LONG-TERM OBSERVATION OF DEEP-SEA BENTHIC ACTIVITIES IN SAGAMI BAY, CENTRAL JAPAN

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ABSTRACT

Sagami Bay locates at the central Japan facing to the Pacific Ocean. Deep trough, called Sagami Trough, that show more than 1500 m deep lines at the central part of the Bay. Sagami Trough is convergent plate boundary between North American Plate and Philippine Sea Plate. Epicenter of huge earthquakes and active submarine volcanoes are located at the western part of the Bay. A lot of cold seepages with Calyptogena-clam colonies are distributed in the bay. JAMSTEC has long been monitoring crustal movement at the deep-sea floor. There is a long-term deep-sea observatory at the Off Hatsushima Island site at the western part of the bay. Since 1993, JAMSTEC continuously monitor benthic activities at the permanent observatory. We could pile up time-series video records and environmental dataset. Through these dataset we can trace environmental changes at continental slope regions and also watch how deep-sea benthic organisms actively dwell at deep-sea floor in relation to environmental changes. We also keep permanent deep-sea station at central Sagami Bay for monitoring long-term changes in population ecology of deep-sea meiofauna since 1991. Using these dataset, we can evaluate deep-sea environmental changes and responses of deep-sea organisms against environmental changes. We believe that human impact has already started to affect even at deep-sea floor. We propose to continue monitoring of deep-sea environments and organisms in Sagami Bay with several innovative approaches. Continual environmental monitoring through cable network at deep-sea observatory of the Off Hatsushima Island site, frequent ROV and AUV observational dives are strong tools for getting deep-sea data in Sagami Bay.

1. INTRODUCTION

The deep-sea floor is one of the most important environments on Earth. In particular, deep-sea sediments, the sediment-water interface (SWI) and the benthic ecosystems these environments support play a key role in global biogeochemical cycling and act as a vital mechanism for particulate and dissolved organic carbon storage in deep-sea sediments. However, little is known about the role of deep-sea ecosystems, in particular at the SWI at the global level and still less on the importance of biodiversity on ecosystem functioning in deep-sea ecosystems. Key unresolved questions include how do anthropogenic influences and inputs reach the deep-sea and affect ecosystem functioning? What role do deep-sea organisms play in deep-sea biogeochemical cycling? Long-term observations and monitoring of the biodiversity, structure, function and dynamics of deep-sea ecosystems at fixed or mobile stations to resolve these questions.

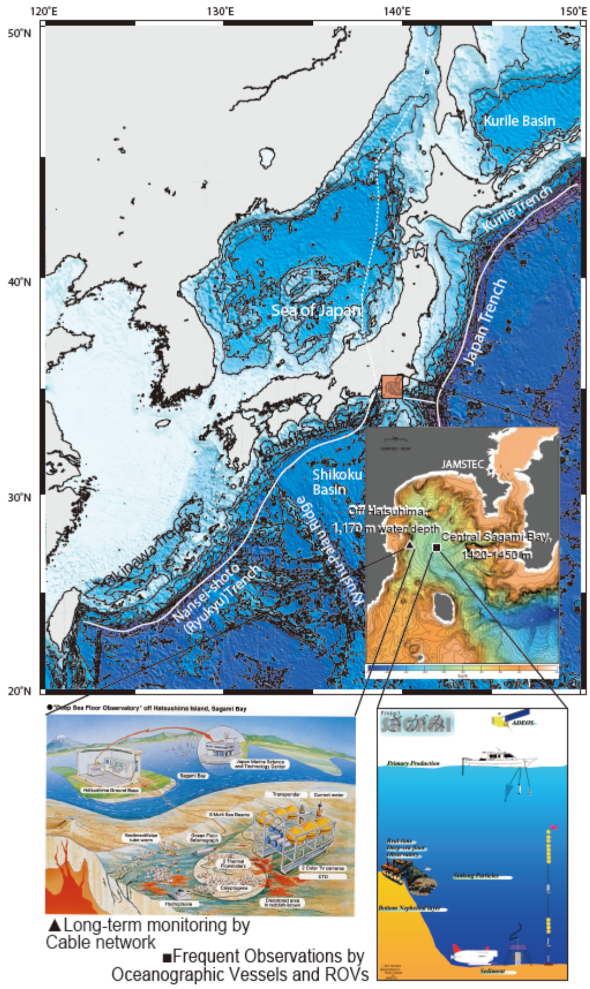

Figure 1. Long-term monitoring areas at Sagami bay, Japan, and schematic figures of cable network monitoring systems and frequent observation by research vessels.

Sagami Bay is located in central Japan facing the Pacific Ocean (Fig. 1). The Sagami Trough (1500 m deep) lies at the central part of the Bay. Sagami Bay is tectonically active, as there exists convergent plate boundary between North American Plate and Philippine Sea Plate along the Sagami Trough. Epicenters of huge earthquakes and active submarine volcanoes are located in the western part of the bay. A lot of cold seepages with *Calyptogena*-clam colonies are distributed in the bay. Japan Agency for Marine-Earth Science and TEChnology (JAMSTEC) has long been monitoring both environmental changes and crustal movements at deep-sea floor off Hatsushima Island, western Sagami Bay. One deep-sea monitoring station, named OBB2, is at the central part of the bay is at the distal part of deep-sea fan of the Tokyo Bay Canyon. Here the substrate is typically organic-rich mud and this supports a typically diverse range of deep-sea benthic organisms.

Here, we show results from long-term time-series at two deep-sea stations and discuss how long-term observation systems at deep-sea floor are important for monitoring both environmental/biodiversity changes.

2. OFF HATSUSHIMA PERMANENT STATION

There is a long-term deep-sea observatory (1177m in the depth) at the off Hatsushima Island at the western part of the bay. The station assembles Conductivity, Temperature, Depth (CTD), Acoustic Doppler Current Profiler (ADCP), video/images from Television cameras and deep-sea cable connectors. The observatory is supported by electric supply from land. Since 1993, the JAMSTEC has continuously monitored both environmental changes and benthic biological activities at the permanent observatory. This has led to a long-term time-series of video records and environmental data. Through these dataset we can trace environmental changes at continental slope regions and also watch how deep-sea benthic organisms actively dwell at deep-sea floor in relation to environmental changes.

2-1. Physical Environment Variation Near The Sea Bottom At Off Hatsushima Permanent Station

At the Hatsushima Permanent Station, physical variables, such as water temperature, salinity, current direction and velocity and others, have been measured continuously from the first half of 1990's to the present day. Long-term environmental monitoring data at the seafloor are the valuable data that are unique in the world. These data are important to understand the relationship between environmental variables and deep-sea biology in relation to environmental change. In addition, current data are basic data to know a transport process of egg and larvae of deep-sea organism.

Fig. 2(a), (b) shows the time series of water temperature and salinity data at the Hatsushima Permanent Station from 1994 to 2006. Water temperature varied from 2.864 °C (average from 1994 to 1999) to 2.920 °C (average from 2000 to 2009). A peak of high water temperature was observed in the winter season (Fig. 2 (a)). Furthermore, we compared the fluctuation of water depth (water pressure) with water temperature. Among a water depth fluctuation and water temperature fluctuation of a period of around 2 weeks (from spring tide to spring tide), trend of variation resembled each other. Alternatively, a pulse-shaped salinity reduction was occasionally observed in salinity fluctuation (Fig. 2 (b)). It was indicated that these sudden variability was the influence of cold seeps from the bottom or low salinity water of the upper layer. Furthermore, the predominant variable period of current velocity (North-south component and East-West component) in Hatsushima Permanent Station, be estimated with semidiurnal period and 14.5 day by power spectral density analysis [1]. That is tidal current is dominant near the Station. However, for variable period of the latter, almost coincide with variable period of Kuroshio frontal wave [2,3]. Therefore, it will be necessary to consider the effect of the Kuroshio frontal wave when we expect that marine environment deep-sea bottom (near Off Hatsushima Permanent Station). A future study plans to make a comparison of existing data, such as oceanographic data, meteorological data and river discharge data etc., in order to clarify a factor to describe the abyssal environment. At the same time, we are thinking about applying model analysis about a transport process of deep-sea biology.

2-2. *In-Situ* Spawning Observations Of Deep-sea Animals

Reproduction is the most important mission for all organisms. Our knowledge of the reproductive biology of most deep-sea animals is very limited due to the logistic difficulties of investigations. *Calyptogena* bivalves are a common taxon and large populations occur at deep-sea vents and seeps, and have been reported to spawn continuously and seasonally [5,6,7]. However, information on spawning behaviour, frequency and spawning cues of *Calyptogena* bivalves remains limited.

Two species of *Calyptogena*, *C. okutanii* and *C. soyoae* live within sediments at methane seep areas at the Off Hatsushima site from 750 m to 1200 m depths. Using the long-term deep-sea observatory over a period of 1 year, spawning cues in association with measurements of current speed and water temperature, behaviour and spawning frequency have been reported [4,8]. Sperm release typically occurred as the continuous release of milky fluids from the exhalent siphon of bivalves for 10 to 20 seconds by a rise in water temperature of approximately 0.2°C (Fig. 2). Some males exhibited a ‘sprinkle siphon’ behavior during which males waved their siphons left and right to sprinkle or disperse sperm into the water. Egg release events were synchronized with followed sperm release within 10 minutes of the first male spawning. Sperm and egg release events occur roughly 4.1 and 1.7 times per a week, respectively. Interestingly, female spawning by egg release into the water column was always preceded by male sperm spawning and decreasing near-bottom current speeds (Fig. 2). A following scenario was proposed as a hypothesis for spawning cues of *C. okutanii* and *C. soyoae* by this long-term observation. First, water temperature increases, which induces spawning by males. Second, females detect the sperm/chemical concentration and are induced to spawn if a threshold concentration is reached.

Observations using a permanent deep-sea observatory have proven valuable in assessing the reproductive strategy of deep-sea animals because human activities give large impacts to deep-sea ecosystems including utilization of food resources, development of oilfield and carbon storage. However, deep-sea observatory requires high cost and high-level technology. We strongly hope to develop simple and low-cost observatories to advance studies of deep-sea biology.

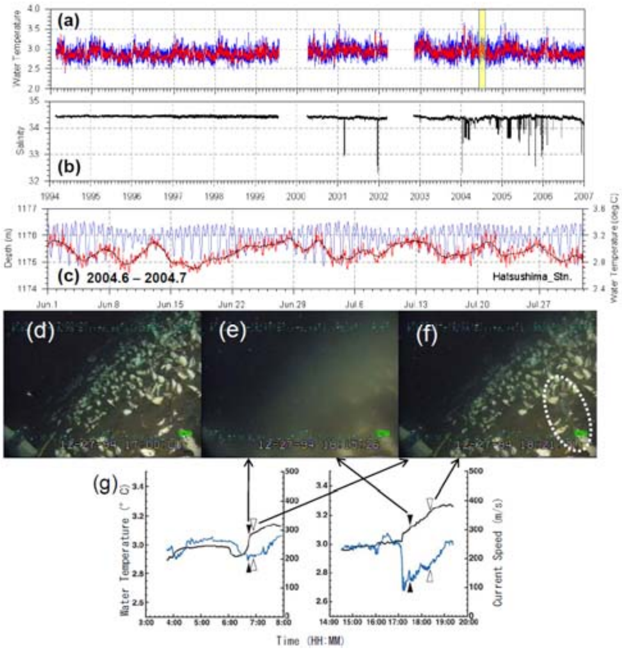

Figure 2. Physical environment fluctuation and biological spawning events using the long-term observatory at the Off Hatsushima Island methane seep site in Sagami Bay, Japan. (a):Water temperature long term fluctuation from 1994 to 2006. Red line shows moving average of 25 hours. (b) Salinity long term fluctuation from 1994 to 2006. (c) Water temperature and water depth short term fluctuation from June 2004 to July 2004. This figure extended a part of a yellow hatch of Figure 2(a). The black line shows moving average of 25 hours. (d-g) In situ spawning video images of deep-sea clams, Calyptogena soyoae/okutanii. After [4]. (d) Before spawning event. (e) Sperm release event. Seawater is cloudy due to high sperm concentrations. (f) Egg release (lower right specimen, encircled). Egg release appears as rising smoke. (g) Occurrence of sperm or egg release events of deep-sea clams, C. soyoae/okutanii corresponds to changes in current speed and water temperature from 3 h before sperm release to 1 h after sperm or egg release. Typical two egg release events that were synchronized with sperm release are shown. Closed triangle: start of sperm release; Open triangle: start of egg release; dashed line: current speed; solid line: water temperature. After [4].

3. SAGAMI BAY CENTRAL SITE

We also have a permanent deep-sea station at central Sagami Bay for monitoring long-term changes in population ecology of deep-sea meiofauna since 1991 [9,10]. Using these datasets, we can evaluate deep-sea environmental changes and responses of deep-sea organisms to these environmental changes. We believe that human impacts have already started to affect the deep-sea floor.

3-1. Frequent Monitoring Of Phytoplankton Bloom, Sinking Particles, And Benthic Organisms By Research Vessels

We have conducted an integrated project focused on the dynamic sedimentary process through the ocean surface to seafloor, which named as “Project Sagami” [10, 11]. The project investigated phytoplankton blooming in the surface ocean [12], mass flux and their compositions of sinking particles in the water column [13, 14, 15, 16], population dynamics of bacteria, protists, and metazoan meiobenthos at the seafloor [10, 17, 18, 19, 20, 21], and anthropogenic pollutants in the sediments [22]. Phytoplankton blooms were monitored several days to week intervals by ocean colour satellite images. Sinking particles were collected biweekly using two sediment traps moored at 20 and 350 m above the seafloor. Surface sediment samplings and natural fluorescent light measurements were carried out ~monthly by several research vessels.

The project figured out the sources and fluxes of organic matters at the central part of the Sagami Bay. The project also revealed the tight coupling of material cycling between the ocean surface to the seafloor. Episodic spring blooms induced a sharp change in quantity and quality of organic matter in the water column and surface sediments. Benthic foraminiferal abundances seem to increase after a spiky phytodetritus deposition which precedes to mass deposition due to the spring bloom. These periodic changes in material cycling and biotic reactions can only be detected by frequent samplings using research vessels, preferably monthly or weekly.

3-2. *In Situ* Monitoring

More recently, we have monitored biogeochemical cycles at the seafloor by conducting *in situ* observations and *in situ* experiments using the manned submersible *Shinkai 2000* and the remotely operated vehicle (ROV) *Hyperdolphin*. Chemical profiles, such as O_2 and NO_3, were measured with microelectrodes or planer optodes which mounted on the Elinor lander system [23, 24, 25]. The lander was deployed on undisturbed seafloor by the ROV and then started measurements semi-automatically. The obtained profiles show substantial spatial and temporal heterogeneities, indicating that sediment-water interface is highly dynamic place than we had predicted. Real-time monitoring is thus required to understand the dynamic processes at the sediment-water interface.

3-3. *In Situ* Experiments

In situ feeding experiments have also been carried out at the central Sagami Bay to examine feeding habits of benthic organisms and associated carbon cycling at the seafloor. *In situ* feeding cores which equipped ^{13}C-labeled organic matters were deployed on the seafloor by the submersible or the ROV. The cores were recovered after several days to weeks *in situ* incubations. According to the enrichment patterns in ^{13}C, benthic foraminifera and microbes are major consumers of phytodetritus on the seafloor [26]. It has also confirmed that they produced their lipid compounds by using ingested carbon derived from phytoplankton [27]. On the other hand, bacterial carbon was not ingested intensively by benthic foraminifera [28], but probably degraded by viral activities according to an onboard experiment [29]. These experimental studies can track complicated pathways of each element both temporally and quantitatively.

4. MONITORING DEEP-SEA BIOLOGICAL ENVIRONMENTS

As briefly described above, continuous monitoring of the deep-sea give us enormous information in terms of changes in deep-sea environments and biodiversity. Here, we propose to continue monitoring deep-sea environments and organisms with several innovative approaches. One example is the continuous high resolution environmental monitoring through a cabled network system such as off Hatsushima Island. This will be achieved by establishing a Deep-sea Observatory and using frequent ROV and Autonomous Underwater Vehicles (AUV) observational dives at deep-sea stations such as central Sagami Bay as strong tools for obtaining deep-sea data in the oceans and ensuring sustainability of these decadal long observations in the future. In addition to these activities, we stress the importance in new approaches for monitoring the changes in biological environments.

Biological Observatory: Among long-term monitoring variables, biological oceanographic components have historically been difficult to collect. Key biological variables that are essential for monitoring biological activity in time and space include Abundance/species distributions, population dynamics and genomic diversitie. Recent deep-sea technical developments give us innovative instrumentations for monitoring the aforementioned variables. For instance, DNA chip techniques can be applied for monitoring deep-sea biodiversity. Ultra-highvision camera system and planar oxygen/pH optode systems can monitor meiofauna-sized microbiological activities [30] and also reproductive behaviour of metazoan organisms [4].

In addition to cabled network systems, mobile observatories supported by long-lived batteries are also effective for monitoring regional or ocean-wide changes in deep-sea environments and can be moved as research questions change or to address future currently unanticipated societal needs.

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