine fauna*

Paul H. LeBlond**

The Sea has played a vital role in the development of many areas of Science. Its rich and varied fauna has provided naturalists with clues from which they have been able to make sense of the diversity of life. The shape of the ocean basins and of the great ridges which traverse them has led to the development of plate tectonics and to a new understanding of the Earth’s crust.

In recent years, there has been increased emphasis on the exploitation of the Ocean, with concerns focusing on the quantitative aspects of marine biology. Questions such as “How many?” rather than “What kind?” of marine organisms have come to the fore.

Have we now perhaps left behind the Age of Exploration to enter that of Exploitation of the Sea? Not entirely. The ocean depths retain much of their mystery and continue to attract daring explorers and broad public interest. Millions thrill with Jacques Cousteau in watching an undersea world where there always seems to be something new to be discovered.

But, is there really anything worthwhile left to be discovered in the ocean? In this age of electronic in-situ sampling, deep-diving submersibles, remote sensing and computer modelling, can there be anything significant left to find? Have we by now explored the oceans widely and thoroughly enough that only matters of detail or of complexity need be settled?

Most oceanographers would argue that our knowledge of the oceans is still incomplete and superficial, that much remains to be discovered and clarified in flow dynamics, fish behaviour, ecological relationships, tectonic processes, climatic mechanisms, etc... Thousands of marine scientists around the world wouldn’t be exploring and studying the ocean with such dedication if they did not believe that something important remains to be discovered!

One should thus have little difficulty in convincing a scientific audience that great discoveries are still to be made in many fields of marine sciences. To explore the broader aspects of future discovery in marine sciences is however a challenge which I will leave for some other occasion. Rather, I have selected a more specific, and more controversial question which exemplifies many of the points related to the anticipation of potential discovery.

The question asked here is the following: Are there any important elements of the marine fauna left to be discovered? In other words, are there still any large, or new, or unexpected animals in the oceans which remain to this day unknown to science? And if so, how many?

Many have answered the general question in the affirmative, and some, like HEUVELMANS (1983), have even ventured to extrapolate from historical rates of discovery...
to obtain an estimate of the number of future discoveries to be expected. Let us refrain from searching for a definite answer to the question: we cannot positively know that there are undiscovered animals until they are actually found, identified and categorized to the general satisfaction of the scientific community. Asking the question nevertheless forces us to consider the process whereby new elements of the marine fauna are become known to science.

Most, if not all, marine animals have been discovered by accident, through man’s efforts at fishing. As its diversity has revealed itself, the marine fauna has been catalogued and apportioned in families, classes and phyla. As in other areas of science, improvements in sampling and harvesting methods have led to unsuspected discoveries: new animals have been added to the marine bestiary. Deep submersibles, for example, have made detailed visual exploration of the ocean floor possible, leading to the discovery of a completely unexpected fauna near deep-sea thermal vents. Parsons (1985) has emphasized the need to explore for the sake of discovery in order to broaden our knowledge of the oceans. His remarks apply directly to the discovery of new marine creatures.

Occasionally, there have also occurred significant and surprising discoveries unrelated to the development of new observational methods. The coelacanth, Latimeria chalumnae, had already been fished up many times from the mid-depths of the Indian Ocean by Comoro Island natives before a specimen came to the attention of Marjorie Courtenary-Latimer in 1938 (Smith, 1956; Courtenary-Latimer, 1979). Because of its kinship to primitive fishes known only from the fossil record, its modern discovery attracted considerable attention. The megamouth shark, Megachasma pelagios, (Taylor et al., 1983) on the other hand did not have a fossil pedigree. The first specimen was brought up in 1976 tangled in the anchor chain of a US Navy ship in Hawaii. Two more specimens have since been found, one off California, the other off western Australia, suggesting a global distribution (ISC, 1988).

In the face of such unexpected discoveries, and considering the prospects for improvement in techniques of observing and sampling the oceans, it would seem presumptuous to declare that no further discoveries are to be expected. We are thus back to the question: “How many?”

One might argue that on the time scale of modern scientific discovery, there is a fixed and finite number of animal species in the oceans. The more have been discovered, the less there remains to be found. That is however of little use since the total remains unknown, and hence so does the residue. Beyond the arguments of plausibility based on expectations of better sampling and on past accidental discoveries, there are however observations which point towards the possibility of additional discoveries and give hints as to their nature.

A definite addition to the fauna is made by catching an animal. But what if the animal is only seen, not caught? How do we account for those that get away? Most zoologists would rather discard near misses and wait until a tangible type-specimen is available to pronounce on species and genus. Until caught, a creature remains a rumour, an unconfirmed visual observation, not yet the object of zoology, but rather that of cryptozoology.

The term cryptozoology was coined by the French zoologist Bernard Heuvelmans in the 1950’s (Heuvelmans, 1982) to describe the study of creatures which are known only through visual or incomplete material evidence. Such animals are also called cryptids, a more appropriate term than monsters; the term is usually reserved for rather large creatures, observable at sea without instrumentation. Cryptids are often well known to natives before attracting the attention of science: such was the case for the coelacanth. Sometimes scientists are awarded a fleeting glimpse of an animal which they can only describe without being able to collect a specimen. This is what happened to Meade-Waldo and Nicoll (1906) as they saw an unidentified marine animal with a long neck.
and a large dorsal fin swim past their ship off the coast of Brazil.

Cryptids provide a clue of what is to be expected in terms of future discoveries, at least for rather large animals. Indeed some erstwhile cryptids have already graduated to zoological acceptance. There are many examples on land: the gorilla, the okapi, the platypus. A marine example is the giant squid Architeuthis, the Kraken of Norse mythology, now known from many strandings.

So, what does cryptozoology tell us? HEUVELMANS (1986) has brought together a checklist of unknown animals, the result of three decades of research on eye-witness reports. Marine cryptids figure prominently. What follows is drawn from HEUVELMANS’ (1986) list; further documentation if found in HEUVELMANS (1968).

Unconfirmed cetaceans lead the list of marine animals for which no specimens have been captured. A high-finned sperm-whale, 60 feet in length, is said to have been frequently seen around the Shetland Islands in the 17th century. It is reported by Sir Robert Sibbald, and described by him as *Physalus turio* (HEUVELMANS, 1986). Another long-finned whale, 20–30 feet long, was reported by WILSON (1907) who saw three specimens in January 1902 and four more the following month while on Robert Scott’s *Discovery* expedition in the Antarctic.

It is not surprising to find a possible new species of beaked whales in the list. A number of beaked whales, the Mesoplodonts in particular (WATSON, 1981), are known only from a few strandings and are difficult to identify at sea. HEUVELMANS (1968) quotes P.H. Gosse as having watched a school of 30 ft long, yet unidentified whales, black above and white below, in the North Atlantic over a century ago.

HEUVELMANS also includes a new kind of killer whale, entirely sepia brown with star-shaped scars, sighted several times in the Gulf of Aden by MÖRZER BRUYN (1971). The same author mentions three dolphins, one from the Mediterranean, one from the coast of Senegal, and one from the Philippines. A black and white spotted dolphin with two dorsal fins has also been reported from the Mediterranean and from the Southern Ocean (HEUVELMANS, 1968).

Tales of less conventional creatures are also to be expected: the undiscovered is bound to be strange. “Mermaids” and “mermen” are mentioned by HEUVELMANS (1986) as having been frequently reported from areas where no recent species of sirensians are known to have lived during historical times. Rumours of survival of Steller’s sea-cow (*Hydrodamalis gigas*) continue to be heard along the Bering Sea shores. Both MACKAL (1980) and HEUVELMANS mention the “sea-ape”, a creature seen off the Aleutian Islands by Steller in 1741.

Reports of large, mostly elongated marine animals usually referred to as sea-serpents have been classified by HEUVELMANS (1968) into seven categories corresponding to their morphological characteristics: the super-otter, the many-lumped sea-serpent, the long-necked sea-lion, the merhorse and a many-finned, armoured archecete—all mammals—with a huge ocean-dwelling saurian and a large eel-like fish in addition. HEUVELMANS examined over 600 reports to arrive at his classification. A more localized survey on the western coast of North America (LEBLOND and SIBERT, 1973) identified three types of marine cryptids: two of them variants of Heuvelmans’ merhorse, the other an elongated creature, all three apparently air breathers and mammalian.

Finally, there are the reports of giant octopus, focusing on a mysterious standing on a Florida beach at the end of the last century (see also MACKAL, 1980).

If only a fraction of these reports is based on fact, there remains a rich harvest of discovery of major faunistic elements in the world ocean. However, because all these observations are based only on eye-witness reports and cannot be backed by tangible specimens, their status remains doubtful. Cryptozoological evidence is subjective and non-reproducible. While there is no a priori reason to reject as fanciful every shred of visual information, the scientific method has
gained respect as a method of arriving at universally accepted truths precisely because it deals with objective and reproducible evidence. Cryptozoology should thus perhaps be seen as a precursor of zoology, arriving at its conclusions earlier, but with less confidence. One should thus not conclude that the various cryptids glimpsed in the sea must all be discovered some day; some may, others may not. Cryptozoology only provides clues as to what may yet be confirmed; it is like a road map based on hearsay: better than nothing, but not entirely to be trusted.

Cryptozoological information should thus be seen as an adjunct to zoological discovery; not a body of information which is to be believed or disbelieved, but a collection of indices which should not be ignored and which may inspire and guide marine scientists in their effort to complete the inventory of the larger elements of the marine fauna. There is no such guide for small or microscopic creatures, where the need for exploratory research is even more acute.

References
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list of apparently unknown animals with which cryptozoology is concerned. Cryptozoology, 5, 1-26.
Internal tidal waves and internal long period waves in the Sanriku coastal seas, eastern coast of northern Japan*

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Abstract: The study of internal tidal waves in a bay was carried out on the basis of observed records in Toni Bay (located in the northeastern area of Honshu) in autumn 1984.

a) It was found that the internal tidal waves were predominant and appeared intermittently with a duration of several days in the bay. On the basis of T-S diagram analyses, it was suggested that the intermittency of the internal tidal waves in the bay was closely related to the intermittent vertical displacement of the offshore thermocline.

b) The cause of the intermittent vertical displacement of the thermocline was investigated by analyzing subsurface water temperature at two bays and the variation of sea surface level anomaly (local difference of tidal deviations) among three bays adjacent to Toni Bay. From the analysis of the variation of the thermocline depth, some evidence was obtained for the existence of internal long period waves propagating southward along the coast. The intermittent appearance of the internal tidal wave in the bay occurred from the superposition of the internal tidal wave propagating onshore and the internal long period wave propagating alongshore. Moreover, it is suggested that the internal long period waves are related to the behaviour of an offshore density front at the sea surface in Sanriku coastal seas.

c) The internal tidal waves of semidiurnal period in the bay were likely related to the 2nd mode of the offshore internal tidal waves from comparison of the dispersion relations of the internal tidal waves in the bay with those out of the bay and from the simple model estimation of an energy efficiency of the offshore internal tidal waves propagating into the bay.

1. Introduction

In reports on observations of internal tidal waves, the intermittency of occurrence of internal tidal waves has been noted only recently. In the open ocean, the internal tidal waves are found as predominant semidiurnal fluctuations of the current velocity in several subsurface depths. For example, WUNSCH (1975) quoted from MAGAARD and MCKEE (1973) and indicated that the intermittency of about 10 days was remarkable in the variation of the amplitude of the internal tidal waves.

In coastal sea areas, there are reports on the propagations of semidiurnal internal waves and their breaking at the shelf break in the northwestern coastal sea area of Australia (HOLLOWAY, 1984, 1985). The intermittency of about 10 days was noticeable in his records of water temperature and velocity components, though he describes nothing about it. In Japan, the reports of the internal tidal waves have increased in recent years; there are only two reports indicating the intermittency of the internal tidal waves for the present. INABA (1981) reported that in the subsurface layer of Suruga Bay, a diurnal period was dominant in the tidal current in contrast to the predominance of a semidiurnal period in the sea surface tide and this was due to the existence of an internal wave in the subsurface layer. MATSUYAMA (1987) suggested the intermittency of 7-10 days in the records of the velocity components in INABA (1981). In Uchiura Bay located at the head of Suruga Bay, the record of sea water temperature in the subsurface layer showed a predominant semidiurnal fluctuation, and this was due to resonance of the semidiurnal tide with the internal seiche in Uchiura Bay (MATSUYAMA, 1985). In addition, he de-
scribed that the semidiurnal fluctuations intermittently disappeared in 3–5 days due to the passing of a typhoon near Suruga Bay. In the coastal sea of Joban, southern neighbour of the Sanriku sea area, the internal tidal waves were dominant in semidiurnal period and propagated onshore, and the intermittent behavior of the semidiurnal internal tide was noticeable in his record of the suburface water temperature (MATSUNO, 1989).

Sanriku coast is one of the suitable fields for studying the phenomena of the internal mode, since the Tsugaru Warm Water (TWW) is lighter than the Oyashio Cold Water (OCW) (in spite of higher salinity, smaller water density than that of OCW is attributed to higher temperature of TWW), the strong thermocline is usually kept offshore. The lighter and warmer water flowing through the Tsugaru Strait to the Pacific Ocean from the Japan Sea is the origin of TWW, which is generally flowing southwards along Sanriku coast in a surface layer with thickness of 150–200 m (HANAWA, 1984). In autumn, TWW spreads sometimes about 100km to the east of the Tsugaru Strait before flows southward along the Sanriku coast. A remarkable pycnocline front (or thermocline front) at the sea surface is observed at the eastern boundary of TWW, because the heavier OCW is found under and off TWW. The depth of the thermocline under TWW becomes deeper shoreward as an extension of the surface front in contrast with the Kuroshio front which is shallower shoreward in the south sea area of Honshu. Thus, the thermocline is also clear near the coast, and the internal wave is easy to generate in such a sea area.

A phenomenon of “Sakashio”, named by Japanese fishermen, occurs sometimes in many bays of the Sanriku coast. “Sakashio” means the subsurface tidal flow opposite to the surface flow. When “Sakashio” occurs in a bay, it is difficult to wind up “the Set Net”, which is a kind of fish net widely used in Sanriku coast. This phenomenon is closely related to the occurrence of the internal waves in the bay. Therefore the internal waves are one of the important oceanographic phenomena for coastal fishery, and they are also important for cultural fishery, since the internal tidal waves force the exchange of coastal sea waters in the bay for offshore sea waters.

In order to clarify the behavior of the internal tidal waves in Sanriku coastal seas, the observations were carried out in one of the bays in Sanriku coast (Toni Bay, located in Kamaishi) from October to December 1984.

In this paper, several properties of the internal tidal waves become clear, especially their intermittent appearance in the bay. In chapter 2, the outline of observations will be given. In chapter 3, some typical examples of records are shown, and the properties of the internal tidal waves observed in Toni Bay and the intermittency in the internal tidal waves with duration of several days are explained. In addition, the intermittent property is described with relation to the vertical displacement of the thermocline. In section 1 of chapter 4, some evidence for the existence of the internal long period wave will be shown. Discussion is extended to the role of such waves as a cause of the intermittent vertical displacement of the thermocline and the relation between such waves and the oceanic front. In section 2 of chapter 4, the properties for propagation of the internal tidal waves in the bay will be stated in relation to the properties of the offshore internal tidal waves, and the shoaling up of the internal tidal waves into the bay will be discussed concerning the nature of the exchange of sea water in the coastal seas.

2. Observations and data

The Sanriku coast is called a Rias type in geology, and has a complicated coast line. The configuration of sea bottom in this sea area is also complicated in areas shallower than 130 m depth, and the bottom contours run almost straight north to south in deeper seas. The sea floor increases gradually in depth toward the Japan Trench. The complicated coast line is conspicuous, especially southward of Miyako Bay in the Sanriku coast. Otsuchi Bay is 33km southward, Kamaishi Bay is 45km southward of Miyako
Bay, and Ofunato Bay is 35km southward of Kamaishi Bay. Toni Bay is 8km southward of Kamaishi Bay (Fig. 1). Its bay mouth faces eastwards to the Pacific Ocean. The sea valley runs into the center of Toni Bay, and the breadth of the bay mouth is about 4km. The depth is about 90 m at the center of the bay mouth and about 40 m on the average; the length of the bay is 5-6 km.

Previous physical oceanographic research in Toni Bay showed that there was a counterclockwise circulation in the bay and the flow in the bottom layer differed from that in the surface layer (TSUJITA, 1974).

Two observations were carried out in Toni Bay from 1 October to 15 December 1984. The first observation was made at 14 stations in Toni Bay (Sta. 0 - Sta. 13) every three days on a ship-contained STD (portable) which measured water temperature and salinity at 1 m intervals from the sea surface to the bottom (or maximum 80 m deep) (Fig. 1). The second observation was the continual observation by means of current meters which were fixed to the bottom by anchors and subsurface buoys of the mooring system. Sta. A (33 m depth) was settled near the head of the bay, Sta. D (65 m depth) was north of the center of the bay mouth, Sta. C (63 m depth) was south of the center of the bay mouth and Sta. B (44 m depth) was at the midpoint of the north side of the bay (Fig. 1). At all stations, Aanderaa current meters were set in the surface layer (10 m below sea surface) and in the bottom layer (5 m above bottom) to measure current speed, current direction, water temperature and salinity every 10 minutes. The record of a current meter was averaged over an hour before analysis. The continual record was divided into two parts, 1 October - 8 November and 9 November - 15 December. Unfortunately, the record of the current meter in the bottom layer at Sta. D was not obtained because of
Fig. 2. An example of the time series of Aanderaa current meter record in the bottom layer at Sta. C (Oct. 1-31, 1984). Wind, vector expression of wind every 3 hours. U, eastward component of velocity (thick line) and its 25 hour running mean (thin line). V, northward component of velocity (thick line) and its 25 hour running mean (thin line). Temp., sea water temperature.

mechanical trouble.

In addition to those records, the following data of the routine observations by governmental offices were available to the present paper:

1) The monthly data of routine coastal observations in 4 lines off the Sanriku coast by Iwate Prefecture Fishery Experimental Station (Fig. 1).

2) The hourly data of tidal observations in Miyako Bay, Kamaishi Bay and Ofunato Bay (the forecasted data and the observed data) by Branches of Meteorological Agency and others.

3) The meteorological data every three hours at Miyako, Kamaishi and Ofunato (air pressure, wind speed and wind direction).

4) Simultaneous data of temporal deep sea observations far off Sanriku, by Meteorological Agency.

The Iwate Prefecture Fishery Experimental Station has carried on the monthly observation of water temperature and salinity in several depths shallower than 300 m at each station in 4 observation lines off the Sanriku coast. In each observation line, 8 stations are set, for example, Sta.1 is 0.7 km and Sta. 8 is about 130 km from the coast in the Osaki line. Details of 4 coastal routine observation lines are:

- Kuroasaki Line (KI - KIII) (40’00’’N, 141°52’-143°30’E);
- Todosaki Line (TD I - TD III) (39°32’N, 142°06’-143°35’E);
- Osaki Line (OS I - OSIII) (39°15’N, 142°04’-143°30’E);
- Tsubakijima Line (TJ I - TJVIII) (38°56’N, 141°44’-143°14’E).

Those routine data were very useful to the present work as indicators of information in the offshore sea area, especially the Osaki line located about 3 km from Toni Bay (Fig. 1).

3. Analysis and results

1) An example of records

a) Time series of current meter records

Time series of several components of the current meter record in the bottom layer at Sta.C are shown in Fig. 2. The variation of water temperature is apparently different from that in the surface layer (refer to Fig. 6). Water temperature fluctuated periodically and its range was 6°C in maximum value. Before 15 October, the period of the fluctuations was semi-diurnal, but it was near-
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Sta.8

\[ \begin{array}{ccc}
33 & 34 & 35 \\
36 & 37 & 38 \\
\end{array} \]

Depth (m)

- Temp. (°C)
- Salt (permil)
- Delt-T (cl/ton)

Sta.9(B)

\[ \begin{array}{ccc}
33 & 34 & 35 \\
36 & 37 & 38 \\
\end{array} \]

Sta.10

\[ \begin{array}{ccc}
33 & 34 & 35 \\
36 & 37 & 38 \\
\end{array} \]

Sta.11(C)

\[ \begin{array}{ccc}
33 & 34 & 35 \\
36 & 37 & 38 \\
\end{array} \]

Sta.12(D)

\[ \begin{array}{ccc}
33 & 34 & 35 \\
36 & 37 & 38 \\
\end{array} \]

Sta.13

\[ \begin{array}{ccc}
33 & 34 & 35 \\
36 & 37 & 38 \\
\end{array} \]

Fig. 3. Vertical distribution of temperature (°C), salinity (permil) and specific volum anomaly (cl/ton) of sea water in the mouth of Toni Bay (14:43 - 15:46, Oct. 1, 1984).

ly diurnal in 16-24 October, though its fluctuation was considerably disturbed. It is of interest that the days of steady and high temperature were 5-8 and 25-29 October. After 29 October, the record is obscure because of some loss of record from troubles with the water temperature sensor. On the other hand, in the surface layer, water temperature tends to decrease gradually, and sometimes drops 1-2°C per day (Fig. 6). This change corresponded to the duration of fluctuation of water temperature in the bottom layer, which suggested that the dominant fluctuation of bottom water temperature was relevant to the lowering of surface water temperature.

The eastward component of velocity (U) in the bottom layer mostly fluctuated in the positive area, which meant that the flow was generally eastward (Fig. 2). The basic flow in the bottom layer at Sta.C was eastward and it seemed to be related to counterclockwise circulation in Toni Bay (TSUJITA, 1974). The magnitude of fluctuation of the U or V component in the surface layer was equal to that in the bottom layer (figure of the record in the surface layer at Sta.C is not shown). U and V fluctuated periodically, but they were rather disturbed by noise compared with the fluctuation of water temperature. The fluctuation of semidiurnal period prevailed in the beginning of October and the fluctuation of diurnal period was found with that of semidiurnal period in the second half of October. When the tidal fluctuation of bottom water temperature was large, fluctuation of U reached 40 cm/sec in range of U (in the term of about 6 hours).

The vector expression of wind was composed of records of wind speed and direction every 3 hours at Kamaishi. During the observations, the wind blew weaker than the usual condition in late autumn. For example, the wind speed was usually 3-4 m/sec and sometimes 7-8 m/sec.

b) Data of STD measurement

Fig. 3 is an example of the vertical distribution of water temperature, salinity and specific volume anomaly at six stations near the bay mouth from STD measurements during the afternoon on 1 October. A very clear thermocline was found at a depth of 30-40 m
in Toni Bay. The thickness of the thermocline was about 10 m and the temperature difference between upper and lower layers was 6°C (20–14°C) in maximum value. On the other hand, salinity was almost homogeneous (Sal. > 34.0 permil) at all depths in Toni Bay, hence, colder sea water in the bottom layer of Toni Bay was not the Oyashio Water (Sal. < 33.8 permil) but the cooled Tsugaru Warm Water.

The strong density stratification in Toni Bay depended on the vertical distribution of water temperature.

2) Properties of the internal tidal waves

Vertical distribution of specific volume anomaly of sea water and currents in stratified sea

The thermocline of about 10 m thickness between the upper warmer sea waters about 20°C and the lower colder sea waters less than 14°C has a very large vertical gradient of water temperature (0.6°C/m, Fig. 3). When stratification occurs in Toni Bay, an inverse correlation between the velocity components in the surface and the bottom layers is shown at top of Fig. 4a. This correlation of currents between both layers indicates a dominant internal mode.

On the other hand, the density distribution in the bay was homogeneous on 13 November at the bottom of Fig. 4c. The vertical distribution of currents was also homogeneous in 13–17 November (top of Fig. 4c).

The density stratification was weak on 8 October, and the correlation between the velocity components in the surface and the
bottom layers seemed to be zero (Fig. 4b). This shows that the vertical distribution of currents in the bay was in a transient state between the strong density stratification state (Fig. 4a) and the homogeneous distribution state (Fig. 4c).

**Spectral property of fluctuations**

As the fluctuation of bottom temperature was different between the terms of 1-4 and 16-24 October (Fig. 2), power spectra of water temperature in the bottom layer at Sta.C were calculated for each of the terms (Fig. 5a). Power spectra of water temperature for the former had predominant period of 13 hours, which nearly equaled the semidiurnal period (left of Fig. 5a). Power spectra in the bottom layer at Sta.A and Sta.B had a prevailing semidiurnal period in this term.

On the other hand, for 16-24 October, the predominant period was about 35 hours in the bottom layer at Sta.B and Sta.C (right of Fig. 5a), and there was no dominant period in density distribution of power spectra at Sta.A in the bay head (refer to Fig. 6).

Comparing eastward components of velocity (U) for 1-4 October with those for 16-24 October at Sta.C (Fig. 2), the amplitude of fluctuation in the former was larger than that in the latter, and those seemed to have a similar period. The power spectral density of U for 1-4 October had a dominant period at about 11 hours near the semidiurnal period (left of Fig. 5b). The density of low frequency was large; this was shown in a gradient of the smoothed curve (running mean velocity) in the fluctuation of U in Fig. 2. In the bottom and surface at Sta.A and Sta.B, and in the surface at Sta.D, the predominant period of the semidiurnal was obtained, but it was about 14 hours in the surface at Sta.C.

For 16-24 October, the power spectra of U had a dominant period of about 31 hours, similar to the case of water temperature (right of Fig. 5b), and in the bottom at Sta.A and Sta.B the dominant periods were about 22 and 19 hours, respectively.

As mentioned above, there was apparently a difference of period between the two terms in both water temperature and velocity component (U).

**The characteristics in fluctuation of water temperature in Toni Bay**

In Fig. 6, water temperature in the surface layer varies similar to an envelope of water temperature in the bottom layer at each station. The patterns of bottom water temperature at the three stations are similar to each other, and their fluctuations seem to decrease gradually from Sta.C at the bay mouth to Sta.A at the bay head. The other noticeable feature of the fluctuation of water temperature in the bottom layer is that there are several calm days or the days of no periodicity. The internal tidal waves seem to be strongly intermittent (Fig. 6). It should be noted that for 8-15 October, the maximum of water temperature at the bottom layer at Sta.C was nearly equal to that at the surface throughout the term. This suggests that the
thermocline disappeared in the bay; the thermocline sank deeper than the depth at the bay mouth and the warm surface water filled the whole depth in the bay. The colder sea water at the bay bottom repeatedly to flow in and to flow out every tidal period for 8-15 October. This is an interesting mechanism for the exchange of sea water in a shallow bay.

3) Intermittency of the internal tidal waves and vertical displacement of pycnocline

a) Intermittency of the internal tidal waves

The pattern of fluctuations of water temperature in Fig. 2 suggests the intermittency of the internal tidal waves. In the record of water temperature, semidiurnal internal tidal waves were predominant for 1-4 and 9-15 October, near diurnal were dominant for 16-24 October, and the terms of the stable and higher water temperature were for 5-8 and 25-29 October. In fluctuations of velocity component (U), amplitudes of U seemed to be diminished in the terms of stable and higher water temperature and this was due to the intermittency of the internal tidal waves in the bay.

To confirm the intermittency, “the figures of the day by day variations of density of power spectra” from records in the bottom layer at Sta.C are shown in Fig. 7. The figure has frequency of fluctuations on the X-axis and the elapsed days of 3-21 October are marked on the Y-axis. Isotherm lines of the power spectra of fluctuation are shown in the figure. Power spectra of fluctuations were calculated at terms of every 5 days from 1 to 23 October. For example, the power spectra of 3 October at bottom in the figure were calculated on data in 1-5 October, next power spectra of 4 October were calculated from data in 2-6 October. Those calculations were carried out to 21 for data in 19-23 October day by day. The dominant periods for fluctuations of water temperature are at 11 hours near the semidiurnal period and at long period component (above 50 hours) on 4 October (the representative day of 2-6 October, Fig. 7a). The density of power spectra decreases to lower levels at all frequency fields in 5-8 October. The semidiurnal period component increases in 10-14 October. After 15 October, the components of frequency shorter than 25 hours disappear and those of frequency longer than 25 hours
Internal tidal waves and internal long period waves

Fig. 7. Day by day variations of power spectra at Sta. C bottom layer. Power spectra were calculated every 5 days sliding a day (Oct. 1–23, 1984). a) Sea water temperature (Temp.). b) Eastward component of velocity (U).

become more dominant.

Another figure of day by day variation in density of power spectra is shown in the eastward component of velocity (U, Fig. 7b) in a similar manner to water temperature. Distributions of isosteric lines differ from those of water temperature, and the peaks at each frequency in each elapsed day are more obscure than those of water temperature. The components of near semiidiurnal period and long period (above 50 hours) are dominant for the first 5 days, and the components at all frequencies are at lower levels for 7–13 October. The predominant component is a semiidiurnal period for 13–14 October and a diurnal period is prevailing for 16–18 October.

To conclude, the figures were very suggestive of the intermittency of the internal tidal waves in the bay.

b) Vertical displacement of pycnocline (thermocline)

The inflowing of colder sea water to the bottom of Toni Bay from offshore was confirmed from the result that the lowering of water temperature generally took place earlier at Sta. C than at Sta. A (for example, Fig. 17).

Next problems were where the origin of colder waters offshore was and how deep the layer of colder waters was. In order to solve those problems, T–S diagram analyses of sea waters for the term of density stratification were made (Fig. 8). The waters in the hatched area (13–15°C, about 34.2 permill) in Fig. 8a were the bottom water in the bay, the waters in area enclosed with broken lines (19–21°C, 33.9–34.2 permill) were the surface water. The waters of similar property to the bottom waters in the bay were found in 70–100 m layer at nearshore stations in three lines north of the Osaki line (Fig. 8b, c, d). An offshore thermocline of 13–17°C (near Sta. OSV) was found at 40 m depth, increased in depth towards the coast, and was found at 75–100 m depth at Sta. OSII (8 km off coast, Fig. 14c). This deepening of the thermocline near the coast is usual in the vertical distribution of water temperature in this season. The bottom sea water in the bay was different from the offshore sea water at the corresponding depth; therefore, it might be the offshore sea water rising up from a slightly deeper thermocline by an unknown external force. When the thermocline nearshore rose intermittently the density stratification appeared in Toni Bay and the internal tidal waves propagated into the bay.

The sea waters similar in T–S property to
the bottom sea water in the bay were not found at stations offshore from Sta. OSV and at all southern stations in the Tsubakijima line (Fig. 8e, f). Therefore, the intermittent vertical displacement of the thermocline occurred only in the northern sea area of Toni Bay.

It is confirmed from observations that the intermittency of the internal tidal waves in Toni Bay was due to the vertical displacement of the thermocline on a time scale of several days. Remarkable meteorological disturbances were not found in the term under investigation since wind was usually weaker than 5 m/sec in October 1984 (Fig. 2). Therefore, the long period waves were of interest for the cause of vertical displacement of the thermocline on a time scale of several days, if those waves existed in the Sanriku coastal seas.

4. Discussions and conclusions
1) Some evidence on the internal long period waves
In chapter 3, it was pointed out that the internal tidal waves appeared intermittently in the time scale of several days, and the T–S property of colder sea waters in Toni Bay coincided with colder sea waters under the thermocline in a slightly deeper layer outside of Toni Bay.

It is only recently that the intermittency in the internal tidal waves attracted scientist's attention (e.g. WUNSCH, 1975). However, there are very few reports on this problem. In Japan, a few researchers have noticed such an intermittency in the continual records of sea water temperature and current velocity in the subsurface layer. They concluded that this resulted from the disappearance of stratification of the ocean caused by a change in the wind system, e.g. access of a typhoon (INABA, 1981; MATSUMOTO, 1985). The intermittent variations were clearly found in the record of bottom water temperature in the Joban coastal sea area, southern neighbour of the Sanriku sea area, though he described nothing about it (MATSUNO, 1989). Similar intermittent variation was found in the record of bottom water temperature and current velocity components in subsurface layers in the northwestern coastal sea of Australia (HOLLOWAY, 1985). Thus the intermittency in the internal mode occurred generally in every sea area in the world, though its origin and structure were different in each sea area.

In the Sanriku coastal seas, it was possible that the space scale of the intermittency of the internal tidal waves had a larger horizontal scale than that of Toni Bay (Fig. 8). Similar variations of temperature were expected in the bay adjacent to Toni Bay. It was very convenient that a continuous measurement of sea water temperature had been carried out in several subsurface layers above 15 m deep at Otsuchi Bay to the north of Toni Bay (Fig. 1, SHIKAMA et al., 1985). A variation of sea water temperature (1 hour running mean values of every 10 minutes records) at 10 m depth in Otsuchi Bay (observing station was located at about 6 km inward from the bay mouth) was very similar to that in the surface layer at Sta. D in Toni Bay (Sta. D was located at about 1 km inward from the bay mouth). The records in Fig. 9 are the subsurface water temperature deviations of 25 hours running mean values from mean value of full data in Toni Bay and Otsuchi Bay. A temporal decrease of water temperature appeared in Otsuchi Bay on 3 and 17 October, and a similar temporal decrease appeared in Toni Bay a day later. Those variations of water temperature in the two bays were in high correlation with each other and the cross correlation coefficient ($\alpha$) was 0.89. The propagating speed of this decrease was estimated from the difference of the propagating distances for the two stations in the bays and the lag (22 hours) of the time when $\alpha$ was maximum in the cross correlation. Therefore, it corresponded to the length of 15 km (= 20 - 6 + 1), and the propagation speed of a long period wave was estimated about 19 cm/sec and from north to south in direction.

This propagating speed was compared with the phase speed of the coastal trapped wave (internal Kelvin type wave) calculated from observed data. The dispersion relation of the coastal trapped wave was calculated by means of a reduced gravity model taking into account the details of bottom configuration. The estimated phase speed of the coastal trapped wave was more than 30 cm/sec; this was considerably larger than the propagating speed of the above long period wave (19 cm/
Fig. 10. Comparison of sea surface levels in three bays (cm). Terms of internal wave type in d) and e) are the same as those in Fig. 6. a) $\zeta_M$ is value of 25 hour running mean of the tidal deviation in Miyako Bay. b) The same as in a) except for in Kamaishi Bay. c) The same as in a) except for in Ofunato Bay. d) $\Delta \zeta_{KM}$ is the sea surface level anomaly (local difference of tidal deviations) between Kamaishi Bay and Miyako Bay ($\Delta \zeta_{KM} = \zeta_K - \zeta_M$). e) The same as in d) except for between Ofunato and Kamaishi Bays ($\Delta \zeta_{OK} = \zeta_O - \zeta_K$).

The small magnitude of the phase speed suggested that the long period wave was a kind of internal wave; the internal long period wave treated here was different from the coastal trapped wave.

In the coastal seas of Japan, some results on the long waves were reported. In the Joban coastal sea area (southward of the Sanriku coast), the periodical current fluctuation (about 100 hours) was dominant and it propagated southward with speed of 3-5 km/hour (83-139 cm/sec), and this corresponded to the second mode and the third mode of the shelf waves (KUBOTA et al., 1981; KUBOTA, 1982, 1985). These reports were related to the external long wave, and the propagation speed was larger than that of the internal long period wave in the present study.

On the other hand, there are a few reports in Japan on observations of the internal long period wave as yet. When the internal long period waves propagate from north to south along the coast, it is expected that the sea surface level changes out of phase to the depth of the thermocline, even if it is very small. The deviations of the observed tide (after correction by atmospheric pressure) from the predicted tide were obtained in each of Miyako Bay, Kamaishi Bay and Ofunato Bay (Fig. 10a, b, c). These sea surface level anomalies are shown in Fig. 10d, e. Although $\Delta \zeta_{KM}$ contains some noise, $\Delta \zeta_{KM}$ is evidently negative with its magnitude of 3-4 cm for 1-5 October and 14-24 October when the internal tidal waves were dominant in Toni Bay (except 9-13 October). The negative $\Delta \zeta_{KM}$ means that sea surface level at Kamaishi Bay was lower than that at Miyako Bay. Because the sea surface level variation caused by the internal wave changes out of phase with that of the thermocline as mentioned above, the negative sea surface level anomaly ($-\Delta \zeta_{KM}$) in Fig. 10d probably indicates upward displacement of the thermocline at Kamaishi, and the dominant fluctuation of the thermocline may appear in the shallow bay in those terms (Fig. 10d and Fig. 6). The time variation of $\Delta \zeta_{OK}$ (Fig. 10e) is out of phase with that of $\Delta \zeta_{KM}$ and the amplitude of $\Delta \zeta_{OK}$ seems to be a little smaller than that of $\Delta \zeta_{KM}$. $\Delta \zeta_{OK}$ is inversely proportional to $\Delta \zeta_{OK}$ (Fig. 11), and the variation of sea surface level near Miyako Bay was in phase with that near Ofunato Bay. Therefore, the tendencies of $\Delta \zeta_{KM}$ and $\Delta \zeta_{OK}$ indicated the existence of the internal long period wave along the Sanriku coast.

Those results suggested the existence of internal long period waves propagating along-shore with an appropriate space scale (about 100 km) that was nearly twice the distance between Miyako Bay and Kamaishi Bay.
Fig. 11. Correlation between the sea surface level anomalies, $\Delta \xi_{KM}$ and $\Delta \xi_{OK}$ (cm) (Oct. 1-31, 1984).

Fig. 12. Correlation between the deviation of sea water temperature ($\Delta T$, °C) at Sta. C bottom and the sea surface level anomaly ($\Delta \xi_{KM}$, cm) (Oct. 1-31, 1984).

Fig. 13. Correlation between the sea surface level anomaly ($\Delta \xi_{KM}$) and the local difference of sea surface water temperature ($\Delta T_{KM}$, Kamaishi and Miyako, data is one a day) (Sept. 3-Oct. 29, 1984).

(about 45 km). The tendency that the amplitude of $\Delta \xi_{OK}$ was a little smaller than that of $\Delta \xi_{KM}$ was speculated to occur because the distance between Ofunato Bay and Kamaishi Bay was about 35km which was fairly shorter than a half of the space scale of the internal long period waves. Also, the amplitude of $\Delta \xi_{KM}$ (3-4 cm) in Fig. 10d was a reasonable order in relation to the magnitude in the density difference of sea water ($\Delta \rho = 0.0011 - 0.0017$) in the surface and bottom layers, compared with the vertical displacement of the thermocline ($H_L$: about 20m, estimated later) caused by propagation of the internal long period waves ($\Delta \xi_{KM} = \Delta \rho / 0.0017 \times 20m = 3.4cm$).

Next, the relation of the time changes in $\Delta \xi_{KM}$ (or $\Delta \xi_{OK}$) and in the vertical displacement of the thermocline will be examined. Unfortunately, there was no continual record of the vertical displacement of the thermocline during this observation. Hence, the record of sea water temperature (after 25 hours running mean) in the bottom layer at Sta. C in Tonai Bay was treated instead of the vertical displacement of the thermocline. When the thermocline becomes shallower (deeper), the deviation of sea water temperature in the bottom ($\Delta T$, °C) will decrease (increase). The correlation between $\Delta \xi_{KM}$ and $\Delta T$ was positive and the correlation coefficient ($\alpha$) was 0.68 (Fig. 12). This meant that negative $\Delta \xi_{KM}$ corresponded to the lower sea surface level near Kamaishi than that near Miyako, and the lower sea surface level corresponded to a shallower thermocline near Kamaishi in the internal mode. Consequently, a shallower thermocline corresponded to the lower water temperature in the bottom layer of Tonai Bay near Kamaishi. The positive correlation between $\Delta \xi_{KM}$ and $\Delta T$ in Fig. 12 was very reasonable. These
results suggested propagation of a wave from Miyako Bay to Ofunato Bay, and supported statistically the existence of the internal long period waves.

However, there was another possibility of high correlation between \( \Delta \xi_{\text{KM}} \) and the deviation of sea water temperature; the time change of \( \Delta \xi_{\text{KM}} \) was possible to depend on the variation of the local difference of sea surface water temperature between Kamaishi Bay and Miyako Bay (\( \Delta T_{\text{KM}}, ^\circ\text{C} \)). NISHI and KUNISHI (1985) investigated the influence of the local difference of sea water temperature in the surface layer upon the difference of sea levels in two distant stations off Shikoku Island. In the present study, there was no relationship between \( \Delta \xi_{\text{KM}} \) and \( \Delta T_{\text{KM}} \) (the latter was only one observation each day, Fig. 13). Therefore, the variation of \( \Delta \xi_{\text{KM}} \) and \( \Delta \xi_{\text{OK}} \) was possibly due to the internal long period waves, and the existence of the internal long period waves was highly possible.

The space scale (about 100 km) was a match for the time scale (several days) of the internal long period waves. Thus, the space scale through the local difference of sea surface levels in the two bays also verified the propagation of the internal long period waves along the Sanriku coast.

As mentioned above, the intermittency of the internal tidal waves in Toni Bay was attributed to the propagation of the internal long period waves accompanied by the vertical displacement of the thermocline. The internal long period waves were independent of the internal tidal waves in their mechanism of generation and propagation. The superposition of these two kinds of waves created a

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new phenomenon (the intermittency of the internal tidal waves) in the bay.

The wave heights of the internal tidal waves and the internal long period waves

From two kinds of records of water temperature in Fig. 14, wave heights of the internal tidal waves ($H_T$) and the internal long period waves ($H_L$) were estimated. From the continual record of the sea water temperature (Fig. 14a) in the bottom layer (58 m deep) at Sta.C, the sea water temperature fluctuated semidiurnally between 19 and 13°C on 1 October. As the magnitude of the semidiurnal fluctuation is related to the height of the internal tidal wave ($H_T$), $H_T$ can be estimated when the vertical distribution of the sea water temperature is simultaneously obtained. Fig. 14b is the vertical distribution of the sea water temperature at Sta.C in the afternoon on 1 October and shows a very conspicuous thermocline in the bay. The isotherm of 19°C was 30 m deep and that of 13°C was 60 m deep, and the difference of these depths was about 30 m. From (a) and (b) of Fig. 14, the wave height of the internal tidal wave ($H_T$) was estimated to be about 30 m (on 1 October).

On the other hand, the continual record of sea water temperature in Fig. 14a shows a fluctuationless period of water temperature higher than 18°C at the bottom in several days after 5 October. This shows that the warmer sea water in surface layer extended all layers and the thermal stratification of sea water was weak in the bay (Fig. 14d). The thermocline existed in the bay on 1–4 October and then it sank deeper and disappeared in the bay on 5–8 October (Fig. 14a, d). The vertical distribution of offshore water temperature (in the Osaki line) was obtained in the morning of 5 October and the sea water of 18°C was distributed from the sea surface to about 60 m deep (Fig. 14c), and the corresponding sea water temperature at 58 m deep (the bottom layer) in the bay was about 18°C (indicated by the arrow in Fig. 14a). The sea water of 13°C found at about 60 m deep in the bay on 1 October (Fig. 14a, b) descended about 40 m from 60 m deep to 100 m deep on 5 October (Fig. 14c). This vertical movement of the isotherm probably corresponded to the vertical displacement of the thermocline by the superposition of the internal tidal wave ($H_T$) and the internal long period wave ($H_L$). Therefore, the wave height of the internal long period wave ($H_L$) of about 10 m was obtained as the difference of 40 m ($H_T + H_L$) and 30m ($H_T$). In addition, the sea water temperature of 18°C in the morning of 5 October was not the maximum temperature of the sea water yet, but the maximum temperature (about 19°C) was found on 7–8 October (Fig. 14a). This meant that, for example, the maximum depth of the isotherms on 7 October in phase with the deepest thermocline might be found about 10 m deeper than that on 5 October (Fig. 14a, c). Accordingly, the vertical displacement of waves ($H_T + H_L$) of about 50 m corresponded to the height of the internal long period wave ($H_L$) of about 20 m. Ultimately, the height of the internal long period wave in the beginning of October 1984 was estimated about 20 m in the Sanriku coastal seas.

The internal long period waves and the behavior of offshore front at sea surface

Considering the characteristic ocean structures off Sanriku containing the Tsugaru Warm Current (coastal boundary current), the internal long period waves are very possibly the internal coastal boundary wave. In some satellite images, there is often a solitary wavelike behavior of a clear front at the sea surface between the Tsugaru Warm Water (TWW) and the Oyashio Cold Water (OCW) off the Sanriku coast. In autumn 1984, TWW spread over the eastern sea area of the Tsugaru Strait. For example, it was found in satellite picture images that the offshore convex-shaped front moved southward with a phase speed of about 16 cm/sec (Fig. 15, YASUDA et al., 1987). This propagation speed of the offshore convex-shaped front was quite similar to the propagation speed (19 cm/sec) of the internal long period waves described above and this suggested some relationships between them. The offshore front between TWW and OCW extended the thermocline in the coastal sea area, and the thermocline became deeper.
approaching the coast (Fig. 14c). From this relation between them, the vertical displacement of the thermocline nearshore was possibly related to the offshore convex-shaped front.

There are many examples of the coastal boundary currents with the sea surface front and those flow generally along the coast on the right-hand side (in the northern hemisphere) in the world ocean. The wavelike behavior of those oceanic fronts is clearly seen in recent picture images of satellites.

Theoretical research on the wavelike behavior of oceanic fronts has been activated in the 1980's.

The semigeostrophic coastal current has two waves in a reduced gravity model in which a little lighter sea water (of uniform potential vorticity) in the upper layer flows along the coast as quasi-geostrophic current over a heavier sea water (of no flow) in the lower layer which has a thickness much larger than that of the upper layer (KUBOKAWA and HANAWA, 1984; KUBOKAWA, 1986). The first wave is a Semigeostrophic Coastal Wave (SCW, Kelvin wave type) and is characterized by the variation in the depth of the upper layer near the coast without change in the breadth of the current. The second wave is a Semigeostrophic Frontal Wave (SFW) characterized by the variation in the breadth of the current and propagates upstream. This was a very simple model neglecting the flow in the lower layer and the sea bottom configuration.

Following these papers, KUBOKAWA (1987, 1988a, b) studied a two layer model with a finite depth of the lower layer, taking into account the effects of shallow depth nearshore and the flow in the lower layer. When there is a flow in the upper layer and the mean flow is zero in the lower layer, a pycnocline between the two layers inclines and a vorticity gradient arises in the lower layer, and the wave of vorticity mode appears in the lower layer. When the wave of vorticity mode in the lower layer couples with SFW in the upper layer, the baroclinic instability is generated and the disturbance of the density front propagates at the speed of the wave of vorticity mode in the lower layer. This disturbance of the front from the baroclinic instability exists when the basic current in the upper layer is weak near the coast or the breadth of the current is large. These conditions were satisfied in the Sanriku sea area in autumn 1984. Furthermore, KUBOKAWA showed that it was possible to grow for small amplitudes of the initial disturbance of the front by coupling the waves of two types in the upper and lower layers as mentioned above, if its initial amplitude was larger than the critical amplitude, even though the basic flow was linearly stable in the upper layer or the basic flow was not small near the coast.

This process suggests some possibility that the frontal disturbance propagates southward along the Sanriku coast with a phase speed of shelf waves, after warmer sea water spread in the eastern sea area of the Tsugaru Strait. The frontal disturbance traveling southward
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Fig. 16. Schematic diagram of circulation of cold sea water in the lower layer and growing solitary disturbance (wavelike front). The shadow indicates the warm water, and the solid lines represent the stream lines in the lower layer. This indicates that the cold sea water in the lower layer flows ashore at downstream side (southward) of wavelike front and the pycnocline becomes shallower (by KUBOKAWA, 1988b).

is accompanied by clockwise circulation in the lower layer at the downstream side (southward) of the peak of the frontal disturbance (the convex-shaped front) and counterclockwise circulation in the lower layer at the upstream side (northward) of the peak (Fig. 16). For this reason, the sea water in the lower layer tends to flow ashore and then the pycnocline becomes shallower in the southern coastal sea area of the peak of the frontal disturbance. Therefore, when the frontal disturbance approaches the northeastern sea area of Toni Bay, the pycnocline (thermocline) becomes shallower in the coastal sea area near Toni Bay (KUBOKAWA, 1987, 1988a, b).

It was speculated that the internal long period waves were related to the behavior of the frontal disturbance offshore of Sanriku. It is important that some evidence for the existence and the propagation of the internal long period waves was obtained from the observation record in the coastal seas and was supported by a theoretical model study. 2) Propagation of the internal tidal waves into shallow bay

a) Phase speed and direction in propagation of the internal tidal waves

The propagation speed of the internal tidal waves was in the range of 35–50 cm/sec from the phase lag in sea water temperature records at the bottom between Sta.C and Sta.A and the distance between them (Fig. 17). If the median value, 42 cm/sec, was a typical propagation speed, the wave length of the semidiurnal internal tidal wave (L) was estimated about 20km (16–23 km, L = phase velocity × period (12.5 hours)). Those waves traveled from the northeast as estimated by the cross correlations of velocity components (U) at Stations B, C, D in Toni Bay (Fig. 1). MATSUNO (1989) reported that the propagating direction of the internal tidal wave in his observation was from the east in the Joban coastal seas. This difference in the direction
Fig. 18. Records of sea surface tide and the internal tide (sea water temperature) (Oct. 1-31, 1984). D, term of diurnal period fluctuation. SD, term of semi-diurnal period fluctuation. a) Sea surface tide at Kamaishi Bay. b) Sea water temperature at Sta. C bottom in Toni Bay.

of propagation might be due to the offshore bottom configuration as a source area of the internal tidal wave.

The relation of the surface tide and the internal tidal wave

The period type is shown as D or SD in Fig. 18; “the day of diurnal period type (D)” was defined as the day when one in two peaks of fluctuation in a day was less than half of the other, and “the day of semi-diurnal period type (SD)” was defined as two peaks of fluctuation in a day were comparable in amplitude. The surface tide was compared with the internal tide (subsurface water temperature); the internal tide had a semi-diurnal period but the surface tide had a diurnal period for 1-3 October. Both had a semi-diurnal period for 9-12 October, and the surface tide had a diurnal period but the internal one had a semi-diurnal period for 13-15 October. For 16-21 October, both of them had a diurnal period. The surface tide was different in the period type from the internal tide for 22-24 October. INABA (1981) reported that in Suruga Bay the internal tide (tidal current) was predominant in the diurnal fluctuation from the observations of currents in the subsurface layer but the surface tide was prevailing in the semi-diurnal fluctuation. The relation between them in Toni Bay was more complicated than that in Suruga Bay.

The surface tide already had a diurnal period on 1 October and the beginning day of a diurnal period was unknown, but the internal tide changed to the diurnal period on 4 October. The surface tide changed to the diurnal period on 13 October, and the internal one changed on 16 October. The beginning day of the diurnal period in the internal tide seemed to be 3-4 days behind that in the surface tide. If the internal tidal waves were generated far offshore by obtaining energy from the surface tide, the internal tidal waves with lower propagation speed than that of the surface tide must arrive at the coast behind the surface tide and both of the period types did not coincide at the coast. If the delay time of the internal tidal wave was 3-4 days and its propagation speed was 42 cm/sec, the generation area of the internal tidal wave was estimated at about 110-150 km offshore. The northeast sea area at 110-150 km from Toni Bay was the edge zone where the sea bottom configuration changed from the conti-
Fig. 19. Comparison of the dispersion relations of the internal tidal waves in Toni Bay with those offshore. a) Comparison of the dispersion relations: thick line, 1st mode; broken line, 2nd mode; thin line, wave length range at semidiurnal period. b) Vertical distribution of specific volume anomaly (cl/ton) of sea water at Sta. OSIV offshore. c) Comparison of vertical distributions of the vertical velocity at Sta. 8 with those at Sta. OSIV. Abscissa, ratio to maximum velocity.

The internal tidal waves are able to propagate into a shallow bay only in the case of a thermocline formed initially in a bay. Fig. 19a shows the dispersion relations of the internal waves calculated from the vertical distribution of sea water density observed at stations inside and outside of Toni Bay. The dispersion relations of the internal wave at Sta.8 and Sta.10 were calculated as the representative data in the bay, and Sta.OSIV (930 m depth, 36 km offshore) was a representative offshore station and the vertical distribution of the specific volume anomaly of sea water at Sta.OSIV was shown in Fig. 19b. If the period was semidiurnal, the wave length of the 1st mode at Sta.OSIV was 35–40 km, and this was inconsistent with the estimated wave length (about 20 km) from observations in Toni Bay (Fig. 19a). The dispersion relation of the 2nd mode at offshore Sta.OSIV was very similar to that of the 1st mode at Sta.8 and Sta.10 in the bay. In this semidiurnal internal wave, the wave length was 16–23km from the estimated speed of 35–50 cm/sec from observations in the bay (thin lines in Fig. 19a show this range). This wave length (16–23km) was easy to resonate with the length of Toni Bay (about 5 km; length of area deeper than 20 m depth). The properties of the 1st mode of the internal tidal waves in the bay were nearly equal to those of the 2nd mode of the internal tidal waves outside of the bay, and the vertical distribution of vertical velocity (W, cm/sec) was also similar in the internal waves inside and outside of the bay (Fig. 19c).

In conclusion, these results showed that the 2nd mode of the internal tidal wave offshore was well related to the 1st mode of that in Toni Bay.

Comparison of propagation ratio of the energy of the internal wave into shallow bay

The probability that the 1st or the 2nd mode of the internal waves offshore propagates into a bay was studied by analytical calculation in a simple model in which the depth in the bay was 50 % of the depth outside of the bay and the basic condition of the vertical distribution of sea water density \( \rho \) outside of the bay was a constant Brunt-Väisälä Frequency, \( N^2 = - \left( \frac{g}{\rho} \right) \times \left( \frac{\partial \rho}{\partial z} \right) \) (CRAIG, 1987). The left in Fig. 20a is the case of initially given the 1st mode of the internal wave outside of the bay, and the density of stream lines indicates the energy...
level. The right in Fig. 20a is the distribution of stream lines after the internal wave propagated into a shallow bay, and it shows that the wave energy transported into the bay is 25% of the offshore incident wave energy. The case of initially given the 2nd mode of the internal wave outside of the bay is shown at left in Fig. 20b. In this case, it is indicated that 39% of the wave energy of the 2nd mode of the offshore incident wave propagates into the bay. It is sure that more energy of the 2nd mode of the offshore internal wave propagates into the bay than the energy of the 1st mode of that wave.

**Shoaling up of the internal tidal waves into the bay**

As mentioned in chapter 3, the record of the internal tidal waves as fluctuations of the sea water temperature in the bottom layer suggested that there were two cases for the propagation of the internal tidal waves into a bay. The first was the general case of the internal wave, and the internal tidal waves propagated through the thermocline which was already formed in the bay. The second was the case of no thermocline initially in the bay and the thermocline was formed after colder sea water flowed into the bottom layer of the bay. In the second case, therefore, the thermocline in the bay disappeared in every cycle of the tidal period.

Semidiurnal periods for 1-3 and 9-15 October corresponded to the second case, because the sea water temperature in the bottom layer rose to near the sea surface water temperature in every tidal cycle (Fig. 6). After the colder sea water in the bottom flowed out of the bay, the thermocline disappeared in the bay. If the thermocline remained always in the bay and the internal tidal wave was dominant, a thermometer (contained in the current meter) in the bottom layer stayed always in the colder sea water under the thermocline (the general case), and the sea water temperature in the bottom layer should remain at 15-16°C (Fig. 6). However, the sea water temperature in the bottom layer was found at 19°C, near that in the surface layer (about 20°C) in the record. In particular, for 9-15 October, the maximum sea water temperature in the bottom layer agreed almost with that in the surface layer. This suggested that “a colder sea water front” shoaled up on the bottom of the bay every semidiurnal tidal cycle.

The raw records of velocity (eastward component (U), in the bottom layer at Sta.
A) and the sea water temperature (in bottom layer at Stations A, B, C) for 1–4 October are shown in Fig. 21. Fluctuation curves of the sea water temperature are not a sinusoidal pattern but have a peculiar pattern. On 1 October, the sea water temperature fell and rose suddenly at all stations and they were different from a sinusoidal wave. If it was the general case (the first case), the changes of the sea water temperature and that of direction of velocity (U) must occur simultaneously in the time when the thermocline passed the station of the thermometer (as shown by arrows 1 in Fig. 21). But, Fig. 21 showed that the sea water temperature changed at a different time from the change in the direction of velocity (as shown by arrows 2 in Fig. 21). At Sta. A, at 14:00 on 1 October when the flow changed suddenly from outward (U > 0) to inward (U < 0), the sea water temperature changed immediately to colder suddenly (arrows 1), but at 19:00 when the flow changed to outward, the sea water temperature was steady (arrows 2), and when the speed of the flow reached positive maximum, the sea water temperature began to be warmer (arrows 3).

The time interval of the minimum temperature on 1 October in the bay mouth (Sta. C) was longer than that in the bay head (Sta. A). This suggested that the flow in the bottom of the bay was not the internal wave case with steady thermocline in the bay, but was the shoaling up and down of the colder sea water front on the bottom of the bay.

The process of the shoaling up and down of the colder sea water front in the bay will be inferred in the schematic picture (Fig. 22).

At the beginning, the colder sea water front starts shoaling up from the bay mouth into the bay which is filled with warmer sea water only, and the flow at a station of the thermometer is outward (U > 0), (1) in Fig. 22. When the colder front passes the station toward the bay head, the direction of velocity changes to flow inward (U < 0) and the sea water temperature falls abruptly to the minimum, (2). The colder sea water front keeps

Fig. 22. Schematic pictures of shoaling up of the colder sea water front, and the corresponding figure of variations of velocity and sea water temperature at the bottom in the bay.  

a) Schematic pictures of the moving cold front: (1) cold front starts to flow into bay, (2) cold front passes the station into bay, (3) cold front stops at head of bay, (4) cold front flows out of bay, (5) cold front passes the station out of bay, (6) cold front stops out of bay.  

b) Schematic figure of variations of the velocity component and sea water temperature at the bottom in the bay. (1)–(6) correspond to (1)–(6) in figure (a).
on flowing inward and then stops at the bay head, (3). When the internal tide starts to ebb, the colder front at the bay head starts to shoal down and the direction of the flow at the station changes to outward of the bay (U>0), but the sea water temperature remains at almost the minimum, (4). When the colder front passes the station toward the bay mouth, the direction of velocity changes inward (U<0) and the sea water temperature rises suddenly up to the maximum, (5). Afterward, the colder front continues to flow outward and stops outside of the bay, (6). At this time, there is only the warmer water in the bay. Those variation patterns were similar to the variation patterns of the observed record of 1-2 October (Fig. 21).

In the case of the semidiurnal fluctuations in the beginning of October, it was concluded that the occurrence of the stratified structure in Toni Bay was temporal and cyclic, and the propagation of the semidiurnal internal tidal wave into the bay must be the shoaling up of the cold sea water front.

CAIRNS (1967) reported on the internal tidal bore in the shallow sea off south California, from the variation pattern of the water temperature observed by thermister arrays. His variation pattern was similar to the shoaling up in Toni Bay, and the shoaling phenomenon seemed to be considerably important in the exchange of the sea water in a shallow bay.

5. Summary

A study of the internal tidal waves in a small bay was carried out on the basis of the observed records in Toni Bay, autumn 1984.

1. The internal tidal waves in the bay were predominant and had the characteristics of intermittent occurrence in several days. From T'-S diagram analyses of the sea water property at stations inside and outside of the bay, the property of the sea water in the bottom layer was closely related to that of offshore sea water in the layer (70–100 m deep, this was the depth under a thermocline) a little deeper than the bottom layer in the bay. It was found that the intermittency of the internal tidal waves was related to the vertical displacement of the thermocline outside of the bay, namely the internal tidal waves appeared in the bay predominantly when the thermocline became shallower.

2. The cause of the intermittent vertical displacement of the thermocline was investigated through the analyses of (a) variations in subsurface water temperature and (b) variations of the local difference of tidal deviations (sea surface level anomaly) at three stations along the Sanriku coast.

a) The cross correlation of variations of the sea water temperature in the surface layer between in Toni Bay and in Otsuchi Bay was very high with a correlation coefficient (a) of 0.89, and the phase of the variation in Otsuchi Bay was in advance of that in Toni Bay. It was found that the variation of the sea water temperature (variation of the thermocline depth) propagated southward at a speed of about 19 cm/sec. This was considerably lower than the wave speed of a coastal trapped wave (internal Kelvin wave, more than 30 cm/sec). The variation of the thermocline depth seemed to be due to a kind of the internal long period wave propagating southward alongshore.

This propagation speed was similar to the southward propagation speed (16 cm/sec) of the pycnocline front with a convex shape at the offshore edge of the Tsugaru Warm Waters from satellite images. It was suggested that the internal long period waves were related to the behavior of the pycnocline front. Recent theoretical research showed that the frontal disturbance propagated as a coupled wave of Semigeostrophic Frontal Wave in the upper layer (KUBOKAWA and HANAWA, 1984) with the wave to be restored by potential vorticity in the lower layer. This frontal disturbance travels southward accompanied by clockwise circulation in the lower layer at the downstream side of the peak of the front (KUBOKAWA, 1987, 1988a, b), where the sea water in the lower layer tends to flow onshore and the thermocline becomes shallower. These features and the lower propagation speed of the frontal distribution were in good agreement qualitatively with those of the internal long period waves.
b) When the internal long waves propagate along the coast, it is expected that the sea surface level changes out of phase to the depth of the thermocline, even if it is very small. When the sea level at Kamaishi minus that at Miyako (ΔξKM) was negative, the thermocline off Toni Bay (near Kamaishi Bay) must become shallower. Accordingly, the cold sea water offshore was able to intrude into the bottom of the bay, and the duration of negative ΔξKM corresponded to that of the predominant internal tide in the bay near Kamaishi. ΔξKM was highly correlated with the variation of the sea water temperature in the bottom layer of Toni Bay; the correlation coefficient (α) was 0.68. Another local difference (ΔξOK) between Ofunato and Kamaishi was out of phase with ΔξKM, which supported also the alongshore propagation of the internal long period waves. The results indicated the existence of the internal long period waves propagating alongshore with a suitable space scale to their time scale, because the distance between Miyako and Kamaishi (45 km) was nearly a half wave length of the wave with time scale of several days and wave speed of 19 cm/sec.

The internal long period waves were independent of the internal tidal waves in their generation and propagation. The internal tidal waves appearing intermittently in the bay occurred from the superposition of the internal tidal waves propagating onshore and the internal long period waves propagating alongshore.

3. The propagation speed of the internal tidal waves was estimated about 42 cm/sec (35-50 cm/sec) from the observations. The source area of the internal tidal waves was roughly estimated at 110-150 km northeast from Toni Bay. The dispersion relation of the 1st mode of the internal waves in the bay was similar to that of the 2nd mode offshore. Moreover, the vertical distribution of the vertical velocity of the 1st mode of the internal waves in the bay was quite similar to that of the 2nd mode offshore. From the dispersion relations, the phase speed of the semidiurnal internal tidal waves was calculated about 40 cm/sec which was consistent with the phase speed estimated from the time lag of observed records mentioned above.

The energy flux transported into the bay due to the 2nd mode of the offshore internal wave was 1.6 times greater than that due to the 1st mode of the wave in an analytical calculation in a simple model. The semidiurnal internal waves in Toni Bay were closely related to the 2nd mode of the internal waves offshore.

In addition, it was suggested that the semidiurnal internal tidal waves shoaled up with the intrusion of a cold sea water front from offshore into the bottom layer of the bay.

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三陸沿岸における内部潮汐波と内部長周期波

岡野守良

要旨: 内湾における内部潮汐波の特性について、1984年秋季、三陸沿岸の唐丹湾において行われた観測を基に、解析を行い次の事がわかった。

1）湾内の顕著な内部潮汐波は長期間連続的に現れるのではなく、数日程度の間欠性がみられた。湾内外の海水のT-S図解析の結果、この間欠性が水温躍層の深さの変動に関係していることが判明した。その間欠的上昇に応じて湾内底層に冷海水が流入して成層構造が形成され、内部潮汐波が間欠的に湾内に出現するものと考えられた。

2）このような間欠的な水温躍層の深さの変動の原因を究めるため、唐丹湾近傍の2つの湾の水温変動の相関を調べ、また3つの湾の海面水位の変動と水温躍層の鉛直変動との関連を調べた。その結果、水温躍層は湾岸に沿って北から南へ伝わる内湾長周期波によって上昇することが示唆された。この内部長周期波は約19cm/secで南進し、約100km程度の空間規模を持っていることが示唆された。これは北東から岸向きに伝播する内部潮汐波とは独立な波であり、これら2つの波が重複したときに、湾内の内部潮汐波に間欠性が現れる。この他、この内部長周期波は津軽暖水帯東端の密度フロントの南への波動的伝播に関連のあることが示唆された。

3）湾内外の観測データから求めた内部潮汐波の分散関係や波速等の比較、及び簡単なモデルによる沖合の内部波エネルギーの湾内への伝播効率の比較の結果、湾内の卓越した半日周期の内部潮汐波は冲合のそれぞれの第2モードに関連の深いことが示唆された。
Density fluctuation of caprellid amphipods (Crustacea) inhabiting the red alga *Gelidium amansii* (LAMOURoux) LAMOURoux, with emphasis on *Caprella okadai* ARIMOTO*

Ichiro TAKEUCHI**, Hiroshi YAMAKAWA*** and Masamu FUJIWARA****

Abstract: Species composition and density fluctuation of caprellid amphipods inhabiting a red alga *Gelidium amansii*, which is a true perennial alga, were investigated in a small inlet of the rocky shore facing the Pacific Ocean, at Amatsu-Kominato, Chiba Prefecture. Six caprellid species were found to be present. Among them *Caprella okadai* was the most dominant species. Its share in the caprellid fauna was more than 67% throughout the year. The density during May to August was 10 times higher than that during September to March, and mature females were found almost all the time. Several species of *Caprella* which inhabit *Sargassum* spp. have been reported to exhibit different occurrence pattern, suggesting that life forms of algae influence the occurrence of caprellids. Review of distribution of *C. okadai* reveals that this species is restricted to calmer zones of rocky shore facing the open sea.

1. Introduction

Caprellid amphipods, as well as gammarid amphipods, represent an important component in the ecosystem of “Garamo-ba” (*Sargassum* zone) which flourishes on rocky shores of southern Japan, as these crustaceans are the major predated forms by rocky shore fishes (FUSE, 1962; HIRAYAMA, 1978; KANAMOTO, 1977, 1979; OMorI, 1980). Ecological studies on the caprellids on the “Garamo-ba” have mostly dealt with either substrate selection (HIRAYAMA and KIKUCHI, 1980; IMADA et al., 1981; NORTON and BENSON, 1983; TAKEUCHI et al., 1987; TAKEUCHI et al., MS) or population dynamics (IMADA and KIKUCHI, 1984; AOKI, 1988). These studies, however, are usually restricted to animals collected from the *Sargassum* species which are larger algae among various kinds of algae found in “Garamo-ba”. Only HIRAYAMA and KIKUCHI (1980) and TAKEUCHI et al. (1987) reported on caprellid species compositions on several species of smaller algae on the basis of seasonal collections.

In this study, we focus on species composition and density fluctuation of the Caprellidea inhabiting the red alga *Gelidium amansii* (LAMOURoux) LAMOURoux, which is a true perennial alga (KATADA, 1963).

2. Materials and Methods

This study was conducted in the innermost part of an inlet called “Jizogi” (Fig. 1) in the vicinity of the Kominato Marine Biological Laboratory of the Tokyo University of Fisheries (KMBL) (now the Kominato Marine Laboratory, Faculty of Science, Chiba University). This inlet is situated on the southwest of Uchiura Bay facing the Pacific Ocean. Sampling was carried out from the center of a thick community of *Gelidium amansii* at the depth of 1.3 m.

Duplicate samples of *G. amansii* from a quadrate of 20 × 20 cm were collected by skin diving at monthly intervals from April 1978 to March 1979. Algae were gently removed and quickly placed in a vinyl bag. In the laboratory, the algae were shaken in freshwater for dislodging free-living epifauna. Caprellids were carefully sorted out and preserved in 10
% buffered formalin. Caprellid species identification was conducted under a binocular microscope. Sex of Caprella okadai, the most dominant species, was determined from the development of gnathopod in males and the presence of oostegites in females. The other small individuals which did not possess the sexual characters were classified as juveniles. Furthermore, females were separated into two categories, i.e. immatures in which oostegites are without setae, and matures in which oostegites with long setae form a brood pouch. Wet weight of algae was measured to the nearest g after leaving them on papers for two hours.

Seawater temperature data based on the daily observation record of KMBL have been used in the present study. It ranged from 13.2 to 25.5°C (Fig. 2). Salinity variation was restricted to 33.1-34.0% during the period of
the investigation (HAYASHI, 1989).

3. Results

The wet weight of Gelidium amansii per 400 cm$^2$ varied from 80 to 175 g and no seasonal fluctuation was recognized.

Six species of the Caprellidae were collected. All these six species belong to the genus Caprella; C. okadai ARIMOTO, 1930, C. simia MAYER, 1903, C. kominatoensis TAKEUCHI, 1986, C. penantis LEACH, 1814, C. decipiens MAYER, 1903 and C. generosa ARIMOTO, 1977. The last species is the same as Caprella sp. III reported from Amatsu-Kominato by TAKEUCHI et al. (1987).

C. okadai was the most dominant species throughout the year. The share of C. okadai to total number of caprellids varied from 67 to 100 % (Fig. 3). Its individual density per 100 g wet weight of the alga increased rapidly from April to May and was kept high until August (> 150 ind./ 100 g wet weight) (Fig. 4). In September, it decreased to 16.2 ind./ 100 g wet weight, and such a low density (< 50 ind./ 100 g wet weight) extended up to March. The density pattern based on their abundance per 400 cm$^2$ bottom area in the quadrat sample also showed a similar projection (Fig. 4).

Juveniles, i.e. those individuals which had a body length less than 4.0 mm, constituted the bulk of the population throughout the year except in August and November (Table 1). Mature females were also collected throughout the year, except during January 1979. This indicates that C. okadai could mature and produce eggs all the year round in this area, where seawater temperature varied between 13 and 26°C (Fig. 2).

The second dominant species was C. simia. Its maximum share was only 33 % and was encountered in October 1978 (Fig. 3). In July and August, its density was relatively high (15.4 and 5.9 ind./ 100 g wet weight, respectively), but in other months it was less than 2.0 ind./ 100 g wet weight. Mature females were not found.

4. Discussion

In this study, Caprella okadai was found to be exclusively dominant throughout the year on the red alga Gelidium amansii in the inner part of the inlet (Fig. 3). Although we did not measure the length of algae, it is estimated to range from ca. 15 to 20 cm throughout the year. TAKEUCHI et al. (1987) report-

![Fig. 3. Seasonal fluctuation in species composition of the Caprellidae associated with Gelidium amansii (LAMOUROUX) LAMOUROUX. Cd, Caprella decipiens MAYER; Cg, C. generosa ARIMOTO; Ck, C. kominatoensis TAKEUCHI; Cp, C. penantis LEACH; and ?, unidentified individuals due to damages.](image-url)
Caprellid amphipods inhabiting the red alga *Gelidium amansii*

![Graph showing seasonal fluctuation in the density of *Caprella okadai* and *C. simia*](image)

**Fig. 4.** Seasonal fluctuation in the density of *Caprella okadai* ARIMOTO and *C. simia* MAYER. Solid circle: the number of individuals per 100 g wet weight of *Gelidium amansii* (LAMOURoux) LAMOUROUX. Solid triangle: the number of individuals per 400 cm² of bottom area.

Table 1. Seasonal variations in proportion (%) of juveniles, males, immature and mature females to the total individuals and sex ratio (males/females) of *Caprella okadai* ARIMOTO.

<table>
<thead>
<tr>
<th></th>
<th>1978</th>
<th></th>
<th>1979</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Juveniles</td>
<td>76.4</td>
<td>84.8</td>
<td>67.1</td>
<td>51.3</td>
</tr>
<tr>
<td>Males</td>
<td>11.8</td>
<td>5.7</td>
<td>14.0</td>
<td>17.6</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>immatures</td>
<td>10.0</td>
<td>4.9</td>
<td>10.2</td>
<td>20.3</td>
</tr>
<tr>
<td>matures</td>
<td>1.8</td>
<td>4.6</td>
<td>8.7</td>
<td>10.8</td>
</tr>
<tr>
<td>Sex ratio</td>
<td>1.00</td>
<td>0.60</td>
<td>0.74</td>
<td>0.57</td>
</tr>
</tbody>
</table>

*Juveniles 1.5 - 4.0mm, males 4.0 - 8.5mm, immature females 3.5 - 6.0mm and mature females 4.5 - 8.0mm in body length.*

ed that *C. okadai* was the dominant species on such large algae (>10cm) as *G. amansii*, *Cladophora wrightiana* HARVEY and *Sargassum piliforme* (TURNER) C. AGARDH, which were growing at the zones protected from wave exposure in the inlet “Heito”. This inlet is located to the north of “Jizogi” (Fig. 1). The present results support their conclusion.

Year-round breeding in different species of *Caprella*, similar to the present observation on *C. okadai*, has been reported in studies carried out in the temperate region; *C. penantis* (BYNUM, 1978; CAINE, 1983), *C. laeviuscula* MAYER (CAINE, 1979), *C. californica* STIMPSON (KEITH, 1971), *C. equilibra* SAY (KEITH, 1971), *C. gorgonia* LAUBITZ and LEWBEL (LEWBEL, 1978), *C. tsugarensis* UTINOMI (IMADA and KIKUCHI, 1984), *C. decipiens* (IMADA and KIKUCHI, 1984) and *C. verrucosa* BOECK (AOKI, 1988).

The occurrence of caprellids is influenced by the life forms of algae with which caprellids are associated. In this study, *C. okadai*
was collected throughout the year, and the high density was recorded during May to August. However, the occurrence of *C. danilevskii* CZERNIAVSKI, *C. tsugarensis* and *C. decipiens*, which were associated with the brown alga *Sargassum horneri* (TURNER) C. AGARDH, was restricted from fall to early summer (IMADA and KIKUCHI, 1984). Similar seasonal fluctuation was also observed in the case of *C. verrucosa* on *S. patens* C. AGARDH (AOKI, 1988). *S. horneri* is an annual alga (TERAWAKI *et al.*, 1983b; TERAWAKI, 1986), and the entire thalli flowed away during spring to early summer (IMADA and KIKUCHI, 1984). The larger parts of *S. patens* thalli, which is a stem-survived perennial species (KATADA, 1963; TERAWAKI *et al.*, 1983a), also flowed away during late spring to early summer, leaving behind short round stems only (AOKI, 1988). TAKEUCHI *et al.* (1987) reported that *C. okadai*, *C. danilevskii*, *C. tsugarensis* and *C. decipiens* were mostly collected from large algae (> 10 cm) which possess filamentous or long thalli. All these four species of *Caprella* are typically similar in having an elongate body with a sharp and short basis of gnathopod II. They observed that these caprellids, except *C. decipiens*, clung the substrata by gnathopod I and pereopods V-VII with body straightened. This reveals a possibility that morphological characteristics of caprellids might have adapted to the feature of algae. Hence, the presence of suitable feature of algae for clinging is one of the most important factors which have influence on the occurrence of caprellid amphipods. Therefore, these species of *Caprella* associated with *S. horneri* and *S. patens* could not be collected during the summer.

This conclusion is also supported by the result of a comparative study on populations of *Caprella penantis* collected from two sites along the Atlantic Ocean of North Carolina (BYNAM, 1978). He compared the population structure of this caprellid from the estuarine site where hydroids and bryozoans were the most common substrate and that from the coastal site where red and green algae predominated. Population at each site peaked during July. During late August, the caprellid density at estuarine site rapidly decreased with disappearance of *Tubularia crocea*, a common hydroid, while the high density continued to prevail at the coastal site.

*Caprella okadai* was reported first from Tateyama, Chiba Prefecture (ARIMOTO, 1930, 1976) and then from Tomioka, Amakusa-Shimosima Island, Kumamoto Prefecture (IMADA *et al.*, 1981) and Amatsu-Kominato (TAKEUCHI *et al.*, 1987). Besides these records, one of the authors (IT) has also found it on several occasions in coastal waters of Japan, i.e. Nabeta Bay of Izu Peninsula, Shizuoka Prefecture, Unose on Amakusa-Shimosima Island and Magari on Notojima Island, Ishikawa Prefecture. In all these instances, *C. okadai* was collected from the rocky shore facing the ocean influenced by either the Kuroshio Current or Tsushima Current. Since this species of *Caprella* has never been found in eutrophic bays such as the Seto Inland Sea, Ise Bay, Tokyo Bay, etc. until now, it can be presumed that the distribution of *C. okadai* is restricted to the areas protected from wave exposure of rocky shore facing the open sea.

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マクサ上のワレカラ類、特にオカダワレカラの密度の周年変動

竹内一郎・山川 稔・藤原正夢

要旨: 千葉県津軽小屋町地先のガラモ場にて、真多呂生海藻であるマクサに棲息するワレカラ類の種組成および密度の周年変動を調査した。オカダワレカラは、一年中、全個体の67%以上を占める優占種であり、密度は5月から8月に特に高く他の季節より10倍以上高い値を示した。成長個体がほぼ一年中採取されたことから、繁殖期が周年にわたるものと推察された。従来のガラモ場のワレカラ類の研究によると、一年生あるいは未熟多年生海藻であるホソウレカラ類の上では、ホソワレカラなどの出現は秋から初夏に限られることが報告されている。これらのことから、海藻の生活形がワレカラ類の出現に影響を及ぼすと考えられる。また、オカダワレカラの分布に関する知見を整理すると、本種の棲息域は外洋に面した岩礁域の波浪の影響の少ないところに限られるのではないかと推察される。
Seasonal changes of the Secchi disc depth and suspended solid at six stations along the main channel of the High Dam Lake, Egypt*

OLFAT Anwar Habib**, IBRAHIM Omar Mohamed**, MOHAMED Shehata Mohamed** and Yusho ARUGA***

Abstract: Seasonal changes of the Secchi disc depth, suspended solid, chlorophyll $a$, ignition loss and particulate organic matter were investigated at six stations (Stns. 1-6) along the main channel of the High Dam Lake in Egypt during the period from September 1986 to December 1988. Water samples were collected from the surface and 2 m layer at each station and analyzed. Patterns of seasonal changes of the parameters and the ratios of chlorophyll $a$ to suspended solid and to particulate organic matter were similar mostly among Stns. 1-3 in the northern part and among Stns. 4-6 in the southern part of the lake. The Secchi disc depth was significantly correlated with suspended solid in a hyperbolic manner when the two parameters were plotted on linear scales. It is shown that both the ratios of chlorophyll $a$ to suspended solid and to particulate organic matter are regionally and seasonally quite variable.

1. Introduction

The High Dam Lake is one of the largest artificial lakes in Africa. It was filled in 1960 after the construction of Aswan High Dam (ENTZ, 1974). In order to know the environmental conditions of the High Dam Lake, the Fishery Management Center (FMC) of the High Dam Lake Development Authority, Egypt, set up stations in the main channel and in Khor El Ramla in 1982, and has been conducting monthly field surveys. The distributions of chlorophyll $a$ in Khor El Ramla and adjacent water in the main channel were partly reported in a previous paper (OLFAT et al., 1987). The results obtained in the main channel were reported by OLFAT and ARUGA (1988). In these reports the relationships between chlorophyll $a$ and Secchi disc depth were presented with rather scattered data, suggesting that the proportion of chlorophyll $a$ in suspended solid might be variable presumably according to the seasons and regions of the lake.

The present paper describes the seasonal changes of the Secchi disc depth and suspended solid at six stations along the main channel of the High Dam Lake in relation to chlorophyll $a$ concentration and ignition loss, mainly focusing on the relationship between the Secchi disc depth and the suspended solid.

2. Material and methods

Water samples were collected from the surface and 2 m depth with a Van Dorn type water sampler at six stations (Stns. 1-6) from September 1986 to December 1988 (Fig. 1). Each water sample was filtered through a glass fiber filter (Whatman GF/C, 47 mm) which was precombusted at 450°C for 3 hrs in a Muffle furnace and weighed, and the filter with suspended solid on it was weighed after drying overnight (or for 24 hrs) in a drying oven at 85°C. The amount of suspended solid (SS) was determined as the difference of dry weights before and after filtration of water sample. The filter was ignited again in a Muffle furnace at 450°C for 3 hrs and weighed after cooling, and the percent decrease of dry weight was regarded as the ignition loss.

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* Received October 15, 1989

Contribution No.5 from the Fishery Management Center, High Dam Lake Development Authority, Egypt.

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(IL). The amount of particulate organic matter (POM) was calculated by multiplying SS with IL.

The transparency of water was measured with a Secchi disc (30 cm in diameter) at each station. The chlorophyll a concentration was determined in the same way as described in previous papers (OLFAT et al., 1987; OLFAT and ARUGA, 1988).

3. Results

The Secchi disc depth was highest, 5.7 m, in February 1987 at Stn. 4 and lowest, 0.2 m, in September 1988 at Stn. 6. Seasonal changes of the Secchi disc depth at Stns. 1-6 are illustrated in Fig. 2. In average, the Secchi disc depth was highest in February and lowest in August. It is noticeable that differences of the readings at six stations were small from April to June but large from August to March. Among the six stations, the Secchi disc depth was mostly lowest at Stn. 6, whereas at Stn. 1 it was highest except in January-March 1987 and February 1988. This suggests the decrease of suspended solid with flowing water along the main channel. Stns. 1 and 2 showed similar seasonal changes of the Secchi disc depth, and Stns. 5 and 6 also showed similar changes. Stn. 3 showed quite similar changes to the average of the six stations. Seasonal pattern at Stn. 4 was different from those at other stations in having big differences between the maximum and the minimum values.

Seasonal changes of the amount of suspended solid in the surface water and 2 m layer at Stns. 1-6 are illustrated in Fig. 3. The level of suspended solid was generally higher (1.0 - 59.0 g/m²) at Stns. 4-6 in the southern part and lower (0.5 - 10.0 g/m²) at Stns. 1-3 in the northern part of the lake. The patterns of seasonal changes of suspended solid were similar among Stns. 1-3 and among Stns. 4-6, but the patterns at the latter stations were
Fig. 3. Seasonal changes of the suspended solid at Stns. 1-6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.
Fig. 4. Seasonal changes of the chlorophyll a at Stns. 1-6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.
clearly different from those at the former stations. The range of variations was quite big at Stns. 4–6 as compared with that at Stns. 1–3. Rapid increases in suspended solid were observed in April and May at Stns. 1–3 in 1987 and 1988, whereas at Stns. 4–6 rapid increases were observed in August and September in 1987 and 1988. The suspended solid was clearly high during the flood season (August–October) at Stns. 4–6.

Figure 4 illustrates seasonal changes of chlorophyll $a$ concentration in the surface water and 2 m layer at Stns. 1–6. Average chlorophyll $a$ concentrations were slightly higher at Stns. 4–6 (1-26 mg/m$^3$) than at Stns. 1–3 (1-21 mg/m$^3$), if the higher values of 28 mg/m$^3$ at Stn. 2 in April 1988 and 30 mg/m$^3$ at Stn. 3 in November 1986 were excluded. The seasonal patterns of chlorophyll $a$ concentration were similar among Stns. 1–3 and among Stns. 4–6, even though the patterns at Stns. 1 and 6 were somewhat obscure as compared with those at other stations. The patterns at Stns. 1–3 were different from those at Stns. 4–6. The range of seasonal variations of chlorophyll $a$ concentration was big at Stns. 4–6 as compared with that at Stns. 1–3. The patterns of seasonal changes of chlorophyll $a$ concentration (Fig. 4) were different from those of the suspended solid (Fig. 3) at each station, even though the corresponding peaks were sometimes observed.

Figure 5 shows seasonal changes of the ignition loss of suspended solid in the surface water and 2 m layer at Stns. 1–6. The ignition loss was generally higher (25–98%) at Stns. 1–3 and lower (6–92%) at Stns. 4–6. The patterns of seasonal changes of ignition loss were similar among Stns. 1–3 and among Stns. 4–6. However, the patterns at the latter stations were clearly different from those at the former stations. The pattern at Stns. 4–6 were characterized by the lower levels of ignition loss mainly in 1988. Variations in ignition loss were big at Stns. 1–3 as compared with those at Stns. 4–6. Rapid increases in ignition loss were observed in August and September at Stns. 1–3 in 1987 and 1988, whereas at Stns. 4–6 rapid decreases were observed in the same period in 1987 and 1988. These differences could be due to the differences of variations in the proportion of inorganic suspended solid to the particulate organic matter or to the total suspended solid in the lake water. The patterns of seasonal changes of the ignition loss (Fig. 5) were quite different from those of the suspended solid (Fig. 3). This suggests that there had been big seasonal variations in the proportion of inorganic suspended solid to the total suspended solid or to the particulate organic matter.

Seasonal changes of the amount of particulate organic matter in the surface water and 2 m layer at Stns. 1-6 are illustrated in Fig. 6. The levels of particulate organic matter at Stns. 1 and 3 were comparatively low as compared with those at other stations. The average amount of particulate organic matter ranged from 0.4 to 7.5 g/m$^3$. Similar seasonal patterns were observed with the maximum in July–September and the minimum in December–February at Stns. 4–6. The seasonal patterns were similar at Stns. 1–3 if the two sharp peaks at Stn. 2 in April 1987 and 1988 were excluded. The range of variation was quite big at Stns. 4–6 as compared with that at Stns. 1–3. Peaks of particulate organic matter appeared a little earlier at Stns. 1–3 (April–July) than at Stns. 4–6 (July–August). The seasonal patterns of particulate organic matter (Fig. 6) were similar to those of suspended solid (Fig. 3) except that at Stn. 6.

Figure 7 shows seasonal variations of the percentage of chlorophyll $a$ in suspended solid in the surface water and 2 m layer at Stns. 1–6. The average percentage of chlorophyll $a$ was higher at Stns. 1–3 (0.1–0.6%) than at Stns. 4–6 (0.01–0.3%). The patterns of seasonal changes of the percent chlorophyll $a$ in suspended solid were similar among Stns. 1–3 with higher values during November–January and lower values during May–July, and between Stns. 5 and 6 with higher values in January or February and lower values in September and October. The seasonal patterns at the former stations were clearly different from those at the latter stations. The patterns at Stns. 4–6 were characterized
Fig. 5. Seasonal changes of the ignition loss of suspended solid at Stns.1-6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.
Fig. 6. Seasonal changes of the particulate organic matter at Stns. 1-6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.
Fig. 7. Seasonal changes of the ratio of chlorophyll a to suspended solid at Stns. 1–6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.

by frequent changes with lower levels especially in 1988.

Relationships were investigated between the chlorophyll a concentration and the particulate organic matter for the surface water and 2 m layer separately (Fig. 8). For both cases, there was positive correlation with considerably scattered data points between the two parameters, and no significant difference was observed between the two cases.

Figure 9 illustrates the relationship between the Secchi disc depth and the amount of suspended solid for all the data of suspended solid in the surface water and 2 m layer from September 1986 to December 1988 at Stns. 1–6. A clear hyperbolic relationship was obtained on a normal diagram and an exponential relationship on a semilogarithmic diagram. The results indicate that the Secchi disc depth was almost directly dependent on the amount of suspended solid in the lake water.

The relationship between chlorophyll a and suspended solid was examined separately for the surface water and for the 2 m layer as illustrated in Fig. 10. Positive correlations can be seen between the two parameters, however the data points were scattered very much. About 90% of the data were in the ranges of 1–30 mg/m² in chlorophyll a and 1–
Seasonal changes of the Secchi disc depth and suspended solid in High Dam Lake

Fig. 8. Relationships between the chlorophyll a and the particulate organic matter at Stns.1-6 in the main channel of the High Dam Lake.

Fig. 9. Relationships of the Secchi disc depth to the suspended solid at Stns.1-6 in the main channel of the High Dam Lake. ○, 0 m; ●, 2 m.

15 g/m³ in suspended solid. There is no significant difference between the relationships in the two layers.

4. Discussion

The seasonal patterns of the Secchi disc depth were similar to those previously reported (OLFAT et al., 1987; OLFAT and ARUGA, 1988) with higher values during the low temperature period and with lower values during the high temperature period. There seems to be a tendency for the Secchi disc depth to be lower in the southern part and higher in the northern part of the lake, which may be correlated with the decrease of suspended solid with water flow along the main channel (Fig. 3).

The levels of suspended solid were generally high during the flood season at Stns. 4-6 in the southern part of the lake. The seasonal patterns of suspended solid were quite similar with a very high peak in August or September at Stns. 5 and 6, and the peaks became lower at Stn. 4. On the other hand,
at Stns. 1-3 the seasonal patterns of suspended solid were quite different from those at Stns. 4-6 (Fig. 3) possibly due to changes in the composition of suspended solid, e.g., the ratio of particulate organic matter to particulate inorganic matter.

In the present investigation a similar trend was obtained in the relationship between the Secchi disc depth and the suspended solid as reported in previous papers (OLFAT et al., 1987; OLFAT and ARUGA, 1988) between the Secchi disc depth and the chlorophyll a concentration, in the latter case the data points being much dispersed. This suggests that the Secchi disc depth was more directly dependent on the amount of suspended solid in the lake water.

According to HURST (1957) about 100 million tons of suspended sediments, composed of 30% fine sand, 40% silt and 30% clay, are carried annually with the Nile water on entering Egypt. The quantities of these sediments greatly increase at the beginning of the Nile flood. ELSTER and VOLLENWEIDER (1961) pointed out that the average value of the suspended matter in the Nile at the Egyptian borders during the flood period (August–October) amounted to 1.6 kg/m². However, after construction of the Aswan High Dam and creation of the High Dam Lake these features were basically changed. In this respect, ENTZ (1980) mentioned that suspended material in Lake Nasser (High Dam Lake) does not exceed a few milligrams per litre and that is mostly organic matter of planktonic origin. This means that the main bulk of suspended clay was sedimentsed in Lake Nubia. According to the High Dam and Aswan Dam Authority (personal communication) no clay reached the Egyptian water only with high turbidity in the southern part of the lake. EL-OTIFY (1985) reported that the total suspended matter fluctuated between a minimum of 10 mg/l and a maximum of 132 mg/l, and a gradual increase in total suspended matter was recorded along the main body of the High Dam Lake from north to south in autumn 1982 and summer 1983. The present results for suspended solid are in agreement with EL-OTIFY's (1985) range of fluctuation.

It should be noted that Stns. 1–3 showed similar patterns of seasonal changes in suspended solid, chlorophyll a, ignition loss, particulate organic matter and the ratios of chlorophyll a to suspended solid and to particulate organic matter, and Stns. 4–6 showed other similar patterns of seasonal changes in
these parameters, even though sometimes Stn. 4 had seasonal patterns somewhat different from Stns. 5 and 6. It is clearly shown that both the ratio of chlorophyll $a$ to suspended solid and the ratio of chlorophyll $a$ to particulate organic matter are quite variable with seasons and regions in the High Dam Lake. This suggests that particulate organic matter is composed of phytoplankton and other variable organic materials, or at least the chlorophyll $a$ content in a cell is quite variable, with seasons and regions, and that the total suspended solid rather than phytoplankton generally plays an important role in determining transparency of water (the Secchi disc depth) of the lake.

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References


ハイダム湖（エジプト）の主水路に沿う6測点における透明度と懸濁物の季節的変動

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要旨：ハイダム湖（エジプト）の主水路に沿った6測点（Stns. 1-6）で1986年9月から1988年12月まで、透明度、懸濁物、クロロフィル$a$、総栄養塩、懸濁有機物を計測した。各測定で表面及び2m深から試水を採取し、分析した。各測定項目及びクロロフィル$a$／懸濁有機物比にクロロフィル$a$／懸濁有機物比の季節的変動は、ハイダム湖沿い（下流）のStn. 1-3、南部（上流）のStn. 4-6でそれぞれよく似たパターンを示した。また、透明度は懸濁物量と極めて強い相関を示した。クロロフィル$a$／懸濁有機物比にクロロフィル$a$／懸濁有機物比は、いずれも地域により、季節により著しく変動することが明らかにされた。
別府湾を含む伊予灘および豊後水道海域における海況特性の解析*

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Characterization of the environment in the Beppu Bay, Iyo Nada and Bungo Channel*

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Abstract: Environmental characteristics of the sea area around Oita Prefecture were investigated by employing the monthly observational data (1965-1988) at 34 stations in Beppu Bay, Iyo Nada and Bungo Channel. Analysis of the horizontal and vertical distributions of water temperature and salinity revealed that the sea area was subdivided into several small areas. The characteristic of the Seto Inland Sea was different from that of the Bungo Channel. There was the isolated mixing zone in the northern and southern parts of the Hayasai Strait where water temperature and salinity were uniform by the strong tidal currents, and the tidal fronts were observed. Beppu Bay seemed to be semiclosed area, which was characterized by large seasonal variations in water temperature and salinity. MEM spectra emerged dominant periods of one year and 2-4 years in water temperature and in salinity. These periods can be related to those of atmospheric temperature and precipitation, respectively. The characteristics of the Seto Inland Sea appeared to depend on the climate of the area. The Kuroshio branch strongly affected the characteristics of the Bungo Channel.

1. 緒 言

海洋が環境に及ぼす影響は非常に大きなものであり、わずか2~3℃の海水温の変化が全地球的な異常気象を引き起こすことがある。このような地球規模の海洋と大気の相互作用は決してなく、小さな内湾や沿岸における環境も、四方を海に囲まれた日本にとっては重要な研究対象である。たとえば、瀬戸内の海域は我が国最大の内湾であり、豊後水道や紀伊水道などのわずかな部分で太平洋とつながっているため、これらの水道付近の海況について研究することは、瀬戸内海の特性を把握する上でも役に立つものと考えられる。

大分県は、豊後水道を境にしてその南側が瀬戸内海、南側は豊後水道に面しており、豊後水道はさらに日本の南西海域に接している。また、瀬戸内海からは豊後水道へ恒流として内湾系冷水が南下している。そのため、この海域の海況はきわめて複雑であり、漁業に与える影響も小さくない。特に大分県沿岸に来遊するイワシ、アジ、サバ類は、主として春から夏にかけて北上し、秋から冬にかけては成魚が南下する傾向があり、この付近の海況について明らかにすることは漁業にとっても大きく貢献できるものと思われる。これらの海域の特性については、既に数多くの報告があるが、広範囲にわたる総括的な報告はあまりなされていない。

以上のことから、主に統計的な手法で、伊予灘、別府湾および豊後水道の海況特性の解析を試みた。
2. データおよび解析方法
(1) データ
大分県水産試験場（1965-1988）は、毎月1回伊予瀬、別府湾および豊後水道の34地点を選んで海洋観測を行っている。これらの観測点は、海底地質や潮流を考慮して選定されている。Fig.1に観測点（Stn.1-54）を示した。1965年4月から1988年3月までの23年間の各観測点における水温（0, 5, 10, 20, 30, 50, 75m深），塩分（0, 5, 10, 20, 30, 50, 75m深），気温，気温および潮汐内海流におけるDO, COD, 空素, リンなどの栄養塩類について解析を実施した。解析に用いたデータベースは、水温および塩分の等高線図を作成した。選ばれた観測点は、伊予瀬のStn.1, 7, 13, 16, 豊後水道のStn.34, 38, 41, 43, 45, 48, 51および54である。同様に、別府湾のStn.18, 20, 22, 26および30を選び、別府湾についても観測した。それぞれの観測点をFig.1に黒丸で示した。
(2) T-S解析
水温分布と塩分分布を把握するために、有効なT-S（水温-塩分）ダイアグラムを作成した。まず、各観測点ごとに海面，5, 10, 20, 30, 50, および75m深における水温と塩分の23年間のデータを月別に平均した。得られたデータをグラフ上にプロットした。また、海流における観測点の値を月別にプロットした。水深10, 20, 30および50m深における値についても同様に処理した。
(3) 水温および塩分の鉛直分布
鉛直方向の水温分布により海況特性を検討するために、伊予瀬北端から進吸側を通って豊後水道南端まで南下する線（観測線と呼ぶ）の海況を考慮。月別平均水温および月別平均塩分から、水温および塩分の鉛直分布図を作成した。選ばれた観測点は、伊予瀬のStn.1, 7, 13, 16, 豊後水道のStn.34, 38, 41, 43, 45, 48, 51および54である。同様に、別府湾のStn.18, 20, 22, 26および30を選び、別府湾についても観測した。それぞれの観測点をFig.1に黒丸で示した。
(4) スペクトル解析
各観測点の水温および塩分データに欠測があるのでは、その欠測月の前後数か月にn次補間多項式を当てはめて補間し（Aitken-Neville法）、サンプリング間隔1か月の時
系列データとした。スペクトルの計算にはMEMを用い、ARモデルの次数は、最大モデル次数を（サンプル数）／3とし、赤池の方法（赤池, 1986）によって決定した。また、12か月周期を消去するために $1 - 2\cos(2\pi/12)$ と12期係数を増分フィルター（岩井ら, 1980）を用いた。また、水温および塩分測定期間に相当する大分市の毎日平均気温および降水率についても、MEMスペクトルを計算した。さらに、海上保松洋水路部より得た黑潮本流の水温観測データについても、MEMスペクトルを計算した。黒潮水温データは、黒潮水温の一部を含む福岡県南部冲および高知県足摺岬沖におけるものを選んだ。

Fig. 2. Representative observation stations of sea area classified with water temperature-salinity diagrams.

3. 結果と考察
(1) データ
観測データは、毎月ほか10日後に得られたものであり、水温は1965年から、塩分は1969年からのものであった。また、各観測点の海面における平均欠測数は水温で21個（最大35個、最小7個）、塩分で21個（最大38個、最小11個）であった。ただし、水温が極端に欠測数が増加した。
(2) T-S解析
54の観測点すべてについて、各月ごとに（すなわち

Fig. 3. Water temperature-salinity diagrams of representative observation stations. ○, February; △, May; □, August; and ▼, November. Numerals denote depth in meters.
別府湾を含む伊予灘および豊後水道海域の海況特性

54×12=648 個の面から観測深度までにいたるまでの T-S ダイアグラムを作成した。全般的に、春季から夏季にかけて海面から観測深度までの変化が大きく、秋から冬にかけてはそれが小さかった。つまり、春季から夏にかけて、成層が発達していることがわかった。ただし、瀬戸内海は塩分の変化の大きい成層であるのにに対し、豊後水道は等密度線に対し垂直に変化している成層であった。また、豊後水道における Stn.33-39 では、年間を通じて非常に変動が小さかった。

つぎに、得られた T-S ダイアグラムを類似の季節変動をする海域ごとに分類し、それぞれの中から代表点を選んだ（Fig.2）。選択された観測点の T-S ダイアグラムのうち、2月、5月、8月および11月をそれぞれ冬季、春季、夏季、および秋季の代表としてFig.3に示した。また、海面における T-S ダイアグラムのうち2月、5月、8月および11月のものをFig.4に示した。Fig.3から、国東半島沿岸のStn.10では、冬季に著しい低温傾向を示していることがわかる。国東半島沿岸は、冬季に特有の冷水塊を形成することが知られており（YANAGI, 1980）、このことはFig.4の2月のT-Sダイアグラムにはっきり現われている。つまり、伊予灘のStn.1、Stn.8-11および21だけが9°C前後の独立した氷水塊を示している。国東半島沖との温度差が著しい沿岸フロントを形成していることが示唆される。これは、冬季の強い北西季風（河村, 1977）によって国東半島沿岸を周囲水系冷水塊が吹き寄せとなって南下しているためと考えられる。この傾向は11月に国東半島北部沿岸から始まり、3月まで続いていた。またFig.3から、速吸瀬戸南側に位置するStn.16では、春季から冬に瀬戸内海としては比較的高温高塩分を示し、夏季に期待される熱帯の程度も小さかった。一方、別府湾内のStn.30では、春季以来面の低温塩分と非常に安定した成長状態を示した。このように春季の別府湾は、成長により地表混合がなく湾口部の湾奥部に比べて相対的に深く停滞しているので、Fig.4からわかるように海面では著しく低温（25-28°C）かつ低塩分（30-32）の水塊を形成した。つまり、春季における浅海冷水の典型である。しかしながら、Fig.5に見られるようにこの低温塩分水塊も海面の一部であり、10, 20, 30mと深さが増すにつれてほぼ安定の低温高塩分を近づいて行くのがわかる。この別府湾の特徴的な例で、別府湾内の大野川河口付近のStn.23であり、Fig.3からわらるように、春季から夏季にかけて海面における著しい低塩分を示し、成層が発達していた。また、秋季でも塩分の差が大きくかつて、梅雨および秋雨期の降雨による河川水流入に起因する塩分の水準が特徴であるが、この塩分水準はたしか5 mくらいまでであり、日本のように水量の少ない河川に特有の現象である。Fig.6に、この解析期間と同じ期間の大分市における月別平均降水量を示す。塩分低下と降水量との関係がよく対応している。さらにFig.3より、速吸瀬戸南側のStn.35は、冬季比較的高温高塩分であり、夏季にも水温および塩分の変化が小さい。また、速吸瀬戸北側のStn.16によく似た傾向を示している。豊後水道のStn.51では、夏季に成層が発達するものの、それ以外の季節では変化が少なかった。豊後水道を南下するにつれて、高温高塩分で変化の小さい T-S ダイアグラムが得られ、より黒潮水系の季節変動に近づいていると考えられる。

またFig.4から、豊後水道ではいずれの季節でも、

Fig. 4. Mean water temperature-salinity diagrams at sea surface from 1965 to 1988. ○, Iyo Nada; △, Beppu Bay; and □, Bungo Channel. Numerals denote station numbers.
Fig. 5. Mean water temperature-salinity diagrams at sub-surfaces in August. ○, Iyo Nada; △, Beppu Bay; and □, Bungo Channel.

Fig. 6. Seasonal variation of mean precipitation at Oita from 1965 to 1988.

Fig. 7. Horizontal distribution of water temperature in Iyo Nada, Beppu Bay and Bungo Channel in August.

水道のStr.38 以北で特に著しかった。また、南高北低温の水温分布であり、従来水温南部と伊予灘北端との差は約7度にも達した。塩分も水温と同様南高北低でその差は1であるが、従来水道のStr.41 以南ではほとんど差がなくなってしまい、ほぼ一定の34.7を示した。

4月になると気温上昇とともに表面水温も上昇しはじめ、5月には明らかに上昇し、速吸波と北北西寄りは南に行くほど海面温度が深瀬開裂域の温差が大きくなった。これに対して、速吸波付近の豊後水道のStr.34 では、ほとんど差がなくなった。塩分は、2月と
同様に豐後水道のStn.41以南では34.5と差がないものの、そこから北上するにつれて海面と最深観測深度の差が生じた。また、南高北低の塩分分布を示し、かつその差は2月より大きく1.5になっており、内海への陸水の流入量が増加していることを示している。

8月には、海面の水温上昇が著しく、海面と最深観測深度との温度差も非常に大きいことがわかる。海面と50m深の水温差は、伊予灘で5度、豊後水道南部で6度にも達した。しかしながら、豊後水道のStn.34では2度ほどしかなく、この傾向は、通所瀬戸の北と南に隣接する伊予灘のStn.15-17および豊後水道のStn.33-35でもほとんど同じであった。塩分も同様に、豊後水道のStn.34ではほとんど差がなく、通所瀬戸からはなるべくしたがって海面と最深観測深度の差が大きかった。このように、夏季には暖海水輸送で水温および塩分ともに通所瀬戸付近で収束する結果が得られた。以上のことから、通所瀬戸付近で鉛直方向の強い混合が起こっていることが明らかであるが、これは、藤原・早川（1978）の瀬戸内海の海況における速い潮流による鉛直混合発生と同様なメカニズムと考えられる。夏季には瀬戸内海の水温と鉛直方向の大きな分布が現われるため混合の様子を明確に観察することができ、この主な原因は潮汐流によるとと思われる。しかし、強い混合は年間を通じて生じているものと推定される。

9月には海面と最深観測深度の水温差が小さくなりはじめ、11月になるとその温度差が全くなくなり、さらに伊予灘と豊後水道側との間も温度差がなくなっていくことがわかる。つまり、水平方向にも鉛直方向にも水温差がない。詳細に見ると豊後水道の北部と南部で1-2度の水温差があるが、この差も年間を通して最も小さい。塩分の分布は2月同様に、南高北低でその差は1程度になっているものの、海面と最深観測深度との塩分の差が小さい。
はほとんど見られなかった。これが、秋季の典型的な海況である。

以上のように、内海ほど気温と陸水の影響による水温および塩分の季節変動が大きく、一方、豊後水道ではあまり影響を受けていない。特に、豊後水道のStn.41以南の塩分は降水量の多い夏季を除いてほぼ34.3-34.7のせまい範囲に納まっていた。また、これらの図を見ると、特に冬季に伊予灘のStn.7と13との間および豊後水道のStn.38と41との間で等塩線または等塩分線の間隔が狭くなってしまい、この部分でフロントを形成している（柳・大遠、1985）ことを見ている。これは、遠吸瀬戸付近の混合域の広さを表しており、遠吸瀬戸の南北の混合海域のStn.13-18およびStn.33-39に相当するものであろう。遠吸瀬戸南側のフロントは、吉岡（1971, 1984）による紀伊水道のフロントに対応するものと考えられる。以上のようない伊予灘－豊後水道で行った解析を、別府湾内でも行った。Fig.10およびFig.11にその結果を示した。選択された観測点は、湾中央部を東西に横断して

（4）スペクトル解析

Fig.12に、観測期間の長い代表的な観測点の水温と塩分の時系列データを示した。瀬戸内海では水温および塩分の振幅が大きく、遠吸瀬戸では小さいことがわかる。また、Fig.13およびFig.14に伊予灘のStn.1における海面水温および塩分のMEMスペクトル式を示した。予想されたように、どちらも1年周期が卓越していた。しかしながら、それぞれのスペクトル強度は水温で10⁺、塩分では10⁻程度にすぎなかった。同様
Fig. 12. Time series of sea surface water temperature and salinity at representative observation stations. Open circles denote the interpolated data.

Fig. 13. MEM spectra of sea surface water temperature at Stn. 1 in Iyo Nada. Solid line represents the spectrum for the raw data and broken line for the data through the harmonic filter.

Fig. 14. MEM spectra of sea surface salinity at Stn. 1 in Iyo Nada. Solid line represents the spectrum for the raw data and broken line for the data through the harmonic filter.
Table 1. Dominant periods of MEM spectra of water temperature, salinity, atmospheric temperature and precipitation.

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* Spectra for the data through the harmonic filter.
第2節を含む伊予灘および豊後水道海域の気温特に

種々の周期性が見られた。大分市の降水量については
3.1年の周期があり、伊予灘および別府湾の塩分、特に別
府湾の河口域の塩分における周期性はよく一致している。
YANAGI (1982) は、同じ豊後水道の愛媛県側の水温およ
び塩分のスペクトル解析により、3～5年の水温周期性と,
3～5年の塩分の周期性を認めている。しかしながら,
本研究における豊後水道の大分県側では種々の周期性が
得られた。これは、秋山・納 (1989) の日間観測データの解析
でも明らかにされているように、豊後水道の
愛媛県側は黒潮分岐部の影響を直接受けるが、大分県
側では瀬戸内海からの南下流と黒潮分岐流の影響を受け
るためと考えられる。そのため、黒潮勢力の変化により
2年から4年にわたる比較的幅広い周期性が観測された
ものと思われる。

4. 結論

本稿の検討結果により、伊予灘、別府湾および豊後水
道はその海況特性が明らかに異なることが明らか
になった。特に、瀬戸内海と豊後水道では豊後水
道は観測されたが、水温および塩分の解析から、観測
の都度の変化が顕著に現れている。一方、別の時期は、
北部に東半島沖の海域と、また南部に豊後水道南部
の海域とのあいだにフロントを形成していることが明らか
になった。一方では、別府湾の閉鎖性があらためて確
証された。水深が浅いため、年間を通じての水温および
塩分の変化が大きいことが特徴で、この閉鎖性は別府湾
南部に行かながって著しかった。

水温および塩分は、1年周期以外に2～4年の周期
がみられ、気温、降水量および黒潮の影響を強く受
けていることがわかった。

謝辞

本研究を進めるにあたり、貴重な資料を提供いただい
た大分県水産試験場および有益な助言をいただいた宮
澤正治教授に感謝いたします。なお、本研究中の黒潮
水の水温データは、海上保安庁水路部の海洋防災使
用させていただいたことを付記いたします。

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日本列島周辺の台風高潮パターン 2 例*

中 村 重 久**

Two patterns of typhoon-induced storm surges around the Japanese Islands*

Shigehisa NAKAMURA**

Abstract: Two recently observed patterns of typhoon-induced storm surges around the Japanese Islands are introduced. Meteorological anomaly of the sea level is obtained after eliminating the predicted tides out of the mareogram at each tide station for the typhoons 8506 and 8719. The meteorological anomaly is separated into two parts, i.e. barometric and non-barometric effects. The local winds are considered in relation to a part of the non-meteorological effects, although only a qualitative notice is given. A discussion is made to know whether any hazardous storm surge is a type of the Kelvin-like waves.

1. 結 言
台風は太平洋西部沿岸域で高潮をひきおこし、水災害の要因のひとつである。この台風や高潮については、伊勢湾台風（1934）や気象庁（1961）によって予・警報に関連した問題としての研究が行われている。一方、DEACON and DEACON（1982）は、北海の高潮を論ずるにあたり、NOMITSU（たとえば、1934）の気象に対する海面の影響について示している。北海の高潮の数値計算（1934年1月31日-2月1日）の例もHANSEN（1956）により発表されている。また、FANDRY et al.（1984）は、サイクロンによって生じたKelvin型の高潮を考えた。台風高潮については、中村（NAKAMURA, 1981; 1988; 中村, 1988）の検討例がある。

本論文では、最近、日本列島に強い影響を及ぼした台風高潮の2例について、検測記録によってとらえられたパターを示す。これによると、台風の影響が異なるとき、台風による潮位変動にも顕著な差異があることを示すことができる。気圧低下の効果のほかに、検測所の位置によって、風の効果が大きいこともある。具体的観測例によると確認するとともに、高潮災害とKelvin型高潮との関連についても考察する。

2. 台風の経路
ここで検討の対象となる台風高潮については、中村（1988）が海面水温と関連づけて調査している。本論文では、それと別に別の研究を試みる。便宜上、2つの台風例を挙げ、その台風の日本列島周辺における経路をFig.1に示した。すなわち、台風8506（実線）と台風8719（破線）である。台風8506は、九州南方沖上から紀伊半島沖を経て静岡県沿岸に上陸し北東進した。台風8719は、四国南方沖上から加古川市付近へ北上し日本海へ出た後に北東進した（cf. Fig. 2）。

3. 台風高潮の特徴
これらの台風高潮の特徴をとらえるため、気象庁所管の検測記録を利用して分析した。台風8506に関連して利用した検測記録は、宮古、大船渡、小名浜、岡田、御前崎、尾鷲、浦添、潮崎、南部、足柄崎、土佐清水、油津である（ただし、南は京都大学の圧力式潮位計による）。上に示した検測所の位置を記号化し、Fig.1に示した。すなわち、それぞれMIY, OFU, ONA, OKA,
Fig. 1. The tracks of Typhoons 8506 and 8719. Solid line: the track of Typhoon 8506 from 29 June to 1 July 1985. Dotted line: the track of Typhoon 8719 from 16 to 17 October 1987. Dots: tide stations where the mareograms of Typhoon 8506 were obtained.

Fig. 2. The track (solid line) of Typhoon 8719 from 20h on 16 October to 8h on 17 October 1987. Dots: tide stations where the mareograms of Typhoon 8719 were obtained.

Fig. 3. Meteorological anomaly (solid line) of the sea level and barometric effects (dotted line) of Typhoon 8506.

OMA, OWA, URA, SIO, MIN, MUR, TOS, ABU である。

台風8719については、土佐清水、高知、室戸岬、潮岬、白浜、和歌山、徳島、高松、瀬戸、神戸、舞鶴、浜田の検潮記録を対象とした。これらの検潮所の位置を記号化し、Fig.2に示した。すなわち、それぞれTOS, KTI, MUR, SIO, SIR, WAK, TKU, TAK, SUM, KBE, MAL, HAMである。

(1) 台風8506の例

各検潮計から予想潮（主として天文潮）を差引いて潮位偏差を求める。台風8506の場合、1985年6月30日～7月1日を対象として、潮位偏差をFig.3の実線のよう示した。また、気圧低下的効果を静水圧近似によって推定した結果を、Fig.3の破線によって示した。一般に、外洋では、台風高潮の潮位偏差は気圧低下的効果
Fig. 4. 風象学的異常のの海面レベルに対するTyphoon 8506. 細線: 非気圧的影響. ポインター: 本地方の風向き.

そして考えてもよいと言われているし、その理論的根拠も与えられている（たとえば NAKAMURA, 1981）。ただ、Fig. 3 では、実線と破線とはかなりずしも一致してはない。

台風高潮の潮位異常が非線形現象の場合には検討が必要になる。簡単なため、線型的なデータ処理が可能なものです。これで、Fig. 3に示した潮位異常から気圧低下の影響を差引いた結果は、Fig. 4の実線のようになる。Fig. 4には、各検潮所に相当する地点の風速を矢印によって示した。これにとって、たとえば南部では、風向の変化が潮位の変化をより適切に対応していることがわかる。これは、いわゆる風による吹き寄せ効果である。小名浜でも短時間ながらこの風の効果が認められる。

御前崎では、風が変わった、西風になると潮位が大きくなる潮位低下の原因となっている。津津、室戸岬、潮崎、岡田では、この潮位は比較的小さく、気圧低下の影響が小さく観察されることが多い。これは外洋性高潮の特徴とみてもよいであろう。また、尾崎と越後では、台風が最短距離に近い位置にある時に潮位が大きくなる。これは、気圧低下の効果の増幅や検潮所周辺の地形条件を考慮する必要がある。

Fig. 5. 風象学的異常（実線）の海面レベルと気圧的影響（点線）のTyphoon 8719。

べきであろう。土佐清水では台風通過後に潮位の値が異常に大きくなっている。

ここでは定性的検討にとどめたが、Fig. 3およびFig. 4では、潮位のさらに短時間の変動はわからない。

（2）台風8719の例

上述の台風8506の倒と同様にして、1987年10月16～17日の台風8719の例を示す。潮位異常はFig. 5に実線で示した。また、気圧低下の効果はFig. 5の破線のように推定される。Fig. 5の実線と破線のパターンは、Fig. 3にみられたパターンと対応的である。これは台風の経路の相異によるものである。
潮位偏差から気圧低下の効果を除いた偏差を Fig. 6 に実線で示した。風は矢印によって示した。高知と佐世保两种で気圧低下の効果を除いた偏差は小さい。舞鶴と浜田では台風通過後に偏差が顕著に大きくなっていることがわかる。これは日本海沿岸の高潮として検討すべきかもしれない。太平洋側の室戸岬、潮崎、白浜では偏差は最大約0.5mである。これには増幅作用が関与しているようにみえる。さらに、紀伊水道・大阪湾の海域では、和歌山、高松、瀬戸内、神戸の各検潮所で、風による吹き寄せ効果が非常に顕著である。特に、大阪湾奥に位置する神戸では、偏差の最大は約1.5mに達している。周辺の海底地形・海岸形状も考慮すべき因子であろう。

4. 外洋に沿った沿岸での高潮

高潮が沿岸に移動する場合、これは、外力によって生じた Kelvin 波の問題として処理される（たとえば GILL, 1982, とくに p.398－403）。この場合、Rossby の変形半径と沿岸の高潮のスケールとの大小関係が重要になる。Rossby の変形半径の決定には対象とする水深が与えられてなくてはならないが、水深の値に任意性があると問題は力学的意義を失ってしまうことになる。しかし、時間のスケールが$t^{-1}$より小さいときは、このようなことは問題の対象ではなくなる。ここで、着目する線度を$\varphi = 30^\circ N$とすると,

$$t^{-1} = \frac{1}{20\sin\varphi} \approx 2.4 \text{ hours}.$$ 

ただし、$\Omega$は地球自転角速度である。

台風 8506 および台風 8719 の例では、高潮偏差の時間スケールは約 20 時間であり、上の$t^{-1}$の値の約 10 倍とみてよい。台風の経路からみて、台風 8506 の場合には高潮偏差が Kelvin 型に近い挙動をするようであったとしても、台風 8719 の場合はそれほど現象は簡単ではない。


ところで、日本列島周辺で高潮をともなった台風の経路は、1934 年の室戸台風や、1954 年の伊勢湾台風、その他の多くの場合、台風 8719 の経路に近い、台風 8506 のような経路の場合には Kelvin 型の高潮があらわれるにちがいないが、かならずしもこれが高潮災害につながらない。高潮の力学的機構や予測についてなお今後の検討を要する必要がある。

謝辞

本研究をすすめるにあたって、気象庁の御好意により気象資料・検潮記録などの利用ができた。
REFERENCES
学会 記 事

1. 1989年12月1日 東京水産大学において平成2年度
学會賞受賞候補者推薦委員会（第1回）が開かれ、委
員長に篠谷明道氏を選出し、推薦の方法及び次回の日
程を決めた。

2. 1989年12月26日 東京水産大学において学會賞受
賞候補者推薦委員会（第2回）が開かれ、評議員から推
薦のあった候補者6名について審議し、2名が適格者
として選ばれた。この2名の代表的な論文リスト等を
委員全員に送付し検討してもらうこととし、第3回委
員会の日程を決めた。

3. 1990年1月12日 東京水産大学において学會賞受賞
候補者推薦委員会（第3回）が開かれ、研究業績につ
いて審議の結果、落合正宏氏（都立大・理）が最適格
者との結論に達し、この結論を全員に報告することと
した。

4. 1990年2月14日 東京水産大学において平成2・3
年度評議員選挙の開票が行われた。

5. 新入会員
（正会員）

<table>
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<tr>
<th>氏名</th>
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<tr>
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6. 退会
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7. 改 順
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日仏海洋学会役員・評議員

(1988～1989年度)

顧問

ユーベール・ショジョー・ジャン・デルサルト

ジャック・ロベール・アレックス・ドランテ

ル・ペルニャル・フレンクル・ミシェル・ルサージュ・ロベール・グルムール・ジャック・マゴー・レオン・ヴァンデルメルジュ・ヨー・ギュスタン・ベルク

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ユーベール・セカルディ

会長

宇野 善

副会長

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折 弥彦、平野敏行、松村 治、松山常治、

丸茂隆三、三浦昭雄、宮本 悟、村野正昭、

森田良美、柳 菊雄

（54名、会長推薦評議員を含む）

編集委員長

有賀祐勝
公開講演会盛誼に終了

平成2年2月 日本学術会議広報委員会

日本学術会議は、平成元年春に主催の公開講演会を3回開催しました。今回の日本学術会議より述べ、その公開講演会の開催をみて、本会議が実施している国際的な活動などについて、お知らせいたします。

日本学術会議主催公開講演会

本會議は、科学の向上発展を図り、行政、産業及び国民生活に科学を反映浸透させるという本会議の設置目的に沿うための活動の一環として、毎年、公開講演会を開催しています。この講演会は、本会議会員が講師となり、学術的香りが高く、かつ、時宜に出たテーマを詳しくして開催している。

今年も3回の公開講演会を開催したので、その概要を以下に紹介する。

Ⅰ．公開講演会「人間は地球とともに生きられるか」

標記講演会は、西元平成元年10月27日（金）13時30分～17時に、本会議会場で約280人への参加を得て開催された。

最初に、吉野正敏・第4部会員（筑波大学理学部教授）が、「地球の温暖化とその影響」と題して、地球温暖化の原因を追究し、気候変動の要因を指摘し農業をも及ぼす影響を述べた。

続いて、久馬一男・第6部会員（京都大学農学部教授）が、「地球温暖化と農業の関係」と題して、地球温暖化の影響を指摘し、農業の産業面について述べた。

最後に、放井隆・第3部会員（名古屋大学経済学部教授）が、「地球温暖化と経済との関係」と題して、地球温暖化の影響を指摘し、経済の影響について述べた。

続く講演は、佐藤久雄・第7部会員（東京大学教授）が、「人間の近代化と地球温暖化」について述べた。

次いで、大石真一郎・第3部会員（明治学院大学経済学部教授）が、「近代日本の人権思想と自由民権運動の人権論を中心に」と題して、主として、明治時代の自由民権運動における人権論について、その特徴、特徴的意義について述べた。

続いて、村松亮一・第4部会員（東京大学教授）が、「科学技術と人権」と題して、近年の科学技術の発展によってもたらされた、広い意味での「人権」と自由の様に様々な相違において、それらの問題と関連問題について述べた。

最後に、南博文・第2部会員（一橋大学法学部教授）が、「人権の進化と創造」と題して、現在までの人権の進化の現状を回顧する中、最近における人権立論や人権思想の新しい展開について述べた。

Ⅱ．公開講演会「王立学問の新未来～これからのくらしと学問～」

標記講演会は、西元平成元年12月8日（金）13時～17時に、仙台市の宮本記念館で約70人の参加を得て開催された。

この講演会の開催に当たっては、東北大学、宮城県教育委員会、仙台市教委員会、関東新報社の後援を受けた。

初めに、林成武・第7部会員（東京大学教授）が、「共生社会の条件～民主主義と科学」と題して、王立学問の新未来を展望し、その条件について述べた。

次いで、澤美嶺・第2部会員（国学院大学法学部教授）が、「犯罪現象への多様な理解」と題して、犯罪防止や被害者の家族の保護などに対する対策としての王立学問の役割について述べた。

最後に、上野寛之・第6部会員（東京農業大学農学部教授）が、「自然と人間との共生」と題して、自然環境の保護に向けた新たな研究活動について述べた。

なお、これらの講演会の講演要旨は、「学術解説」として、（財）日本学术協力財団から出版されます。
地球環境問題における工学研究の
在り方について——第5部報告

このたび、本会の第5部は、標記報告書のとりまとめを、
会議の開催者会合の承認書を含めて公表した。

（要 目）

近年における人間活動の巨大化が、地球環境に急速な
変化をもたらし、その変化が地球の生存基盤そのものさえ
も脅かすようになってきた。そのため、次の世紀に向けて
人間が地球を愛を含む取り組むべき、極めて重要かつ緊急の
課題として地球環境問題が広く国際的な関心を集めている
のは既に知のとおりである。

元来、地球環境問題は、科学的にも空間的にも極めてスケー
ルが大きく、かつ、気候、水、土質、生態系、生物等生物圏全体に
わたる相互関係の結果として現れるものだけに、対応策を選
択するに当たって、従来とは異なった長期的、学術的かつ
国際的視点に立ち、持続的に取り組む必要がある。また、
局所的な視点をも含めた一時的な対応や規制ではなく、
地球全体における持続的発展という観点から、地球を一
つのシステムとして捉え、自然環境と人間活動をいかに
保つ価値に基づいて調和させていくべきかという視点から、
総合的に取り組むべき問題である。

地球環境問題が人間活動の結果として現出したことを考
えると、今すでにこれは、地球環境に配慮した健全な人
間活動のために新しい工学的基準を導入する必要もあり、
人間活動と地球環境の調和に役立つ新しい学問領域を
創出することである。

そのうえ、地球人間活動と統合して一つのシステム
として捉え、その一環における物質・エネルギー循環・エネ
ルギー能率の変化を定量的に評価できる手法を開発
し、人類の生活を支える新しい技術体系を構築する学問領域
である。このような地球システム工学を「地球システム
工学」と呼ぶこととする。

このような新たな科学領域創造と新たな技術体系構築の
ためには、既存の学問分野からの協力により連携から研究
体制を構築する必要がある。これには、当面、研究プ
ロジェクトを設定することにより強力な研究推進を行う必
要があるが、我が国が存する学術機関を維持し再構築し、国
内外の研究者ともに地球環境問題解決に取組むことは、
研究発展、技術革新に対する海外の期待をも含むものと考
えたら、我が国の責務と考えられる。

平成2年（1990年度）共同主催国際会議

本会議は、昭和58年3月に開催され4件の学術関係国際会
議を関係学術研究会共同主催しておき、平成2年（1990年度）に
於いては、2件増えることとなり6件の国際会議を開催する。

■第15回国際微生物学会

開催期間　平成2年9月13日～22日
開催場所　大阪城ホール（大阪市）
参加者数　国内2,000人、国際5,300人、計7,500人
共催団体　日本微生物学会

■第11回国際数学ユニバーシティ大会及び第22回国際数学者会議

開催期間　平成2年8月18日～29日
開催場所　神戸国際会館（神戸市）
参加者数　国内1,500人、国際2,000人、計3,500人
共催団体　日本数学会等

■第11回国際数学者会議

開催期間　平成2年9月2日～8日
開催場所　横浜国立大学会館（横浜市）
参加者数　国内2,000人、国際1,500人、計3,500人
共催団体　日本数学会等

■第5回国際生態学

開催期間　平成2年8月29日～31日
開催場所　横浜ビッグendsWith（横浜市）
参加者数　国内800人、国際1,600人、計2,400人
共催団体　日本生態学会

二国間学術交流事業

日本学術会議では、二国間学術交流事業として、毎年2
件のプロジェクトを実施し、各国の科学者等と学術上の
関係者の会合を行い、相互理解の促進を図る事業を行
っている。

平成元年度には、第2回日本学術交流会議を実施し、
日本学術会議とイタリア学術会議との間で、科学技術
に関する内容を交換し、相互理解の促進を図った。

2004年には、新たに「二国間科学技術交流会議」を
実施し、両国間科学技術の交流を推進するための
会議として設立された。この会議を通じて、両国間
の科学技術交流を深化させることを目的としている。

この会議では、科学技術の発展に寄与するため、両国
間の科学技術交流を推進し、両国間の科学技術交流を
促進するための会議として設立された

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