Subject Title: Assessment of the Effects of Sediment Disturbance on the Tropical Seagrass Ecosystems: Elucidation of Interacting Effects of the Catastrophic Tsunami and Local Disturbances

Principal Investigator: Masahiro Nakaoka (Hokkaido University)

Collaborative Investigators from Japan: Toshihiro MIYAJIMA (University of Tokyo), Teruhisa KOMATSU (University of Tokyo), Takao Suzuki (Tohoku University), Masatoshi Matsumasa (Iwate Medical University), Hiroya YAMANO (National Institute for Environmental Studies), Masakazu HORI (Fisheries Research Agency), Yoshiyuki TANAKA (Japan Agency for Marine-Earth Science and Technology),

Collaborative Investigators from Thailand: Chittima ARYUTHAKA (Kasetsart University), Chatcharee SUPANWANID (Kasetsart University), CHATCHAREE, Yaowaluk MONTOM (Kasetsart University)

Abstract: This project aims to examine the interactive effects of catastrophic disturbance caused by the tsunami, and local environmental modification on tropical seagrass communities in Thailand. Integrative approaches revealed the long-term, broad-scale dynamics of seagrass ecosystem before and after the tsunami in December 2004. The tsunami impacts varied greatly within a region, suggesting that other sources of disturbances, such as those by monsoon, river discharge and burrowing activities of benthic organisms deeply involved for the observed ecological dynamics.

Keyword: Catastrophic Disturbance, Coastal Ecosystem, Biological Community, Tropical Region, Seagrass Bed, Material Cycle, Benthic Organisms

1. Introduction

A tsunami happened on December 26th, 2004, following the Indian Ocean Earthquake gave a serious damage to coastal communities along Indian Ocean. It has been pointed out that the quantitative evaluation of such unpredictable, catastrophic events is difficult due to the lack of data collected before the event. We have been monitoring biodiversity and ecosystem functions of coastal areas in southwestern Thailand since 2001. Some of our research sites were heavily affected by the disturbance by the tsunami, whereas the impact was smaller in other sites. The situation gave us a rare opportunity to quantitatively assess the tsunami impact on coastal ecosystems based on before/after comparisons. Using integrated approach combining community ecology, ecosystem ecology, geographical informatics and biogeochemistry, we planned and conducted the research project to elucidate long-term changes in seagrass beds and to evaluate the interactive effects of catastrophic disturbance caused by the tsunami and local environmental modification on tropical seagrass communities in Thailand.

2. Research Subjects

2.1. Long-term changes in biological community of seagrass beds

We carry out quantitative census of seagrass species and seagrass-associated benthic animals at several seagrass beds with different impacts of the tsunami and other environmental factors using the same methodology. By incorporating existing data collected past, we show long-term changes in biological community for a decade before and after the tsunami.
2.2. Dynamics of particulate organic matter (POM) in seagrass bed area

POM supplied to seagrass beds is originated from (1) particles derived from planktonic productivity inside and outside seagrass beds, (2) particles derived from dead seagrass body, (3) particles derived from epiphytic algae on seagrass blades, and (4) particles derived from terrestrial and mangrove ecosystems by transport through rivers and coastal currents. We examined the sources of POM because they are critically important for regeneration processes of seagrass beds by catastrophic disturbances like tsunami.

2.3. Analyses on nitrogen supply processes from outside of seagrass bed

Nitrogen sources supplied to seagrass beds are classified as (1) nutrient and soluble organic nitrogen transported from outside seagrass bed area, (2) nitrogen fixation within seagrass beds, (3) nutrient and soluble organic nitrogen of terrestrial origin supplies via river and ground water, and (4) atmospheric nitrogen supplies with precipitation. Nitrogen supply was important for recovery process of seagrass beds from catastrophic disturbance because tropical seagrass beds are generally considered nitrogen-limited. We thus evaluated relative importance of above-mentioned different supply processes.

2.4. Nitrogen nutrient uptake and isotope sorting by seagrass

Types of nitrogen mostly supplied to seagrass beds are easy-soluble organic nitrogen such as PN. Organic nitrogen, however, should be inorganized to nitrogen nutrient before utilized by seagrass. In addition, NO\textsubscript{3} derived from river and supplied by precipitation is also considered as major nitrogen sources of seagrass. We carried out an aquarium experiment adding nutrient to major seagrass species to quantitatively assess the uptake rate of NH\textsubscript{4} and NO\textsubscript{3} by seagrass. We also estimated sorting coefficient of nitrogen and oxygen isotope ratio by NO\textsubscript{3} uptake.

2.5. Evaluation of detritus formation process in seagrass beds

Medium disturbance of sediments by sand movement in seagrass beds cause death of seagrass by sand deposition, which increases organic detritus originated from seagrass. In addition, loss of seagrass physical structure leads to decline in accumulation and deposition rates of particulate matters. These processes change organic content in the sediments and their composition. We carried out a sediment burial experiment in a seagrass bed mimicking intermediate disturbance, and examined the changes in organic matter amount and composition, and community structure of benthic organisms utilizing detritus. Furthermore, we buried a major seagrass species, Enhalus acoroides, into the sediment to monitor changes in organic matter amount and composition.

2.6. Estimation of grazing and detrital food chain

Physical sediment disturbance produces detritus derived from seagrass and changes the amount of organic matter in seagrass beds. This may change food web structure of seagrass beds from grazing to detrital food chain. To test which positions of food web each organism belongs to, we analyzed stable isotope ratio and cellulase activity of major animals. With analyzed data, we estimated species which can directly consume seagrasses, and classified grazing and detrital food chains.

2.7. Collection of sediment core samples and description of collected sedimental materials

To understand the burial process of seagrass beds by the tsunami, and subsequent changes in organic matter content and biological community, it is necessary to collect sediment cores and to analyze depth variation in organic matter content. To achieve this goal, we developed an effective core sampler and described the sediment conditions collected by the corer.

2.8. Effects of bioturbation by burrowing shrimps on sediment conditions

Sediment disturbance in seagrass beds is caused by a variety of different processes, including large-scale disturbance by tsunamis, medium-scale disturbance by typhoons and river discharge, as well as small-scale disturbance by biological activities of benthic species inhabiting seagrass beds. In tropical seagrass beds, burrowing shrimps make sand mounds on the surface of seagrass beds by ejecting sediments from deeper part of the bottom, causing changes in local interactions of species. To understand this process, we measured morphology, density and ejection rates of sands in the mounds made by the burrowing shrimps.
3. Materials and Methods

3.1. Long-term changes in biological community of seagrass beds

We carried out a series of field census of species diversity and abundance of seagrasses and marine invertebrate communities on March 2008, February 2009, January and December 2010 at 3 sites in seagrass beds of Kuraburi, Phangha Province, and at 3 seagrass beds in Haad Chao Mai National Park, Trang Province. In these sites, we had data on biodiversity since 2001. The census methods were the same as in the previous study. Namely, we set 15–25 census points at each site for seagrass monitoring and visually measured coverage and species composition. For marine invertebrates, we collected them in vegetation and outside vegetation of seagrass using a core of 15 cm diameter, and counted all animals retained on 0.5 mm mesh sieve.

3.2. Dynamics of particulate organic matter (POM) in seagrass bed area.

We examined POM supply to seagrass beds by measuring carbon and nitrogen content of POM, and carbon and nitrogen stable isotope ratio (δ¹³C, δ¹⁵N). We collected 5–10 L seawater around the study areas, and extracted POM by filtering through GF/F filter. POM samples were dried, decalcified, and measured by element analyzers and mass spectrometers. The samples were collected in February 2009 at 10 sites between the river mouth and offshore at Kuraburi, and at 5 sites around seagrass beds in Trang (Haad Chao Mai National Park). At the burial experimental site (see below), the sampling was conducted at both high tide and low tide.

3.3. Analyses on nitrogen supply processes from outside of seagrass bed

In the previous study before the tsunami, we conducted a monitoring of nitrogen nutrient concentration, particulate nitrogen concentration (PN) and nitrogen stable isotope ratio (δ¹⁵N) of water which came from rivers. In this study, we measured the nutrient and PN at offshore areas and seagrass beds area. In addition, we tried to analyzed nitrogen derived from atmospheric fallout. Nutrient concentration was analyzed by autoanalyzer, and PN and δ¹⁵N as described above. We also measured δ¹⁵N, δ¹⁸O of nitrate (NO₃⁻).

3.4. Nitrogen nutrient uptake and isotope sorting by seagrass

Seagrasses collected from the seagrass beds were taken to aquarium tanks. With additions of NO₃⁻ 30 µM or NO₃⁻ 30 µM plus NH₄⁺ 15 µM, the specimens were cultured for 20–30 hours either under natural light conditions or dark conditions. Nutrient concentrations in the seawater of aquaculture tank were monitored regularly. Finally, temporal change in δ¹⁵N and δ¹⁸O of NO₃⁻ was measured using the method described above.

3.5. Evaluation of detritus formation process in seagrass beds

We carried out a field experiment from February 2008 to February 2009 at a seagrass bed in Trang where Enhalus acoroides dominated. Three treatments were set as follows; (1) sediment burial treatment with PVC cage, (2) procedural control with only PVC cage but no sediment burial, and (3) natural control. Six plots were established for each treatment. Sediment samples were collected from each plot and organic supply to each plots were measured by sediment traps. At the end of experiment, sediment samples were collected for analyses of nutrient composition, stable isotope ratio, organic matter concentrations and benthic animal abundance.

The second experiment was conducted from February 2010 to December 2010. E. arocoides were buried in the sediment at two different depths (20cm and 60cm) whereas only plastic markers were buried in the control plots. At the end of experiment, sediment cores were collected for the analyses of element composition, stable isotope ratio and benthic animal composition.

3.6. Estimation of grazing and detrital food chain

Marine invertebrates and fish in the seagrass bed of Trang were collected using seine net and by hand. Digestive duct of collected animals were used for cellulase assay and muscles for stable isotope measurement. Cellulase activity (Ce activity) indicates ability of animals to use seagrass as major organic sources. The stable isotope samples were analyzed by mass spectrometer. As seagrass has higher δ¹³C values than algae, the organisms with high δ¹³C value are considered to utilize
seagrass as food sources.

3.7. Collection of sediment core samples and description of collected sedimental materials

For collecting deep sediment corers in a remote area where the tsunami happened, we developed a compact, light-weighed core with PVC pipes of 1m length, which is inserted to sediment by weight and air hammer. The inserted core was recovered by lifting with water jet pulse. The collected sediments were divided into two sections. A half was used for observation of sediment profile by digital camera and soft X-ray, whereas the other half was used for chemical analyses.

3.8. Effects of bioturbation by burrowing shrimps on sediment conditions

We measured volume of sediment mound made by the burrowing shrimps. We also measured the density of the mound by 5m x 5m quadrat. We then removed all mounds from the research plot after the mapping the position, and measured amount of sand deposited at new mounds to estimate sand ejection rate.

4. Results and Discussion

4.1. Long-term changes in biological community in seagrass beds

Analyses of seagrass abundance and species diversity at the 6 seagrass beds over 10 years in the tsunami-affected areas revealed that the tsunami impact varied greatly within a region depending on local topographical conditions. The magnitude of temporal variation in benthic community structure before and after the tsunami did not always correlated with the magnitude of the tsunami disturbance. More importantly, it was shown that the presence or absence of seagrass vegetation before the tsunami influenced greatly for the observed patterns of spatial variation in benthic community. For example, species richness and abundance of benthic animals decreased greatly in sites without seagrass vegetation, whereas they did not change or even increased in sites with vegetation. The findings demonstrate that the importance of maintaining seagrass beds for ameliorating catastrophic physical disturbances like tsunami on biodiversity and ecosystem services of coastal areas.

4.2. Dynamics of particulate organic matter (POM) in seagrass bed area

C/N ratio and δ13C of POM at Kuraburi did not vary greatly whereas δ15N did greatly, with the high value especially measured at the river mouth. C/N ratio and δ13C at Trang did not vary greatly in high tide at Trang although δ13C was significantly higher than Kuraburi. δ15N at Trang greatly fluctuated and it was highest at offshore stations. At low tide, C/N ratio and δ15N at the experimental site was not different from that at high tide, whereas δ13C was significantly higher than at high tide.

Because δ13C was higher than representative values for organic matters derived from terrestrial plants, and because among-site variation is small, it is considered that POM originated from land and mangrove area did not reach the seagrass beds. C/N ratio also suggests that POM in the seagrass beds was mostly derived from microalgae plankton in offshore pelagic areas. However, high δ13C value at the experimental sites at low tide indicates the influence of resuspended detritus from seagrass on POM composition.

4.3. Analyses on nitrogen supply processes from outside of seagrass bed

Nitrogen nutrient concentration was less than 1 µmol L−1 at most seagrass beds without river influence although it occasionally reached 2-3 µmol L−1 in low tide. Nutrient concentration was high in river mouth due to nutrient supply from river water, and thus negatively correlated with salinity. PN concentration in seagrass beds and adjacent areas was more than twice higher than nutrient concentration. δ15N was within a range of +1.4‰ − +3.6‰. PN concentration was more than 4 µmol N L−1, and δ15N was ca. +7‰ in the river mouth. This is due to the increase in phytoplankton by consumption of river-derived nutrient with high δ15N values.

For stable isotope ratio of NO3−, δ15N was stable, whereas δ18O was lower in the river and higher in offshore area. NO3− concentration in rain was ca. 10 µmol L−1 and δ15N was as low as −5‰, whereas δ18O was as high as +64‰. NO3− derived from atmosphere and accumulated on mangrove leaves had also low δ15N and high δ18O.
Based on the obtained data, it was considered that nitrogen nutrient of terrestrial origin supplied by river was consumed by phytoplankton in river mouth area and converted to PN. In ocean, nitrogen of atmosphere origin was supplied with rainfall, and its relative abundance increased with the distance from river mouth. Nitrogen supply to seagrass beds was mainly made by PN because δ15N value of PN in the seagrass beds is similar to that of δ15N of atmosphere-derived matter and nitrogen fixation.

4.4. Nitrogen nutrient uptake and isotope sorting by seagrass

Two seagrass species, Enhalus acoroides and Thalassia hemprichii can utilize NH4+ and NO3-. Uptake rate was higher for NH4+ than NO3-, and NO3- uptake ratio decreased in the presence of NH4+ although total inhibition of NO3- uptake did not occur. Both NH4+ and NO3- were uptaken actively even in dark conditions. Isotope sorting coefficient with NO3- uptake was 4.2-5.1 under natural light condition, and 2.7-3.6 under dark conditions. It was 3.6-6.0 for oxygen, and systematic difference was not found between different light conditions.

Based on the obtained results, it is considered highly likely that seagrass in natural conditions mostly rely on NH4+ derived by inorganization of digestible organic nitrogen as main nitrogen sources. However, seagrass can also uptake NO3- derived temporally by river discharge and rainfall. It can also uptake and accumulate NH4+ and NO3- during night time. Isotope sorting by NO3- uptake was within a range of that observed by other aquatic plants, and thus the contribution of seagrass beds on the spatiotemporal variation in stable isotope ratio of NO3- can be modeled as those for phytoplankton.

4.5. Evaluation of detritus formation process in seagrass beds

At the start of the 1st experiment, C/N ratio, nitrogen and carbon concentrations, and δ13C was different between the burial plots and the control plots. In the control plots, some terrestrial-derived organic matter was found. For the sediment trap samples, no significant variation was found between the treatments although the difference was detected between suspension traps and sand traps. Average value of δ13C did not vary between the two types of the traps, whereas the range of δ13C was more pronounced for the sand traps. It is considered that suspended organic matter mostly consisted of that derived from marine phytoplankton microalgae. Organic matter in drifted sand consisted of sedimentary organic matter and those derived from seagrass.

At the end of the 1st experiment, organic matter in the sediment was divided into two major sources; seagrass-derived and terrestrial-derived ones, and their relative abundance varied among different types of plots. In the sediment burial plots, organic matter from seagrass origin was small in amount, whereas it was greater in the control plots. It is likely that new supply of seagrass-derived organic matter occur consistently in the control plots, while it was only consumed without new supply in the burial treatment. Animal species richness and abundance tended to higher with more organic matter content originated from seagrass.

In the 2nd experiment, organic matter derived from buried Enhalus acoroides was found in the burial plots. However, the marker for the control plots of the shallow treatment (20 cm) was not detected at the end of the experiment. This suggests that organic matter from seagrass cannot remain in the shallow depth of the sediment where small-scale but frequent disturbance occur.

4.6. Estimation of grazing and detrital food chain

A total of 89 animal species were collected for biochemical assays. Echinoderms had high Ce activity, whereas species with high and low Ce activities were both found for fish, bivalves, snails, crustaceans and polychaetes. For fish, species with high Ce activity included both herbivorous fish and some carnivorous species. The results of stable isotope analyses indicated that species with high Ce activity did not necessarily showed high δ13C values, suggesting that Ce activity does not directly linked with feeding on seagrass. Some species with high δ13C values but low Ce activity showed high δ15N values, suggesting that they utilize seagrass-derived organic matter which microbial activities are involved, or that they consume prey which feed on seagrass.

4.7. Collection of sediment core samples and description of collected sedimental materials

A total of 11 core samples were collected from seagrass beds, tidal flats and sand dunes. The maximum depth is 2m from the bottom surface. The corer developed in this study can successfully
be utilized to collect deep cores in high current sites within the short period. No major disturbance was made to the sediment upon collection.

For the cores collected from the tsunami affected area, we observed sand and cobble layer of sediment at 10cm layer from the surface which were accumulated by the tsunami. In the deeper layer, we further observed layers with shell which were reported as tsunami-derived deposition by other studies. The findings indicate the studied area were affected by several different tsunami occurred in the past.

4.8. Effects of bioturbation by burrowing shrimps on sediment conditions

The density of mound made by the burrowing shrimp was 8-28/100m². The average volume per each mound was 9 L. Sand ejection rate was estimated to be 28 L per 2 days and 100 m². The amount ejected per year is calculated as 5,110 L which is as thick as 0.5mm sand deposited assuming homogeneous environment. Accounting for spatial heterogeneity, however, the sediment depth become 1 cm per 5 days at the mound area, which is deep enough to bury seagrass. The burrowing rate of the shrimp was estimated as 3.3 m per day.

5. List of Publications

In peer-reviewed journals

Books

Presentations in academic meetings

Nakaoka M (2010) Biodiversity of seagrass bed: its function in coastal ecosystems. 57th Annual Meeting of Ecological Society of Japan, March 20, Tokyo, Japan

Nakaoka M (2010) Earth environmental change and ecosystem services. A Symposium at 2010 Japan Fisheries Society Spring Term Meeting, March 26, Fujisawa, Japan


Nakaoka M, Fortes MD (2010) Towards an integrated coastal ecosystem conservation and adaptive management of coastal areas of Southeast Asia. 9th International Seagrass Biology Workshop, November 28th, 2010, Trang, Thailand

Nakaoka M (2011) Scaling up our (your?) research for better understandings of coastal ecosystem dynamics. International Symposium on the Sustainability and Productivity of Coastal Resources, January 20, 2011, Nagasaki, Japan