Mapping is a Key for Sustainable Development of Coastal Waters: Examples of Seagrass Beds and Aquaculture Facilities in Japan with Use of ALOS Images

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1. Introduction

Sound coastal ecosystems provide important ecological services such as food supply, nutrient cycling, and stabilizing effects of environments (Costanza et al., 1997). They are indispensable for sustainable development of coastal areas. However, human impacts such as fisheries or reclamation destroy coastal environments and ecosystems (e.g. Huitric et al., 2002). To conserve or restore sound coastal ecosystems, it is necessary to know present situation of coastal areas including coastal ecosystems such as seagrass beds, seaweed beds, coral reefs and tidal flats, and also human activities such as fisheries related facilities and reclamation. Diving and observation from the boat are usually used for checking bottom habitats. However, these methods are laborious and time consuming (Komatsu et al., 2002a). If a boat is employed to survey a broad area with many aquaculture facilities, it requires a long time to survey it due to obstruction of rafts against navigation. The survey with the boat is unsuccessful to localize many aquaculture facilities with GPS in the cases that the boat can't easily approach to the aquaculture facilities due to ropes and rafts. Thus, it is desired to develop efficient mapping and monitoring systems of coastal areas.

Satellite remote sensing has been developed for land use studies in forestry and agriculture but not for sea surface utilization studies in fisheries science. One of the reasons of less attention on the sea surface utilization studies using satellite remote sensing is attributed to low spatial resolution of satellite images formapping such as LANDSAT (resolution: 30 m) and SPOT (resolution: 15 m) (Jensen and Cowen, 1999). Aerial photography, which has a high spatial resolution, has been used to analyze objects smaller than 4 m. However, aerial photography requires geometric correction and mosaic processing of scenes. Recently, multiband images with high spatial resolution have been provided. Commercial ones are QuickBird, IKONOS, Worldview2 etc., and non-commercial one is ALOS AVNIR-2. ALOS launched on by Japan Aerospace Exploration Agency [JAXA] in 2006 has a multispectral sensor, AVNIR-2, with 10 m spatial resolution and a panchromatic sensor, PRISM, with 2.5

m spatial resolution. These sensors, spatially more precise than those of LANDSAT 7 ETM, may permit us to map coastal areas with various ecosystems and fishing activities.

For sustainable development of fisheries, it is necessary to conserve coastal habitats such as seagrass and seaweed beds that play an important role in marine coastal ecosystems. Seagrass beds support flora and fauna, including epiphytic organisms, as well as coastal fisheries (Coles et al., 1993; Fortes, 1996), and contribute to the marine environment by stabilizing bottom sediments and maintaining coastal water quality and clarity (Jeudy de Grissac and Boudouresque, 1985; Komatsu et al., 2004; Komatsu and Yamano, 2000; Ward et al., 1984). Additional effects of seagrass beds include those of seaweed forests such as buffering of water flow (Komatsu and Murakami, 1994), pH distribution (Komatsu and Kawai, 1986), and dissolved oxygen distribution (Komatsu, 1989; Komatsu et al., 1990). Many commercially important species spawn in seagrass beds (e.g. sea urchins, balaos, cuttlefish); larvae and juveniles use the beds as nursery grounds (Arasaki and Arasaki, 1978). Thus, seagrass beds support biodiversity and are an important habitat for marine animals.

Increased seafloor reclamation and industrial and agricultural pollution as a result of economic development have decreased the size of large areas of seagrass beds in coastal zones (e.g., Hoshino, 1972; Komatsu, 1997). Since seagrass beds are sensitive to pollution and water quality deterioration, they serve as “bio-indicators”. Lower depth limit of seagrass distribution in Chesapeake Bay was used as a bio-indicator when runoff impacted water quality, causing changes in light penetration and consequently affecting seagrass abundance and distribution patterns (Dennison et al., 1993). Monitoring has also been carried out at 24-33 survey sites along the coast of Provence and the French Riviera since 1984, using the lower limit of *Posidonia oceanica* L. as a bio-indicator, (Boudouresque et al., 2000). Thus, mapping of seagrass beds is a very practical method to assess the condition of coastal environments.

Recently, it has been stressed that preservation, restoration, and creation of seagrass beds are necessary to recover coastal environments, biodiversity, and bioresources for sound littoral ecosystems and for the sustainable development of fisheries. To preserve or conserve seagrass beds, it is very important to map and monitor them (Lee Long et al., 1996). This study examined possibility of ALOS AVNIR-2 images as recent non-commercial ones for mapping seagrass beds as a typical coastal habitat. We targeted seagrass beds in Akkeshi Lake, Hokkaido Island, in boreal waters in Japan.

In coastal waters, aquaculture has been developed in the world since 1980s (Katsuky et al., 2000). On the other hand, aquaculture has sometimes destroyed natural ecosystems. For example, it is well known that shrimp aquaculture has caused deforestation of mangrove forests. Therefore it is needed to establish databases and information networks to collect, share and disseminate data related to aquaculture activities to manage aquaculture facilities for sustainable development of coastal fisheries. Sound aquatic ecosystem has to be also conserved and maintained for sustainable development of fisheries and society. Thus it is necessary to monitor present states of fisheries and aquatic ecosystem.

In Japan, aquaculture has been already developed since 1970s. A lot of aquaculture facilities are deployed in sheltered waters. Fishermen’s cooperatives manage practically fishing rights in coastal waters on behalf of a local government. Usually, a map of fishing right territory used for management depicts not positions of each fishing gear and facility but only zones of fisheries in coastal waters. When aquaculture facilities are numerous, it is difficult to map all by sea truthing. When more than one fishermen’s cooperative exist in the bay, it is hard to map aquaculture facilities with the same method or at a same level of precision by hearing from the coopeartives.

We tried to map aquaculture facilities in Sanriku coast, Japan, where shell fish and seaweed aquacultures are developed intensively, by the satellite remote sensing using ALOS AVNIR 2 with PRISM satellite images with high spatial resolution.

This chapter apply satellite images taken by ALOS to map seagrass beds in Akkeshi Lake in Hokkaido Island and many aquaculture facilities in Yamada Bay along the Sanriku Coast for developing methods to monitor present situations of coastal waters.

2. Study sites and methods

This section describes here study sites and methods for mapping seagrass beds and aquaculture facilities.

2.1 Seagrass beds in Akkeshi Lake

Akkeshi Lake is located in Hokkaido Island northern part of Japan facing the Pacific Ocean (Fig. 1). This area belongs to boreal coastal waters. Although Akkeshi Lake is a bay, it is called "lake" as a geographical name. Hereafter we use its geographical name, Akkeshi Lake. The maximum bottom depth was 9 m. The seawater comes into the lake by tidal currents through the narrow bay mouth (400m). Since Nature Conservation Bureau, Environment Agency of Japan (1994) reported that broad seagrass, *Zostera marina* L., was distributed in this lake, it is suitable for examining possibility of AVNIR-2 images to map seagrass beds in shallow waters. Inside the lake, aquacultures of oysters and manila clams have been developed on the tidal flats since 1930s. Seagrass beds are an important source of particulate organic matter as foods for oysters and clams. Therefore conservation of seagrass beds is needed for sustainable aquacultures.

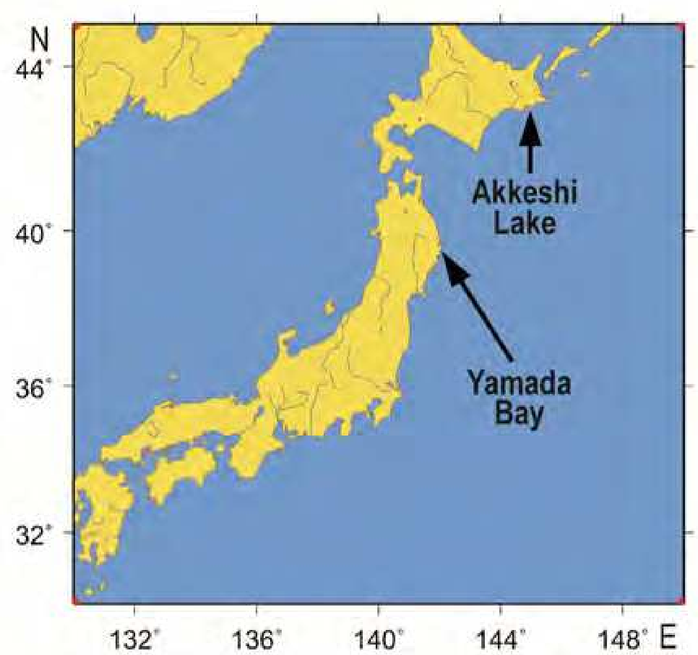

Fig. 1. Map showing Akkeshi Lake and Yamada Bay in Japan

2.1.1 Sea-truthing survey

In applying a remote sensing method for mapping seagrass beds, field surveys are essential for sea truth (Lee Long et al., 1996). Sea truth of bottom substrates was conducted from 30 June to 3 July 2009. A researcher observed bottom feature from the boat localizing survey points with a portable Differential-GPS (D-GPS) and divers with SCUBA took seagrass samples within a quadrate of 0.5 x 0.5 m^2 at 6 stations consisting of three from dense and the others from sparse seagrass beds. Samples of seagrass were preserved in plastic bags with 10 % formalin seawater.

2.1.2 Seagrass biomass

Plant materials were rinsed in fresh water and cleaned of sand and shells in the laboratory. Shoot density (i.e. density of only the above-ground foliar portions of a plant) and shoot length (i.e. length from the bottom end of a shoot to the top of the longest blade) were measured. Samples were also sorted into above- and below-ground parts. Epiphytic plants and animals were removed from leaves by dipping the plants into 5% acetic acid water. Wet weights were taken prior to drying the seagrass in a hot-air oven (DX300, Yamato Scientific Co. Ltd) at 60ºC for 48 hrs. Dry weights of the samples were then obtained and used to calculate above- and below-ground biomasses. Biomass was expressed as dry weight (g) per unit area (i.e. g DW/m^2), which is the most widely used expression for biomass.

2.1.3 Satellite image and analysis of seagrass distribution

Image data of ALOS AVNIR2 sensor taken on 29 September 2006 were analyzed with image processing software, TNTmips (Microimage Inc., USA). Since the red and especially the near-infrared part of the spectrum attenuate rapidly in water (Mumby and Edwards, 2000), the near-infrared band is usually used for detecting land area (White and El Asmar, 1999). The land area outside the Akkeshi Lake was masked using the infrared band of ALOS AVNIR2 because the terrestrial radiance variations were too wide compared with those occurring in marine areas, preventing us from classifying the sea area accurately. Pixels inside the lake were classified by a supervised classification with regard to the different bottom-type areas. Five different classes were highlighted: dens seagrass and sparse seagrass beds consisting of *Z. marina*, muddy bottom, river turbid water and tidal flats (Fig. 2). Sea-truth data and satellite images were overlaid using the abovementioned software to obtain training data and then to classify every pixel with reference to the five classes designed into dense seagrass beds, sparse seagrass bed, muddy bottom, river turbid water and tidal flat with supervised classification (maximum likelihood method) after masking land area.

2.2 Aquaculture facilities in Yamada Bay

Yamada Bay is located in Sanriku Coast facing the Pacific Ocean. The bay is one of the rias-type ones in Sanriku Coast in temperate coastal waters (Fig. 1). There are a lot of aquaculture facilities for oysters and scallops in the bay. Thus the bay is suitable for the study site.

2.2.1 Fishing right territory and aquaculture licenses

Fishing right territory in Yamada Bay was divided by four fishermen's cooperatives, Yamada, Orikasa, Ohsawa and Oura. Aquaculture facilities were classified into two types:

wood-raft type and buoy-and-rope type. Fishermen used two types of facilities for scallop and oyster aquacultures. Aquaculture license of the former type by Iwate Prefecture stipulated for the size of the raft; it was rectangular and its length and width were 12 m and 4 m, respectively. On the other hand, aquaculture license of the latter type stipulated not for size and color of buoys but for rope length. Clusters of oysters or scallops were attached to vertical rope, which was suspended from the raft or buoy-and-rope facilities. The length of horizontal rope ranged between 50 and 100 m. Number, size and color of buoys depended on a facility. We compared positions of representative rafts and buoy-and-rope facilities localized by image analysis with those by D-GPS in situ. Differences in positions localized with both methods were within several meters equivalent to those of errors of D-GPS.

2.2.2 Satellite image data and analysis of aquaculture facilities

Some satellite images provide a high spatial resolution while other focus on providing several spectral bands. The fusion process brings the information from different sensors with different characteristics together to get the best of both worlds. Most of the fusion methods in the remote sensing deal with the pansharpening technique. This fusion combines the image from the panchromatic sensor of one satellite (high spatial resolution data) with the multispectral data (lower resolution in several spectral bands) to generate images with a high resolution and several spectral bands. Panchromatic sharpening increases the spatial resolution and provides a better visualization of a multiband image using the high-resolution, single-band image where the two rasters fully overlap. JAXA provides low-resolution, multiband images, AVNIR2, with a spatial resolution of 10 m and higher-resolution panchromatic images, PRISM, of the same scenes with a spatial resolution of 2.5 m. Image data of ALOS AVNIR2 and ALOS PRISM taken on 10 September 2006, respectively, were used for producing pansharpened RGB image with the image processing software (TNTmips, Microimage Inc.). There are several methods to produce pansharpened images such as HIS transformation, wavelet transformation etc. We used the Brovey transformation. The Brovey transformation uses a method that multiplies each resampled, multispectral pixel by the ratio of the corresponding panchromatic pixel intensity to the sum of all the multispectral intensities (Anon., 2011). It assumes that the spectral range spanned by the panchromatic image is essentially the same as that covered by the multispectral channels. Enhanced pansharpened image was used to detect aquaculture facilities.

3. Results and discussion

This section introduces results and discussion about mapping of seagrass beds in Akkeshi Lake and aquaculture facilities in Yamada Bay, respectively.

3.1 Seagrass beds in Akkeshi Lake

3.1.1 Sea survey

Sea survey revealed that broad seagrass beds were distributed whole lake and dense seagrass beds were distributed around the center of the lake (Fig. 2). River turbid water was distributed northwest and east of the lake where the rivers discharge fresh water. Tidal flats were distributed mainly in east area of the lake and near the lake mouth.

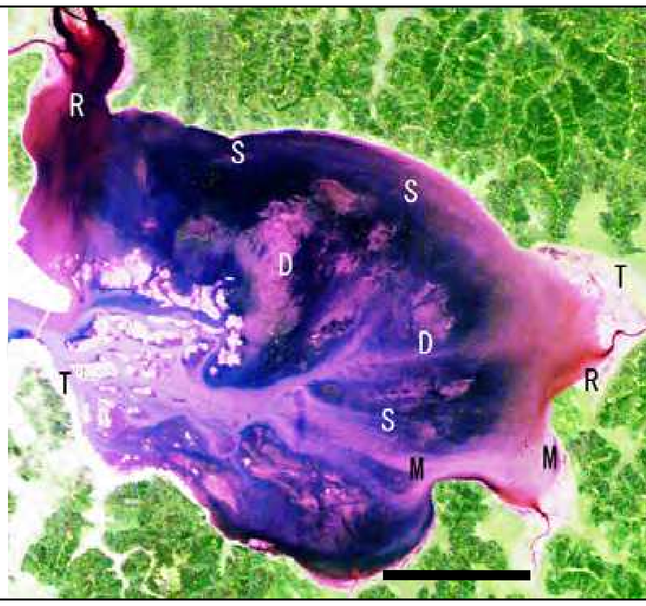

Fig. 2. Enhanced image of ALOS AVNIR2 on Akkeshi Lake. Characters of D, S, R, M and T are dense seagrass, sparse seagrass, river turbid water, muddy bottom and tidal flat, respectively. Small dots near characters are areas belonging to these classes identified by sea truth. Black bar shows a distance of 2 km.

	Above-ground biomass		Below-ground biomass	
	g WW/m^2	g DW/m^2	g WW/m^2	g DW/m^2
Dense seagrass	2743.9±528.3	227.1±19.2	481.3±54.3	48.0±11.1
Sparse seagrass	1251.5±408.0	143.9±38.4	340.7±167.6	46.4±20.8

Table 1. Above- and below ground biomass of dense and sparse seagrass beds consisting of *Zostera marina* obtained by three quadrat sampling at each category in Akkeshi Lake on 3 July 2009. WW and DW are abbreviations of wet weight and dry weight, respectively.

3.1.2 Seagrass biomass

Above-ground biomass of dense seagrass was 227.1±19.2 g DW/m^2 (n=3) while that of sparse seagrass was 143.9±38.4 g DW/m^2 (n=3). Below-ground biomass of dense seagrass was 48.0±11.1 g DW/m^2 (n=3), while that of sparse seagrass was 46.4±20.8 g DW/m^2 (n=3).

The maximum and minimum biomass of *Z. marina* growing at depths of about 5 m in Otsuchi Bay were 370 g DW/m^2 in August and 30 g DW/m^2 in January (Iizumi 1996). At depths between 4 m and 5 m in Iida Bay the maximum and minimum biomass of *Z. marina* was 170 g DW/m^2 in July and 20-30 g DW/m^2 in November (Taniguchi and Yamada 1979). Therefore, biomass of *Z. marina* in Akkeshi Lake is between those in Otsuchi Bay and Iida Bay.

3.1.3 Image analysis of Seagrass beds

Enhanced image of AVNIR2 was shown in Fig. 2. Bands of NIR, R and G were allocated to red, green and blue colors (Fig. 2). Field survey showed that the seagrass beds were distributed in the areas of dark blue (sparse seagrass) and grey colors (dense seagrass). River turbid water, tidal flat, muddy bottom were reddish, brighter grey and purple, respectively. Using the distribution information (Fig. 2), supervised classification was conducted.

The result demonstrated that classification well corresponded to ground truth data (Figs. 2 and 3). User accuracy of dense seagrass was 97.8% while that of sparse seagrass was 78.5% lower than dense seagrass due to misclassification of dense seagrass as sparse seagrass (Table 2). User accuracy of tidal flat was 97.5%. User accuracies of muddy bottom and river turbid water were 82.0 % and 85.3%, respectively. Overall accuracy was 86.0%. If dense seagrass class was combined with sparse seagrass class as seagrass, user accuracy of seagrass became 93.5%. Overall accuracy was ameliorated to 90.0%.

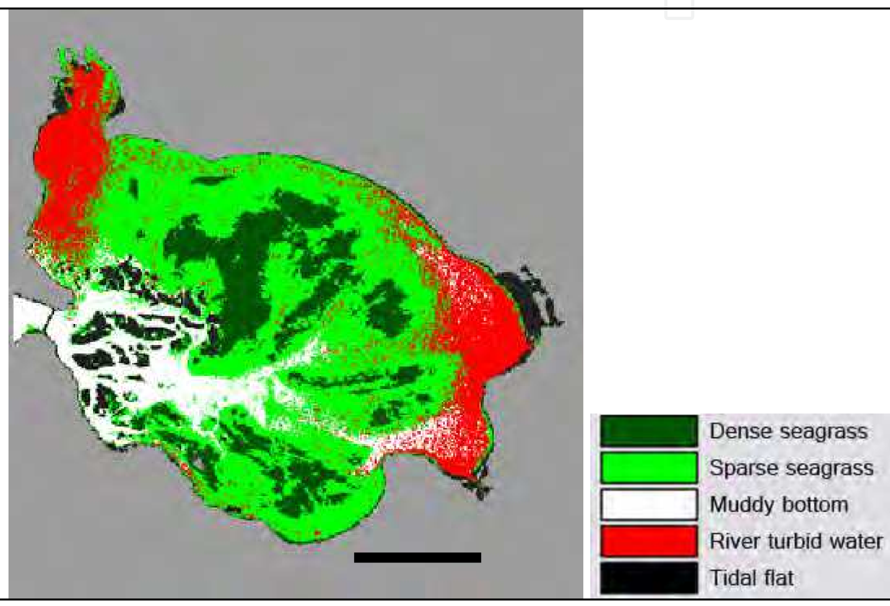

Fig. 3. Supervised classification of five classes of dense seagrass, sparse seagrass, muddy bottom, river turbid water and tidal flat. Black bar shows a distance of 2 km.

Accuracies of classification for mapping and monitoring habitats are required to be 80% and more and 90% and more, respectively (Mumby and Green, 2000). Therefore, our results of two seagrass classes were nearly above or eaqual to the necessary accuracy for habitat mapping. If we combine two seagrass classes to one, seagrass, we can use the distribution data of seagrass beds mapped by the ALOS AVNIR2 image data for monitoring temporal change in spatial distribution.

ALOS AVNIR2 could detect seagrass beds in Akkeshi Lake. Shallow bottom depth and clear water except river turbid water lead successful classification in the lake. The high accuracy levels were attributed to the broad homogeneous distributions of habitats in Akkeshi Lake, which bring good matching locations on image and field data sets. Accurate mapping of seagrass cover in this lake, using simple approaches, corresponds to high-spatial resolution (< 10 m) and multi-spectral image data. Further work is required to examine ability of ALOS AVNIR 2 to detect seagrass beds with more patchy distributions.

Acoustic surveys are also strong in detecting seagrass beds due to acoustic reflection of seagrass stronger than those of sand or mud (Komatsu et al., 2003). Echosounder can detect

		Sea truth						
	Class	Dense seagrass	Seagrass	Muddy bottom	River water	Tidal flat	Total	User Accuracy (%)
Classification	Dense seagrass	44	1	0	0	0	45	97.8
	Sparse seagrass	11	73	6	3	0	93	78.5
	Muddy bottom	0	9	41	0	0	50	82
	River water	1	5	3	58	1	68	85.3
	Tidal flat	0	0	0	1	35	36	97.2
	Total	56	88	50	62	36	292	
	Producer accuracy (%)	78.6	83	82	93.6	97.2		86.0

Table 2. Error matrix of supervised classification of five habitat classes in Akkeshi Lake. River turbid water is abbreviated to river water.

vertical distribution of seagrass beds along a track (e.g. Komatsu and Tatsukawa, 1998). Sidescan sonar can detect horizontal distribution of seagrass with a wide band width such as 30-50 m along a track (e.g. Sagawa et al., 2008; 2010). Narrow multi-beam sonar can measure three-dimensional spatial distribution of seagrass (Komatsu et al., 2003). However, usually, the boat equipped with these materials navigates at 3 to 4 knots (about 5 to 7 km/hr) with narrow swath width. Thus, it is impossible to cover broad area with acoustic surveys of seagrass beds in horizontal scales of more than 100 km^2. It is also difficult to survey seagrass beds with dense canopy preventing the boat equipped with acoustic devices from navigating. Satellite image analysis is suitable for mapping in these scales.

Class	Area (km^2)	Percent (%)
Dense seagrass	6.12	17.82
Sparse seagrass	15.19	44.25
Muddy bottom	4.71	13.72
River turbid water	5.88	17.14
Tidal flat	2.42	7.06
Total	34.32	100

Table 3. Areas and percentage of each class mapped by supervised classification in Akkeshi Lake

3.1.4 Biomass estimation of seagrass

The areas occupied by dense and sparse seagrass beds calculated from the sum of pixels were 6.12 km^2 and 15.19 km^2, respectively (Table 3). Mean biomasses of above-ground and below-ground parts of *Z. marina* were 227.1±19.2 (±SD) g DW/m^2 and 48.0±11.1 g DW/m^2 in dense seagrass beds and 143.9±38.4 g DW/m^2 and 46.4±20.8 g DW/m^2 in sparse seagrass beds, respectively. The total biomasses of above- and below-ground parts were estimated to be 1390±118 t DW and 294±68 t DW in dense seagrass beds, and 2186±583 t DW and 705±316 t DW in sparse seagrass beds, respectively. Total biomasses of above- and below ground parts in Akkeshi Lake were 3576±701 t DW and 999±384 t DW, respectively. Finally, total biomass of seagrass was 4575±1085 t DW. This standing stock of seagrass beds contributes to foster oysters, clams and other organisms in the lake. Some of the biomass is transported from the lake to offshore by currents and become debris on the ocean which may be consumed as prey for benthic animals. Thus it is very important to monitor the seagrass beds in coastal waters not only for coastal fisheries but also probably for offshore fisheries.

3.2 Aquaculture facilities in Yamada Bay

Aquaculture facilities consisted of two types: wood-raft type and buoy-and-rope type (Fig. 4). This section describes mapping results of two different types of aquaculture facilities.

Fig. 4. Pictures of wood-raft (left picture) and buoy-and-rope (right picture) types of aquacultures in Yamada Bay.

3.2.1 Distribution of wood-raft type facilities

Pansharpened AVNIR2 true color image hardly distinguished wood-raft type aquaculture facilities from the sea (Fig. 5). On the other hand, enhanced image showed rafts distributions around north and west sides of the bay clearer (Fig. 6). Cloud like pattern from north-northwest to south-southeast was distributed on the seasurface in the east side of the bay. Since radiance of this pattern was similar to those of rafts, it was impossible to process the image of the whole bay to extract rafts from the seasurface at once. Then we divided the image of the bay into several sections with similar radiance of rafts. The sections were enhanced to examine rafts distributions. One example was shown in Fig. 7. Radiance of wood rafts was greater than those of the seasurface because the rafts were completely exposed on the sea surface. Then they were extracted from the image. All the wood rafts in the bay were shown in Fig. 8.

Iwate Prefecture licensed 179, 313, 825 and 1625 wood-type rafts to Oura, Orikasa, Yamada and Ohsawa Fishermen's Cooperatives, respectively (FY2006, Iwate prefecture). From Fig. 8, 189, 311, 811, and 1525 rafts belonged to waters of above-mentioned cooperatives, respectively. Only rafts number of Ohsawa Fishermen's cooperative between licensed and counted numbers was different by 100 wood-type rafts. However, percent of counted number to the licensed number was 96.4%. The result obtained by image analysis of ALOS image is enough accurate for practical use.

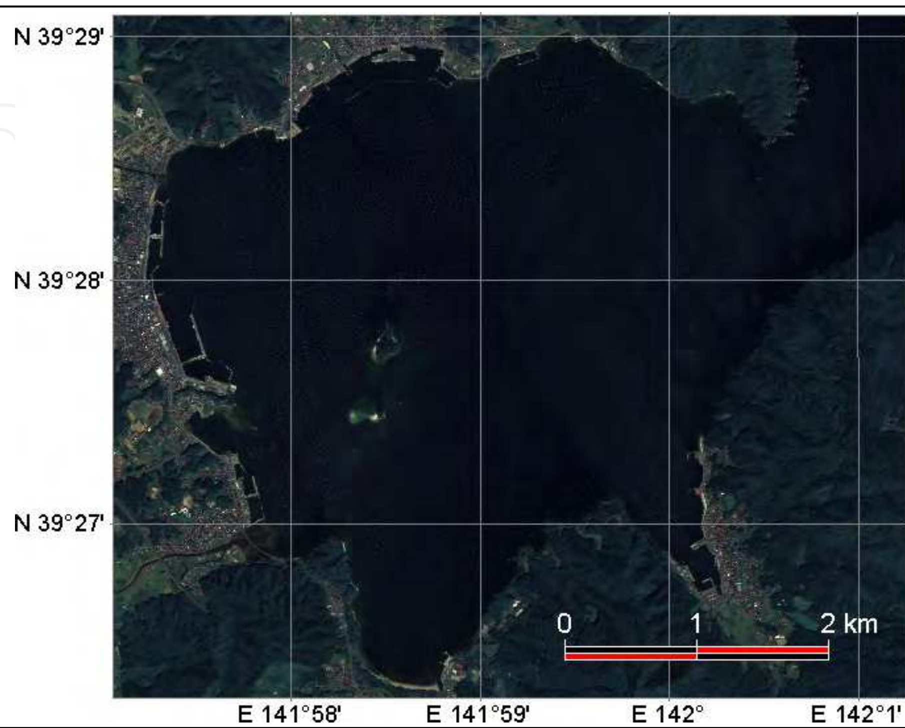

Fig. 5. Pansharpened true color AVNIR2 image of Yamada Bay

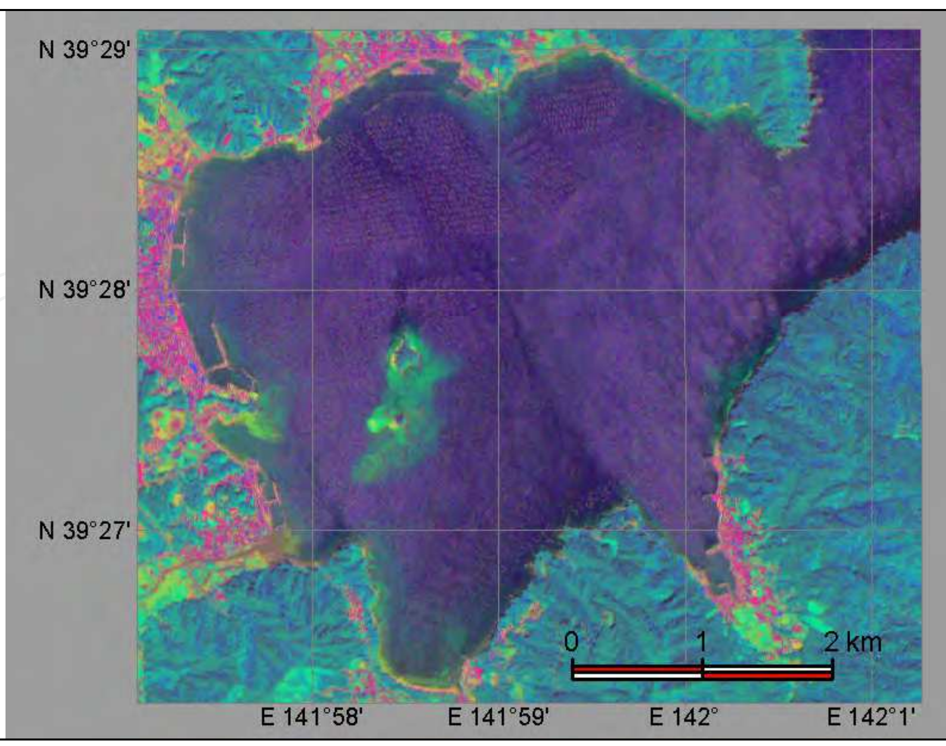

Fig. 6. Enhanced pansharpened true color AVNIR2 image of Yamada Bay

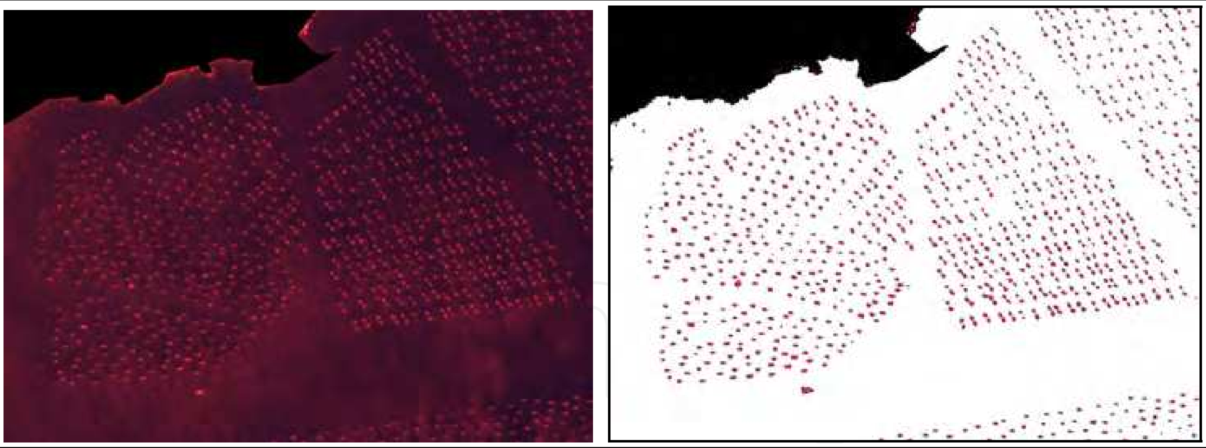

Fig. 7. Pansharpened image of the northwest area of Yamada Bay of which red color was enhanced (left picture) and extracted rafts (right picture).

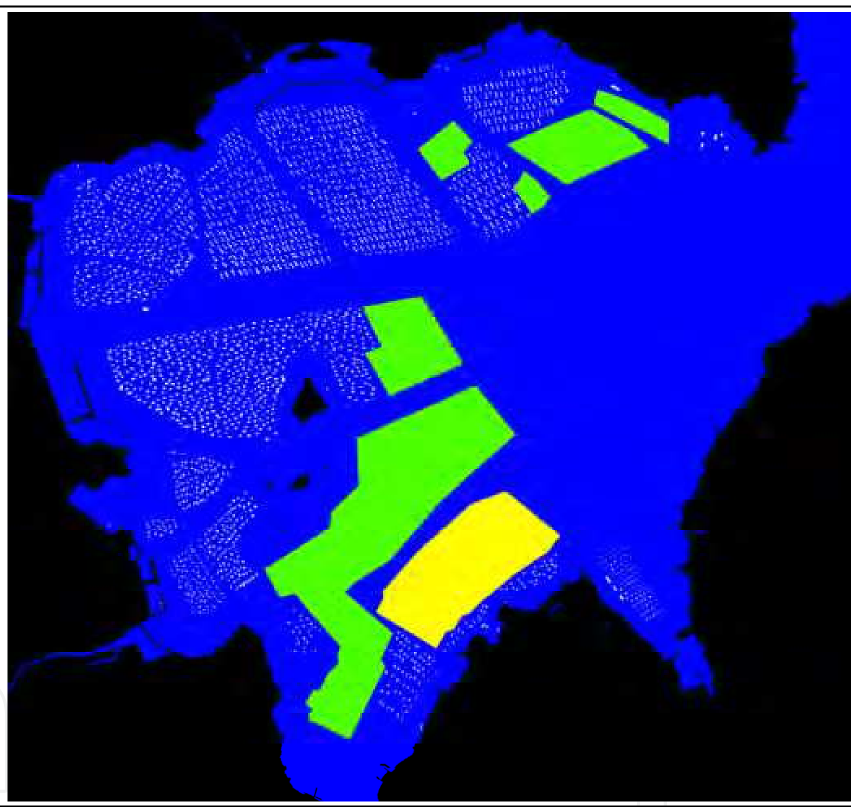

Fig. 8. Distribution of wood-raft type aquaculture facilities (white points) and buoy-and-rope ones. Green and yellow areas were occupied by measurable and non-measurable facilities of buoy-and rope types, respectively.

The license of Iwate Prefecture determined the size of raft was 48 m^2 (12m x 4m). Since the resolution of one pixel of ALOS pansharpened image is 2.5x2.5 m^2, one raft consists of about 2 x 6 pixels. In reality, wood rafts on the image consisted of more than 12 pixels. It is known that image analysis of satellite image overestimates a plane area of object with strong reflectance due to light diffusion. It is also true for rafts in Yamada Bay because they had relatively strong reflectance.

Komatsu et al. (2002b) analyzed IKONOS pansharpened image with a spatial resolution of 1 m to detect wood raft type. The present result shows that ALOS pansharpened image provides information similar to that of IKONOS in a scale of wood-raft type aquaculture facility with 12 m x 4 m. Thus pansharpned AVNIR2 image is very practical to detect wood raft type.

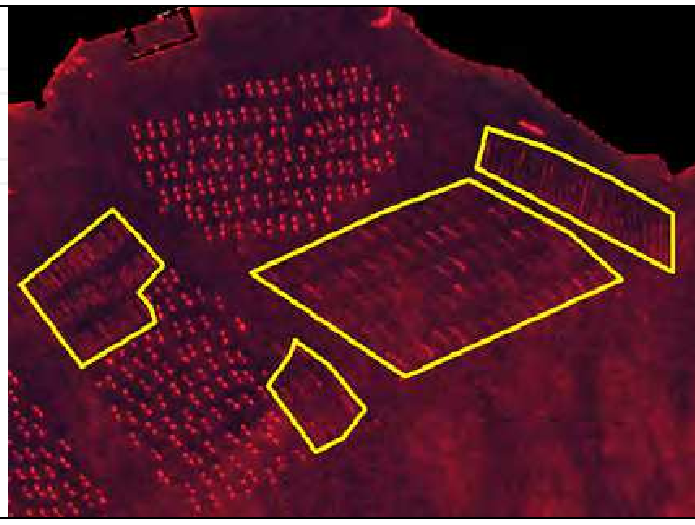

Fig. 9. Pansharpened image of the north area of Yamada Bay of which red color was enhanced.

3.2.2 Distribution of buoy-and-rope type aquaculture facilities

Buoy-and-rope type aquaculture facilities in Fig. 9 were clearer than those in Fig. 6 due to enhancement of image characteristics through adjustment of color tone levels. They were distributed east and south of the island in the center of Yamada Bay (green area in Fig. 8). The other type of buoy-and-rope aquaculture facilities were distributed in southeast area of the bay (yellow area in Fig. 8). Field observation showed that this kind of facilities was composed of black buoys and their diameters between 0.4 and 1 m. Since the buoys were smaller than 1 m below the resolution of ALOS PRISM sensor, image analysis couldn't distinguish them. In some cases, suspended clusters of scallops or oysters were so heavy that buoys were submerged under the sea. Thus, it is very difficult to measure the lengths of the facilities of this type, which appeared as bands parallel to northwest-southeast in a southwest part of the bay (Fig. 6), due to pixels with low radiance (yellow area in Fig. 8). Surface area occupied by the aquaculture facilities of buoy-and-rope type were summarized in Fig. 8.

Figure 6 shows darker green area surrounded with light green around the islands in the center of the bay. This area corresponds to seagrass beds consisting of *Zostera caespitosa* Miki classified into threatened seagrass species by the red data book of Japan (Wildlife Division, Environment Agency of Japan, 2000). Therefore, Figure 8 gives important information to conserve this species and to realize sustainable aquaculture fisheries.

The results above-shown well agree with those of image analysis of IKONOS pansharpened multispectral image with 1 m spatial resolution (Komatsu et al., 2002b). Therefore this method mapping aquaculture facilities in Yamada Bay using ALOS image data is very practical and useful for management of coastal aquaculture activity like as IKONOS image data.

4. Conclusion

Mapping with ALOS AVNIR2 is a simple, laborsaving, and efficient method to assess the seagrass bed distribution in boreal waters. It can be used to estimate the area occupied by seagrass, and, in conjunction with quadrat sampling, the biomass of seagrass beds can also be estimated.

It is verified that the image analysis can obtain information on distribution of small-scale aquaculture facilities including aquaculture facility types in the rias-type bay in Sanriku Coast from the pansharpened image created with ALOS AVNIR2 and PRISM. The image analysis of ALOS AVNIR2 and pansharpened image data serves as a tool for management of coastal fisheries for the long-term conservation of coastal environment and sustainable use of fisheries resources. This method is applicable to monitor small-scale fishing gears and aquaculture facilities not only in rias-type bays but also in any coastal waters.

We developed two practical methods to map seagrass beds and aquaculture facilities that are indispensable an aquatic ecosystem and an element of coastal fisheries in coastal waters. Our future work is to examine applicability of the methods to other regions where seagrass beds or aquaculture activities are developed.

5. Acknowledgment

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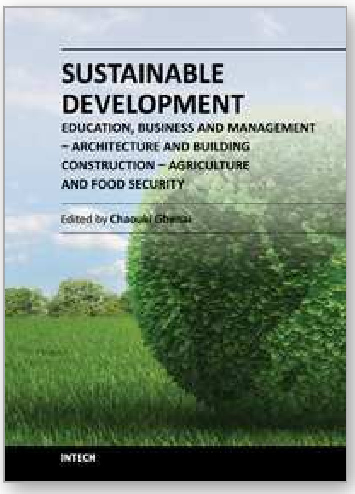

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Securing the future of the human race will require an improved understanding of the environment as well as of technological solutions, mindsets and behaviors in line with modes of development that the ecosphere of our planet can support. Some experts see the only solution in a global deflation of the currently unsustainable exploitation of resources. However, sustainable development offers an approach that would be practical to fuse with the managerial strategies and assessment tools for policy and decision makers at the regional planning level. Environmentalists, architects, engineers, policy makers and economists will have to work together in order to ensure that planning and development can meet our society's present needs without compromising the security of future generations. Better planning methods for urban and rural expansion could prevent environmental destruction and imminent crises. Energy, transport, water, environment and food production systems should aim for self-sufficiency and not the rapid depletion of natural resources. Planning for sustainable development must overcome many complex technical and social issues.

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