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Introduction of underwater video system for the observation of coastal macroalgal vegetation

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Abstract— Benthic vegetation has important roles in coastal ecosystems. Vegetation analysis and biomass estimation are urgently required for proper utilization and conservation of coastal area and also for sustainable fisheries. Although remote sensing methods such as aerial photography and satellite imaging give us efficient ways for vegetation mapping on wide area, these methods are limited to shallow and flat bottom waters where seagrasses mainly occur. For macroalgae, predominant on rocky littoral and sub-littoral zones, direct visual observation with SCUBA has been used. The accuracy of species identification is expected to be high, but the time consuming procedures result in limited coverage of area. To overcome the limitation we have developed a monitoring system for seaweed vegetation in conjunction with underwater video, GPS and depth sounder. Although limited resolution of the image might affect the accuracy of species identification, the synchronized recordings of video image and three-dimensional positioning of vegetation enabled quick monitoring to cover certain spread of area. It was possible to deploy the system in different ways, from traditional quadrat placement on transect line, to serial towing, so that the diversity of species and bottom environments could be adequately observed. Bathymetry and monitoring of bottom substrate and invertebrates were also enabled with the system.

For the effective extraction of information from observation and also aimed to improve the accuracy of biomass estimation, we developed a numerical analysis using generalized additive models (GAMs). The two distinctive properties of GAMs analysis, constraint free smoothing and model selection by AIC, enabled versatile modeling of macroalgae distribution in direct/indirect association with environmental factors. Together with categorization by life forms of macroalgae, it was possible to deduce a possible vegetation pattern and a numerical prediction of standing stock biomass for each category even from small sample-sized quadrat observations.

The application of this system in the Otsuchi bay, Tohoku districts, Japan was introduced, and further expansion of the methods to include tropical waters were discussed.

Key words: macroalgae, GPS, abundance, underwater video

Introduction

Marine benthic vegetation has significant roles in coastal ecosystems. Coastal areas are subject to human impact such as degradation of environment by constructions and pollution (Gray 1997). Nowadays environmental issues caused by rapidly growing economic activities are not only a domestic matter but also a global concern. Therefore it is urgently required to monitor marine benthic vegetations in coastal area, and to elucidate the functions and roles of them in coastal ecosystems for proper utilization and conservation of coastal area and also for sustainable fisheries.

"Biodiversity" is the key concept to understand the ecological integrity. The taxonomical knowledge is to be firstly required as a basis of research. But ecological observation on marine benthic macroalgal communities should be also put on high priority. Traditionally line transect and quadrat methods have been used to observe marine benthic macroalgal communities. But this method requires intensive observatory work with taxonomical knowledge and experience in the field. Vast areas yet remain to be explored in Southeast Asian countries that are covered by JSPS biodiversity project. Therefore efficient observation methods and new analytic frameworks are required. The authors have successfully introduced low cost digital equipments such as GPS, echosounder, underwater video camera to observe marine benthic vegetation in Otsuchi bay. A versatile statistical method using generalized additive models (GAMs) to describe and predict macroalgal abundance is also introduced. To apply our methods to tropical marine benthic vegetations some modifications could be required, as our methods are originally developed in temperate zone. In this paper we describe and discuss 1) introduction of digital equipments for observation on benthic macroalgal vegetation, 2) observation using underwater video camera in Otsuchi bay, 3) abundance estimation using generalized additive models, and 4) the deployment in tropical waters.

Digital Equipments for Observation on Benthic Macroalgal Vegetations

Recently modern observation systems have been more often used for research on seagrass than on macroalgae. Seagrasses tend to form uniform community on flat and shallow sandy or muddy bottoms. Therefore optical remote sensing methods such as satellite imaging and aeral phtotography have been widely used to estimate the area of cover by these plants (eg. Belsher et al. 1988). Komatsu et al. (2003b) emphasized the importance of cartography for seagrasses research. The heights of the plants are usually regulated by shallow tidal height. Norris et al. (1997) used underwater video to estimate seagrass abundance, and established the statistical method for abundance estimation using cluster sampling. For echosounder, the method to determine the abundance using echogram indicating density of plants has also been developed (Komatsu and Tatsukawa 1998). More recently, multi-beam sonar, a three-dimensional measuring equipment, has proven to be useful to determine both the cover in fine scale and also the biomass of seagrasses very quickly (Komatsu et al. 2003a).

For macroalgal research , the utilization of echosounder or underwater video can be traced back to 1980's in Japan. But the applications of such modern equipments have been limited in number. Kitoh (1983) and Tanaka and Tanaka (1985) introduced echosounder for the estimation of macroalgal abundance. But as the seaweed body is very wavy, the resulting echogram may be complicated (Tanaka and Tanaka 1985). Though the trials to use aeral photography to identify the type of algal beds have been repeatedly attempted, the results have not been necessarily successful. Macroalgae mainly occur on rocky shore, where the geography tend to be rough and rugged. When satellite imaging is used, wave motion prevents the visibility in shallower waters, and also turbidity easily interferes in deeper waters. As the optimal method to observe marine benthic vegetation differs depending on the purpose, geography, vegetation itself and budget, it is advisable to make full use of flexible combinations of low cost digital equipments that meet research demands.

Observation Using Underwater Video Camera in Otsuchi Bay

We developed an underwater video system in conjunction with global positioning system (GPS) and depth sounder to monitor benthic macroalgal vegetation in Otsuchi bay (Fig. 1). An underwater video camera, FM-4100 (QI coporation) with a large stainless frame was used, and it was connected to on-boat handy DV camcorder. The frame was used to stabilize the camera when submerged in seawater and also settled down on the bottom. Therefore two different deployment of video system were possible, serial towing and traditional quadrat placement on transect line. We set the main transect line perpendicular to the shore, using 50 m plastic rope placed on the bottom. Camera frame was settled down on the bottom at every 5m interval targeting the marks on the rope. Sub transects were parallel to the shore, and camera frame was towed with recording of position and depth (Fig. 2). For positioning, a 12 parallel channel single GPS receiver (15 m 2DRMS) was used. Differential GPS singal was known to be very weak and easily lost in this area by preliminary experiment. It was also known that 2D positional resolution of this GPS is high enough to keep relative position correct (less than a meter) within a short period (typically an hour) of measurement. For depth sounding, portable

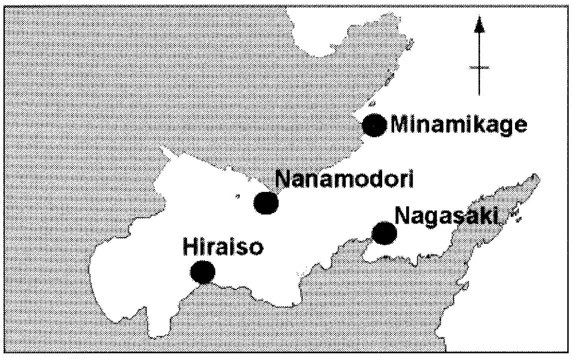

Fig. 1. Map of Otuschi Bay.

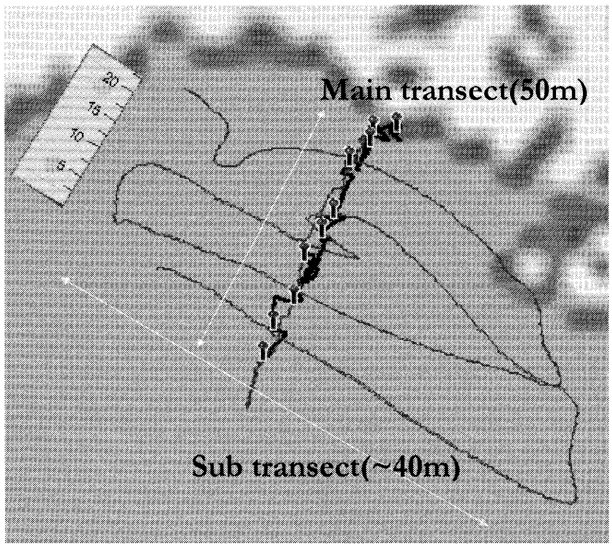

Fig. 2. Tracking lane of macroalgal observation at Nanamodori station in Otsuchi bay.

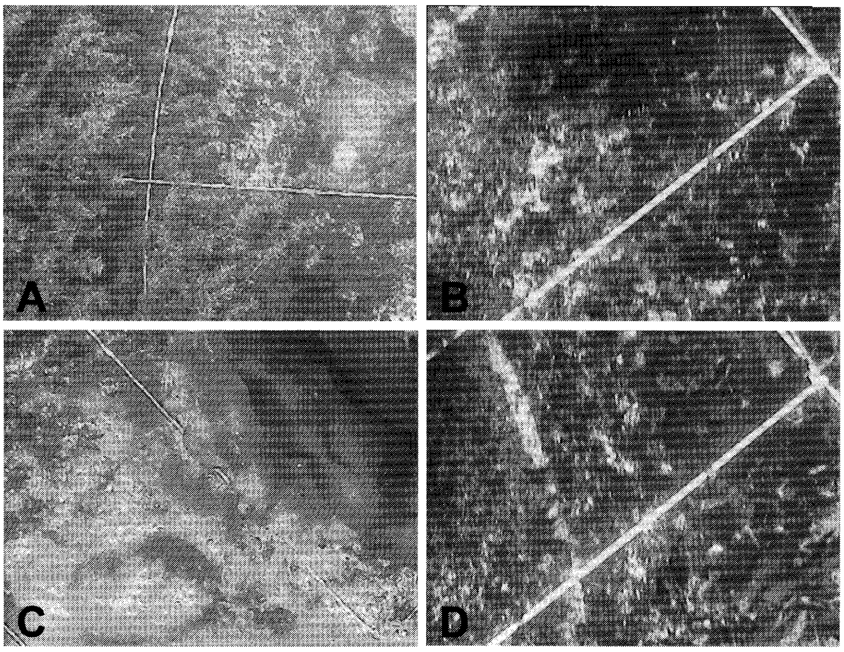

Fig. 3. Photo of video plots. *Sargassum yezoense*: 3.4 m depth at Nanamodori, Aug. 18, 2003(A), 4.7 m depth at Minamikage, Dec. 5, 2003(B), *Laminaria japonica*: 4.0 m depth at Minamikage, Aug. 25, 2003(C), 4.8 m depth at Minamikage, Dec 5, 2003(D).

fishfinder equipped with 20 degree cone angle and 200 KHz transducer was used. The footprint on the bottom is about 1/3 of depth. These equipments are connected to a laptop PC by serial line with NMEA protocols. Captured video image and its position and depth were synchronized by time code on video calibrated by a shot of GPS time and its time code.

The stainless frame camera was set about 1m up from the bottom, and the footprint of video shot was about 0.5 m^2. Camera could be close to the target macroalgae and robust against turbidity when settlement method was taken. For abundance estimation, coverage and also number of individuals or shoots of large macroalgae were measured. To verify the species occurence and its distribution, in situ observation and sample collection using physical quadrat were also conducted seasonally. Using this system, seasonal changes of key species were clearly monitored. Canopy forming large brown algae such as *Sargassum* and *Laminaria* were abundant in spring (Fig. 3A, C). In autumn they lost the upper part of the body and only basal parts remained (Fig. 3B, D).

Abundance Estimation Using Generalized Additive Models

Originally statistical properties and ecological meaning of generalized additive models were described with land plants. Due to the easiness of remote sensing on land plants, vast amount of vegetation data and environmental factors including geographical data such as digital elevation model (DEM) are compiled. Their statistical treatment was a key to elucidate environment-species association that has been the major issue in plant ecology. Therefore many statistical treatments have been developed (Austin 2002, Jongman et al. 1995). Recently increasing concern on global warming and environmental modification by development have enforced numerical evaluation and prediction methods to be refined, and predictive habitat distribution models have been developed (Guissan and Zimmermann 2000). Generalized Linear Models (GLMs; McCullagh and Nelder 1989) for absence/presence data and Generalized Additive Models (GAMs; Hastie and Tibshirani 1990) are in top priority for developing prediction models.

To relate algal abundance and environmental factors, let us consider the relationship between large algal abundance and water depth. Because of the large size, this species might be weak in shallows. And also it is weak in deep due to the limitation of light. At any given midpoint between two extremes this species might be predominant. Therefore the change of abundance along the water depth might be smooth and might convex on downward. However, when a prior information on the function form is not available, it is convenient to use local smoothing, a kind of nonparametric function. And if south-north abundance difference in the bay was conceived, one might try ANOVA that is a parametric linear model. But be aware that both factors might not be controlled well. An independent comparison has no meaning. An additive model of two terms is the simplest solution to evaluate both factors simultaneously. This is the idea of generalized additive models. These models are nonparametric extensions of GLMs, and are called semiparametric models. Data fitting are done using back-fitting algorithm, which is a computer-intensive method. Recent personal computers should not

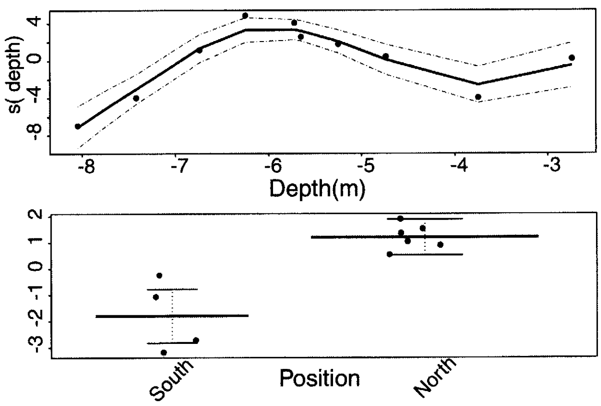

Fig. 4. Estimated response of abundance of brown alagae to depth (upper) and position (lower) using generalized additive models.

have difficulties for operations.

For the effective extraction of information from observation and also to improve the accuracy of biomass estimation, we developed a numerical analysis using generalized additive models (GAMs). The two distinctive properties of GAMs analysis, constraint free smoothing and model selection by AIC (Akaike 1974), enabled versatile modeling of macroalgae distribution in direct/indirect association with environmental factors.

As an example, the abundance response of large brown algae in Otsuchi bay to environmental factors is shown in Fig. 4. Total of eleven quadrat data taken in June 1996 at four stations Otsuchi bay (Fig. 1) were used for GAMs analysis. Though only water depth and position in the bay were used as environmental factors, several combinations of factors were possible by pooling locality. When observed data were fitted to the models, two factors model with water depth and locality for north and south separation was selected as the best model by AIC. For water depth, maximum abundance was yielded at 6 m. And clear south and north difference in abundance was observed (Fig. 4). Steep rocky shore of north side of the bay could supply stable bottom substrate for perennial large brown algae like *Sargassum* species that were dominant there.

Deployment in Tropical Waters

From preliminary surveys it is known that some modifications are required for the system to meet the requirement in tropical waters. Geographic difference is one possible issue. Development of corals can make unique coastal landscapes in tropical waters. Vast shallow and flat sandy beach may spread where mainly seagrasses occur and *Halimeda* and *Caulerpa* can be associated. Beyond such huge intertidal flat, shallow subtidal zone may spread where vegetation is not yet well documented. For either cases wide area mapping is highly demanded. It is noteworthy that availability of high-resolution satellite image such as Ikonos or Quickbird for arbitrary time and place in SE Asia can be very limited. Use of balloon or kite with digital camera is a candidate for shallow and clear waters. For deeper area, boat based observation with submerged underwater camera with GPS and echosounder is recommendable. Both mapping and bathymetry should be enabled simultanemously, and if echosounder is recordable for sonar image, abundance estimation is worth to try with such system following Komatsu and Tatsukawa 1998.

For intertidal flat, observations should be flexible in their deployment. According to tide level, peripatetic, swimming, and boat-based observations can be chosen. For either cases depth sounding for shallower than 60 cm is impossible by ordinary echosounder. Swimming with system set in styrofoam box can be a cheap and convenient way to cover small area.

Although viewing motion of macroalgae helps to determine algal edge from our experience, digital still camera should be a good alternative. The advantage of digital still camera is that one can have high-resolution image with lower cost. Use of tripod on which is set a camera downward helps to get same-sized image easily. For shallows or dried up bottoms, as a camera can stay in the air, a hood against wind and strong sunshine might be required to get good images.

Freely available satellite images can help the design of field research, and detailed tide information is indispensable not only for field research but also for bathymetry.

Care should be taken for the source of electricity in the field. Under high temperature, lifetime of batteries can be shorter than we expected.

Concluding Remarks

Although direct visual observation with traditional line transec and quadrat method is indispensable for detailed examination of macroalgal communities, introduction of novel methods are urgently required to cover wide and unexplored waters, where marine biodiversity are potentially threatened by human impact. Nowadays, low cost digital equipments are available all over the world, and to build them as a system is feasible according to the purpose of research. Exploring with such system upon shallow subtidal zones where their vegetations have not been well documented is our new challenge.

On the other hand long time continuous ecological monitoring on same marine benthic vegetation is also required, which may not only be an indicator of habitat degradation but also a clue to the response of marine vegetation to global climate change.

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