Distribution, Biodiversity and Long-term Changes of Seagrass Beds in Okinawa Island: Effects of Terrestrial Ecosystems

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Abstract

We investigated large-scale distribution and biodiversity of seagrass beds and their temporal changes along eastern coast of Okinawa Island by an integrated approach using RS, GIS and field monitoring. Nine seagrass beds of various sizes are recognized by maps and aerial photographs along the middle part of the eastern coast. Patterns of temporal changes in distribution between 1977 and 1993 varied among different seagrass beds, with some seagrass beds extending its area, whereas others remaining stable. Regional and local species diversity of seagrasses also varied among beds. Species diversity was low in beds with larger watershed areas behind coastline, and high in beds with smaller watershed, suggesting possible impacts of terrestrial ecosystems on seagrass beds through river discharge.

1. Introduction

Seagrass bed is one of the most conspicuous components of coastal ecosystems around the world (Short & Green 2003). It is known as the most productive habitats in the world with its annual productivity equivalent to that of tropical rain forest (Hemminga & Duarte 2000). It also provides habitats for a variety of plant and animals species, producing "hot spot" of biodiversity in marine ecosystems (Williams & Heck 2001).

Over the past centuary, seagrass beds have been decreasing due to a variety of human-induced disturbance worldwide (Shorts & Wyllie-Echeverria 1996), and especially in tropical regions (Fortes 1988, 1995). For example, deforestation causes massive sediment discharge from terrestrial to coastal areas, resulting in increase in turbidity and light attenuation. Urbanization along the river areas and development of farmland and aquaculture hatcheries cause heavy nutrient loads, leading to serious eutrophication in coastal waters. Seagrass beds are considered to be most susceptible to alteration of terrestrial ecosystems because they generally locate soft bottoms near river mouth.

To promote conservation of seagrass beds, we first need to know their exact distribution and its temporal changes over large spatial scales. For such purposes, macroscale analyses using RS and GIS have been shown to be effective and adopted widely for terrestrial and open ocean ecosystems, but to less extent for coastal ecosystems.

The aims of the present study are (1) to determine large-scale distribution of seagrass beds along eastern Okinawa Island, (2) to examine spatial and temporal changes in seagrass beds by integrating existing data on past distribution by GIS, and (3) to examine effects of terrestrial ecosystems on distribution, abundance and biodiversity of seagrass beds. We analyzed spatial and temporal changes in large-scale distribution of seagrass beds using existing maps and aerial photographs in addition to field census on seagrass distribution and species diversity. We also analyzed spatial and temporal changes in terrestrial ecosystems corresponding to watershed areas behind each seagrass bed using maps of land use and satellites images.

2. Materials & Methods

2.1 Study site

This research was carried out at eastern coast of Okinawa Island where seagrass beds are known as major components of shallow water ecosystems (Fig. 1). Based on existing information on literature (Toma 1999, Yoshida et al. in press), we selected our study areas along the coastline between Cape Teniyazaki (26° 34' N; 128 ° 9' E) and Cape Kinn (26° 26' N; 127 ° 57' E). Nine subtidal seagrass beds are chosen as main study sites; East Kayo, West Kayo, Abu, Henoko, Toyohara, Matsuda, Ginoza, Kanna, and Kinn.

In this region, eight seagrass species have been known to occur. They are *Zostera japonica*, *Halophila ovalis*, *Thalassia hemprichii*, *Syringodium isoetifolium*, *Cymodocea serrulata*, *Cymodocea rotundata*, *Halodule uninervis* and *Halodule pinifolia* (Toma 1999). All the species except *Z. japonica* occur at subtidal zone of these seagrass beds.

For the investigation of the influence of terrestrial ecosystems, we collected data for the whole watershed area of coastline where nine seagrass beds exist, which corresponded to ca. 70 km^2 area in middle part of Okinawa Island, covering districts of Nago City, Ginoza Town and Kinn Town.

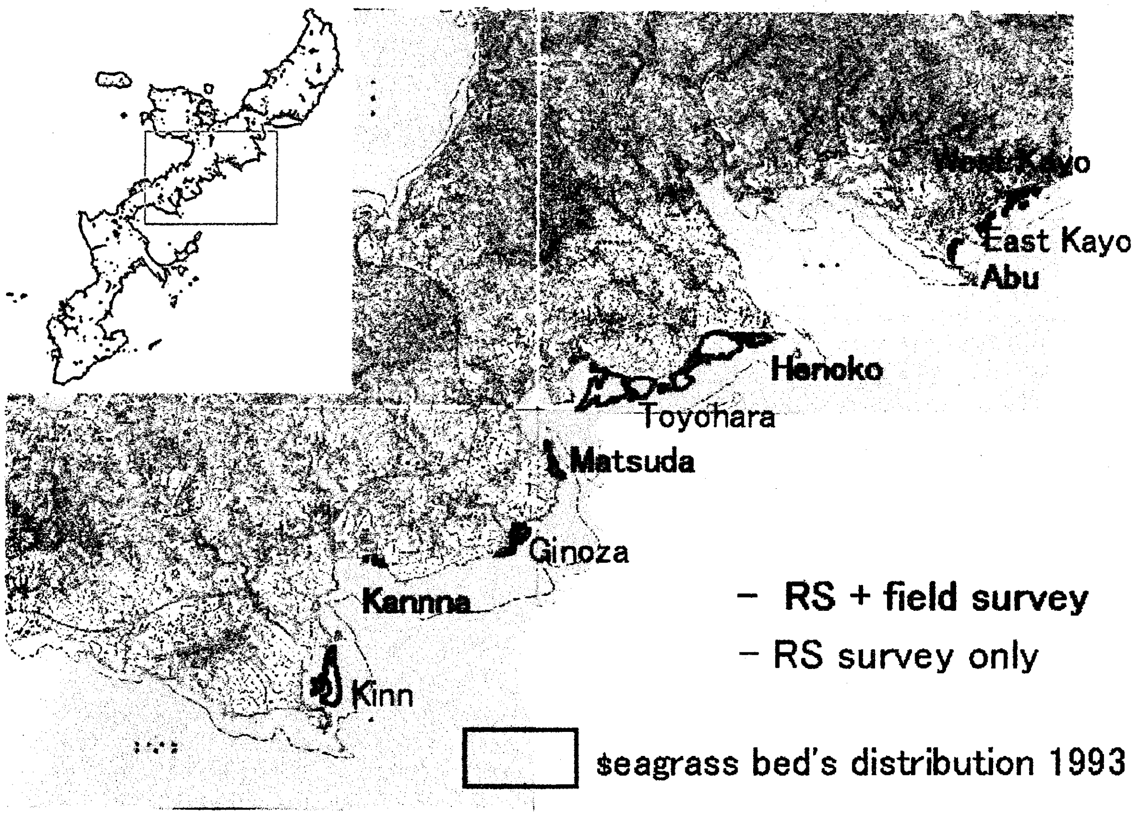

Fig.1. Study site along eastern coast of Okinawa Island. Nine seagrass beds are analyzed using RS among which field survey was carried out at five seagrass beds (East Kayo, Abu, Henoko, Matsuda and Kanna).

2.2 Analyses of seagrass bed distribution

Large-scale spatial distribution of seagrass beds and its temporal change were analyzed using map data and aerial photographs as follows. (1) Color aerial photographs of 1/10,000 magnification taken in 1977, (2) those taken in 1993, (3) Wildlife and Plant Distribution Map of Okinawa Prefecture that was made based on the 2nd National Survey on the Natural Environment (Environment Agency of Japan 1981) in which seagrass distribution was surveyed between 1978 and 1979, and (4) Environmental Sensitivity Index Map issued in 2000 (Ministry of the Environment of Japan 2000). Data on seagrass distribution of the latter two maps were used after digitalization with a scanner. Aerial photographs were first digitalized, and the area of seagrass beds were then discerned and plotted by eye. These data were superimposed on to the same map using GIS. Area of seagrass beds in each dataset was then calculated directly on the map.

2.3 Field survey

Field survey of seagrass beds was carried out in July and September 2003 at five sites: East Kayo (July 2003), Abu, Henoko, Matsuda and Kannna (September 2003). At each site except for Henoko, we established a census plot of 15,000 m^2 in area. Three to five parallel transects were first set perpendicular to shoreline at the interval of 50 m. Along each transect, three to five census points were set at the interval of 50 m. As the result, a grid consisting of 15-25 census points were established at each station (three to five points parallel to the shoreline, times three to five points along the depth gradient). For Henoko, census was undertaken for overall seagrass distribution by setting a grid at the interval of 200 m (See Yoshida et al. in press).

At each point, we randomly placed three to five 0.5 x 0.5 m quadrates haphazardly. Species composition of seagrasses and coverage by each seagrass species were recorded for each quadrat by one observer. Later, biases in coverage estimates among observers were calibrated using the methods in Yoshida et al. (in press). Data on coverage of each seagrass species per quadrat were averaged for each census point.

Diversity of seagrasses in each seagrass bed was represented by two parameters: species richness and Simpson diversity index (See Miyashita & Noda 2003 for detailed information and methods of calculation of these two indices). They were calculated at the two different spatial scales: local diversity (per each census point within a site, based on seagrass occurrence and coverage per 1.25 m^2) and regional diversity (per each seagrass beds by using data of all the census points). For Simpson index, the subtraction from the latter estimates

(D_γ) by the former (D_α) equals turnover diversity (D_β) representing differences in species composition and abundance among census points at each site (Miyashita & Noda 2003).

2.4 Analyses of terrestrial ecosystems

For each of nine watersheds behind each seagrass bed, we collected data on land use and satellite images. For the land use map, we analyzed the fine grid data for 1976, 1987, 1991. Five different satellite images taken at the different periods were collected for the whole watershed areas; i.e., Landsat-1 MSS 1976, Landsat-5 TM 1985, JERS-1 VNIR SWIR 1993, ADEOS Mu Pa 1998, and Landsat-7 ETM 2002. The maps and satellite images are digitalized and analyzed using GIS.

3. Results and Discussion

Nine seagrass beds along the eastern coastline of Okinawa Island varied greatly in size. According to the data from aerial photographs in 1993, the largest bed extend continuously between Henoko and Toyohara, followed by Kinn, Ginoza, Matsuda, West Kayo, East Kayo, Abu and Kanna. Estimated area of each seagrass bed varied greatly among four different sources. Analysis of temporal changes in seagrass distribution cannot be made using data in 1981 and 2000 because of different survey methods in these studies. We thus used two aerial photograph data for examining temporal changes in seagrass bed. Comparison of seagrass bed distribution in 1977 and 1993 revealed different patterns of temporal changes in different seagrass beds. For example, the seagrass bed extended largely toward shoreward in Henoko during 1977 and 1993, whereas the distribution was relatively stable in Kayo.

Seven seagrass species were found in all of the five seagrass beds where the field survey was conducted, except for *C. serrulata* in Abu (Table 1). Thus, regional diversity over entire seagrass bed scale measured by species richness did not differ largely among seagrass beds. However, greater among-site variation in regional diversity was found in Simpson diversity index (D_γ). It was highest at East Kayo, followed by Kanna, Abu, Henoko and Matsuda. For local species diversity at smaller spatial scale (within each census point), average species richness per 1.25 m^2 area was higher in the two northern seagrass beds (East Kayo and Abu) than the three southern seagrass beds (Henoko, Matsuda and Kanna). Local diversity measured by Simpson diversity index (D_α) showed a similar pattern of spatial variation. Turnover diversity (D_β), representing spatial heterogeneity in species composition, was greatest at Kanna and lowest in Abu.

Table 1. List of species and species diversity of seagrasses at five seagrass beds surveyed in summer 2003.

Seagrass bed	Occurrence of each seagrass species							Species richness	Mean species richness per station	Simpson's diversity		
	Ho	*Th*	*Cr*	*Cs*	*Hu*	*Hp*	*Si*		($1.25m^{-2}$)	D_α	D_β	D_γ
East Kayo	O	O	O	O	O	O	O	7	4.8	0.59	0.20	0.79
Abu	O	O	O	×	O	O	O	6	3.4	0.60	0.02	0.62
Henoko	O	O	O	O	O	O	O	7	2.0	0.36	0.18	0.53
Matsuda	O	O	O	O	O	O	O	7	2.7	0.13	0.36	0.49
Kannna	O	O	O	O	O	O	O	7	2.7	0.23	0.49	0.72

Ho: Halophila ovalis; Th: Thalassia hemprichii; Cr: Cymodocea rotundata; Cs: Cymodocea serrulata
Hu: Halodule uninervis; Hp: Halodule pinifolia; Si: Syringodium isoetifolium

Watershed of three northern seagrass beds (East Kayo, West Kayo and Abu) is smaller in area than that of five southern seagrass beds (Fig. 2). The latter five contain larger areas of forest, agricultural and urban areas than the former three.

Present study revealed that combinational analyses of RS, GIS and ground survey of seagrass beds are effective for understanding large-scale distribution of seagrass beds and its long-term dynamics. Spatial variation in distribution, abundance and species diversity of seagrass beds was found to be large in east coast of Okinawa Island. Most notably, species diversity in northern seagrass beds with smaller watershed area was greater than that in southern beds with larger watershed, suggesting different impact of terrestrial ecosystems. In reality, environmental deterioration due to run-off of massive red soil from rivers has been known to be intense in the southern seagrass beds such as Henoko and Matsuda, which are likely to affect distribution and species composition of seagrasses.

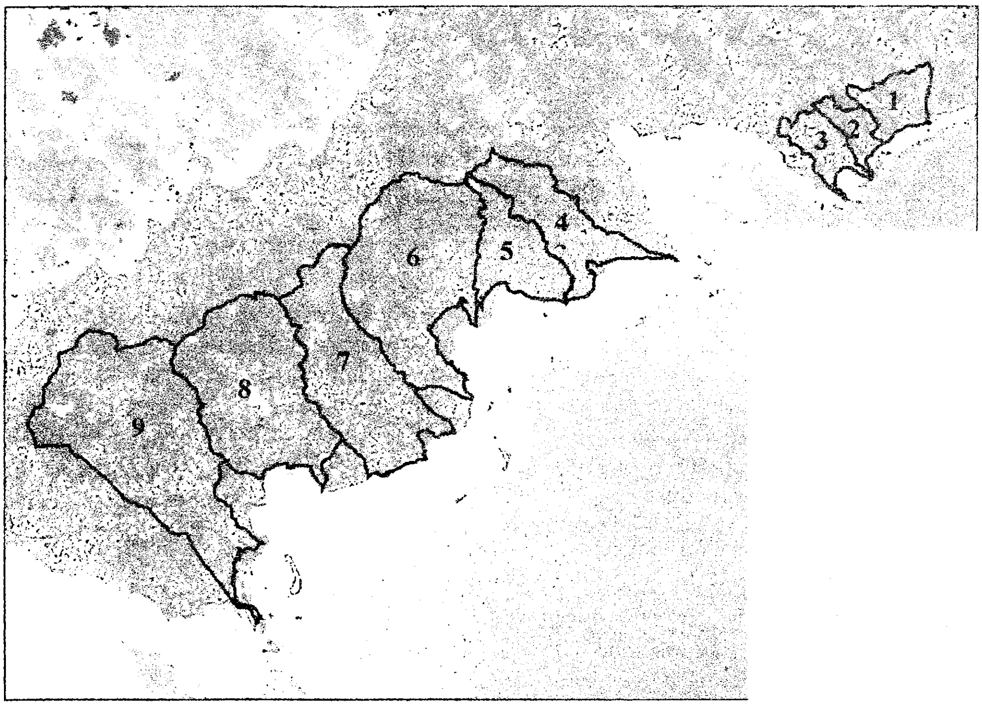

Fig.2. A map showing watershed areas behind nine seagrass beds in the present study. 1: East Kayo, 2: West Kayo, 3: Abu, 4: Henoko, 5: Toyohara, 6: Matsuda, 7: Ginoza, 8: Kanna, 9: Kanna.

In future studies, incorporation of information on coastal environmental processes such as hydrodynamics and water quality changes is necessary for further understanding of the processes and mechanisms how alteration of terrestrial ecosystems affects large-scale and long-term dynamics of seagrass beds locating along the coastal areas of Okinawa Island.

Acknowledgements
We are grateful to NACS-J for kindly permitting us to use their data on seagrass census. We wish to thank M. Yoshida, N. Kouchi for their help in data analyses on seagrass distribution and biodiversity, N. Kouchi, E. Sakamaki and participants of 5th and 6th Jangusa Watch for their help in the field survey, and F. L. Tjandra and other members of Kondoh Lab for instructions on the use of GIS.

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