Development of mapping methods for macrophyte beds in Japan by using ALOS AVNIR-2

Tatsuyuki SAGAWA*[a], Tomohiro WATANABE[b], Akira WATANUKI[c], Tetsu KOIKE[d], Haruchika KAMIMURA[e] and Teruhisa KOMATSU[f]

[a] Remote Sensing Technology Center of Japan (RESTEC),
TOKYU REIT Toranomon Bldg., 3F, 3-17-1, Toranomon, Minato, Tokyo 105-0001, Japan;
Tel:+81-3-6435-6752; E-mail: sagawa_tatsuyuki@restec.or.jp

[b] Remote Sensing Technology Center of Japan (RESTEC), JAXA Tsukuba Space Center, 2-1-1 Sengen, Tsukuba, Ibaraki 305-8505, Japan; Tel:+81-29-859-5572; E-mail: tomozo@restec.or.jp

[c] Alpha Hydraulic Engineering Consultants Co., Ltd., U・Y Bldg., 2F, 2-7-9, Higashikanda, Chiyoda, Tokyo 101-0031, Japan; Tel: +81-3-5829-6543; E-mail: watanuki@ahec.jp

[d] Alpha Hydraulic Engineering Consultants Co., Ltd., U・Y Bldg., 2F, 2-7-9, Higashikanda, Chiyoda, Tokyo 101-0031, Japan; Tel: +81-3-5829-6543; E-mail: koike@ahec.jp

[e] Japan Aerospace Exploration Agency (JAXA), Hulic Kudan Building 8F, 1-13-5, Kudanshitakita, Chiyoda,, Tokyo 102-0073, Japan; Tel; +81-50-3362-7763; E-mail: kamimura.haruchika@jaxa.jp

[f] Atmosphere and Ocean Research Institute, The University of Tokyo, 5-1-5, Kashiwanoha, Kashaiwa, 277-8564, Japan; Tel: +81-4-7136-6222; Fax: +81-4-7136-6223; E-mail: komatsu@aori.u-tokyo.ac.jp

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ABSTRACT: In coastal waters, macrophyte beds (seagrass and seaweed beds) are important habitats for many marine organisms. However, decrease in macrophyte beds has been reported in all over Japan. Seagrass and seaweed are considered to be affected by climate changes or human impacts. Mapping and monitoring of seagrass and seaweed distributions are necessary for revealing the mechanism of their decrease and making counter measures for those conservation and restoration. Satellite remote sensing is thought to be one of the most efficient methods for macrophyte beds mapping because a satellite image covers a large area at once and making mosaic is relatively easy compared with that of aerial photographs. So far, some researchers have studied on seagrass mapping and a few researchers also focused on seaweed beds. Most of studies on macrophyte bed mapping have limited in areas of test sites. Only a few studies focus on national scale mapping using a set of satellite images. This study was conducted as a part of JAXA projects aiming to develop methods for mapping seagrass and seaweed beds all over Japan. ALOS/AVNIR-2 images were selected for analysis because its spatial resolution (10m) is high enough to cover almost all Japanese coast with its archived images for mapping. Four geographically separated sites were selected as test sites focusing on differences in dominant species of four sites, *Ecklonia cava*, *Eisenia*

bicyclis, Sargassum species and *Zostera* species. Problems of mapping encountered through analysis are examined. This study elucidates these experiences and solutions to present suitable methods for mapping macrophyte beds in coastal waters all over Japan.

1. INTRODUCTION

Macrophyte beds (seagrass and seaweed beds) are important habitats where many marine organisms are staying, feeding and breeding. They also create unique marine environments such as water flow (Komatsu and Murakami, 1994), water temperature (Komatsu *et al*., 1982), pH (Komatsu and Kawai, 1986) and dissolved oxygen (Komatsu, 1989). Macrophyte beds are sensitive to the environmental changes and decrease of macrophyte beds have been reported in the world. Mapping and monitoring of seagrass and seaweed distributions are necessary for examining the mechanism of their decreases and making strategy for those conservation and restoration.

Remote sensing is one of the most efficient methods to cartography macrophyte beds rather than diving or observation from the boat (Komatsu *et al*., 2002). So far, many studies and projects focus on developing remote sensing technique as a mapping tool for macrophyte beds (Pasqualini *et al*., 2005; Sagawa *et al*., 2008). Although these efforts have reported success of mapping in their test sites (Komatsu *et al*., 2012), the method for large scale mapping with use of plural satellite images has not been established. One of the reasons is mapping macrophyte beds requires a spatial resolution higher than 10 m due to their patchy or narrow distributions. Although commercial satellite images have high spatial resolution, they are too expensive to cover all coastal lines in Japan. Recently, JAXA launched ALOS satellite with optical sensor AVNIR-2 which can take an image with 10 m spatial resolution and an image of AVNIR-2 is provided by reasonable price. Since the ALOS AVNIR-2 archives cover all coast in Japan, it is possible to achieve national scale mapping of macrophyte beds. This study was conducted as a part of JAXA ALOS projects and we aim to develop methods for mapping seagrass and seaweed beds in national scale.

In this study, four geographically separated areas were selected as study sites in Japan to cover four most dominant macrophyte beds in Japan (*Eisenia bicyclis, Ecklonia cava, Ecklonia kurome, Zostera species* and *Sargassum species*). We analyzed satellite images covering these areas to identify possibility of macrophyte beds mapping in a national scale.

2. STUDY SITES

Our selected study sites and dominant macrophyte species in each site are listed in Table 1. In this study, we focus on only large macrophyte species as mapping targets, which are *Eisenia bicyclis, Ecklonia cava, Ecklonia kurome, Zostera* species and *Sargassum* species.

Table 1: Study Sites

Study Site	Dominant macrophyte species
Ojika Peninsula	*Zostera* species, *Eisenia bicyclis, Sargassum* species
Oki Islands	*Eisenia bicyclis, Sargassum* species
Seto Inland Sea	*Zostera* species
Bungo Suido	*Ecklonia cava, Ecklonia kurome, Zostera* species, *Sargassum* species

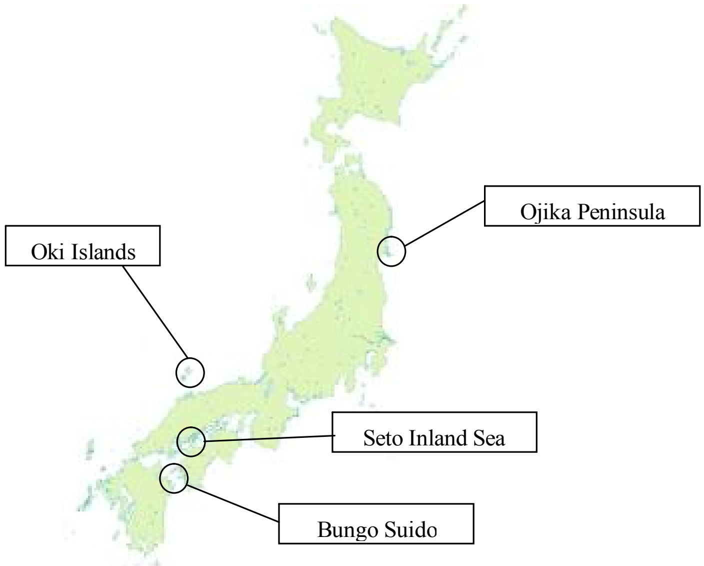

Figure 1: Study Site Positions

3. METHOD

3.1 Analysis flow:

Satellite image analysis in each test area was conducted according to the flow shown in Figure 2. A GIS software (ENVI 4.8, ITT Corporation) was used in the image analysis. Firstly, we selected suitable satellite image satisfying the following conditions: (1) cloud free, (2) less wave and (3) high water transparency. Clouds and high waves intercept the light reflected by sea bottom surface. High water transparency permits us to distinguish differences in sea bottom types. These conditions were checked by visual examination. It is easy to judge first two conditions from images. On the other hand, it is necessary to compare several images on a target site for selecting the best image with high water transparency.

Prior to main analysis, we masked areas not to analyze land and deeper than 20 m where macrophyte are generally not observed in Japan. Depth data were required to exclude the deep water area. Then, two types of radiometric correction (DII and BRI) were applied to the selected satellite image to remove scattering or absorption effects of atmosphere and water column, respectively. Temporal two macrophyte bed maps were created by supervised classification using corrected images derived from DII and BRI methods. Truth data were needed for both radiometric correction and supervised classification. We calculated mapping accuracies for these two maps and selected better map in accuracy as our mapping result. After removing noise of images by filters (Majority, Opening and Closing filters of ENVI functions), a final map was obtained.

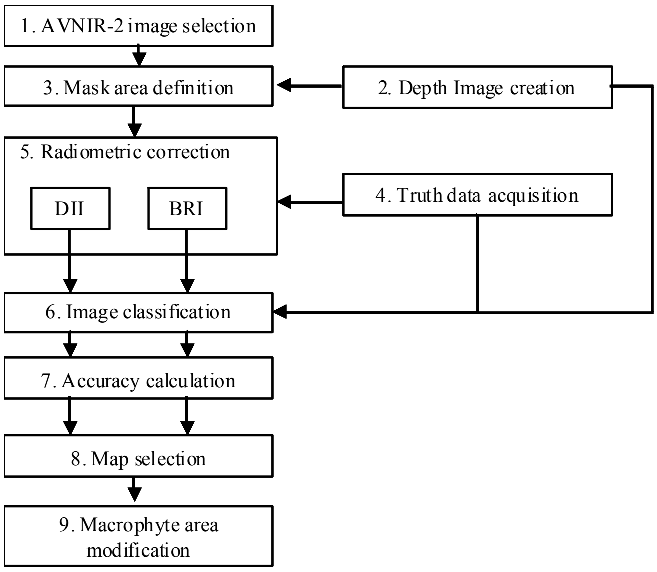

Figure 2: Analysis Flow

3.2 Radiometric correction :

The radiometric corrections including atmospheric correction and water column correction is the key process which has an influence on mapping accuracy. Prior to this process, Digital Number (DN) value recorded by satellite sensor was converted into physical quantity, radiance. In case of AVNIR-2, conversion equation is following.

$$L_i = \mathrm{a}_i \cdot DN_i + \mathrm{b}_i \tag{1}$$

where

i represents spectral band *i*.

L is the radiance value received by AVNIR-2 sensor.

a and b are the coefficients provided by JAXA.

Two types of radiometric correction: Depth Invariant Index (DII) (Lyzenga, 1978) and Bottom Reflectance Index (BRI) (Sagawa *et al*., 2010) were applied. Conversion equations of DII and BRI are as followings.

$$DII_{ij} = \frac{\mathrm{K}_j \ln(L_i - L_{si}) - \mathrm{K}_i \ln(L_j - L_{sj})}{\sqrt{\mathrm{K}_i^2 + \mathrm{K}_j^2}} \tag{2}$$

where

i and *j* represents spectral bands *i* and *j*, respectively.

L_s is the radiance recorded over deep water (external reflection from the water surface and scattering in the atmosphere).

K is the effective attenuation coefficient of the water (m^{-1}).

$$\mathrm{BRI}_i = (L_i - L_{si})\exp(\mathrm{K}_i \cdot \mathrm{g} \cdot Z) \quad (3)$$

where

g is a geometric factor to account for the path length through the water.

Z is the water depth (m).

3.3 Truth data acquisition:

Truth data are provided by several organizations as listed in the Table 2.

Table 2: Truth data provider

Study sites	**Truth data provider**	**Data acquisition date**
Ojika Peninsula	Fisheries Agency	September 2004
Oki Islands	Oki-Suisan high school	2008 - 2009
Seto Inland Sea	AIST（National Institute of Advanced Industrial Science and Technology）	August 2009
Bungo Suido	Oita Prefecture	February 2012

4. RESULTS & DICUSSION

The results of image analysis are shown with macrophyte maps and mapping accuracies in each study sites.

4.1 Study sites and selected Images:

Selected images are shown in the Table 3**.** Number of AVNIR-2 data which covered a study site was about 30. After selection of images by cloud cover less than 20%, number of images was decreased to about 10. By further selection by wave and transparency, only one or two images were finally selected at each site. Although cloud free images were obtained at each study site, these images were not always fine concerning wave and transparency.

Table 3: Selected Satellite Data Images

Site and Data Information	**Overall Image**

Site and Data Information	Overall Image
【Site Name】 Ojika Peninsula 【Acquisition Date】 2009/3/18 【Data Condition】 Cloud Cover: Less than 5% Wave: Weak Transparency: High	
【Site Name】 Oki Islands 【Acquisition Date】 2009/6/26 【Data Condition】 Cloud cover: Less than 5% Wave: Strong (especially in eastern side of islands) Transparency: High	
【Site Name】 Set Inland Sea 【Acquisition Date】 2008/2/23 【Data Condition】 Cloud cover: Less than 20% Wave: Slightly strong in some parts Transparency: Partially turbid	
【Site Name】 Bungo Suido 【Acquisition Date】 2007/2/20 【Data Condition】 Cloud Cover: Less than 5% Wave: Weak Transparency: High	

4.2 Macrophyte Bed Maps:

Macrophyte bed maps in four sites are shown in Figure 3 to Figure 6. Macrophyte bed is expressed as green area in these figures. Distribution features of macrophyte beds were different among the sites. Macrophyte beds in Seto Inland Sea and Ojika Peninsula were widely distributed in the study sites, while macrophyte beds in Bungo Sudo and Oki Islands maps were distributed in narrow bands along the coast.

Figure 3: Bungo Suido Map

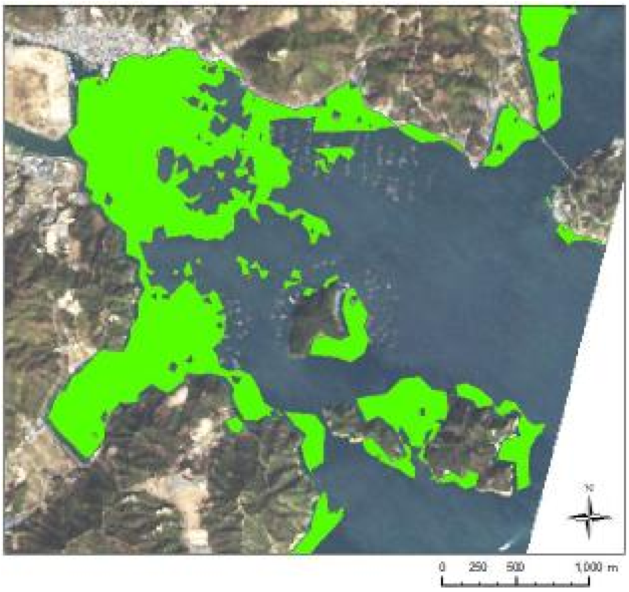

Figure 4: Seto Inland Sea Map

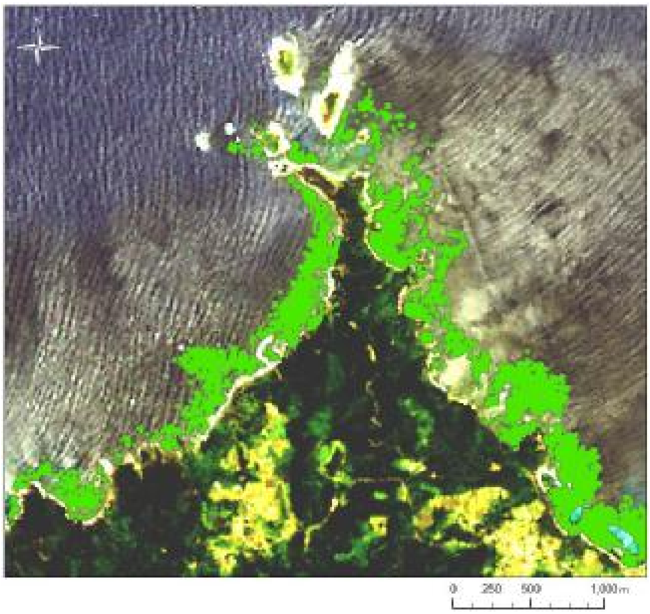

Figure 5: Oki Islands Map

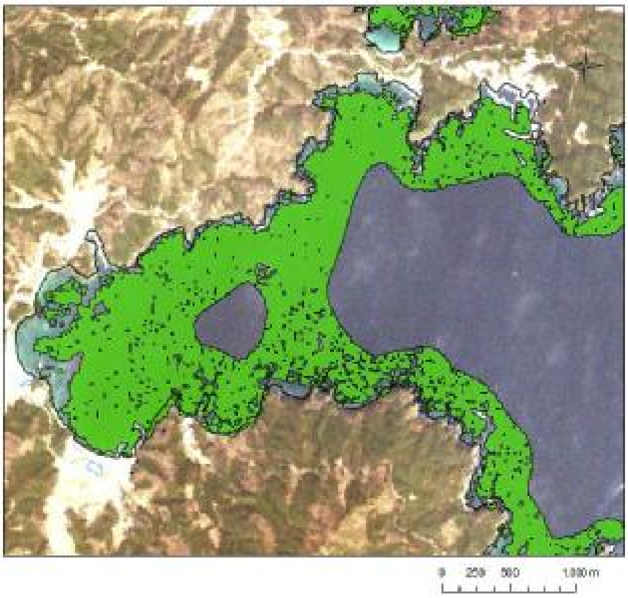

Figure 6: Ojika Peninsula Map

Table 4: Mapping accuracies

Study Site	Overall Accuracies (BRI) (%)	Overall Accuracies (DII) (%)
Bungo Suido	62.5	68.8
Oki Islands	73.3	79.0
Seto Inland Sea	92.7	71.9
Ojika Peninsula	86.2	88.0

Mapping accuracies of four sites were variable (62.5 – 92.7 %) (Table 4). According to Sagawa *et al* (2010), BRI should be better than DII in accuracy. Unexpectedly, BRI was superior to DII only in Seto Inland Sea. The possible reason is linked with depth data accuracy which has influence on BRI values. Average spatial resolution of depth data used in this study is less than 30 m and is inferior to the satellite image spatial resolution (10 m). Flat sandy bottoms extend in Set Inland Sea, while rocky and mugged bottoms do in other sites. Thus, high spatial resolution depth data may improve the mapping accuracy based on BRI. In a case of national mapping, it is better to apply both radiometric correction methods for mapping macrophytes.

5. CONCLUSION

This study gives us lessons. Firstly, image selection is considered as one of the most important processes, because if the image is not suitable, post analysis process is meaning less. We can not extract information of sea bottom surface from turbid water or through sea surface covered with strong waves.

Secondly, it is necessary to select a suitable radiometric correction method because it greatly influences mapping results. We propose both applications of two methods. DII is suitable for rugged rocky bottom where the depth data with high spatial resolution are not available. BRI is suitable for mapping macrophyte beds on the flat sea bottom.

Mapping results are valuable to understand current seaweed situation. Combination of the results with other parameters such as water temperature, industry facilities or reclamation on a GIS system may give us the cause of decrease mechanism of macrophyte beds. Since systematical national scale mapping is required urgently, next step on the study will challenge to map all over Japanese costal area based on the lessons learned in this study.

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