UTILIZATION OF ALOS DATA FOR MAPPING COASTAL HABITATS AND FISHING ACTIVITIES IN ASIA

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1. INTRODUCTION

In 21 century, it is stressed that sustainable development of coastal area is indispensable under a condition keeping sound coastal environments in both developed counties and developing countries [1]. Sound ecosystems provide important services such as habitats for animals and plants, and stabilizing effects of environments such as seagrass beds [2] and seaweed beds [3]. In coastal areas, population density is higher than in inland areas. Therefore human impacts concentrate in coastal areas. Therefore coastal ecosystems have been destroyed due to human impacts such as fisheries, reclamation and pollution during economic development [4]. Aquaculture (e.g. shrimp farming) has been developed in the world since 1980s. It has sometimes destroyed natural ecosystems. For example, it is well known that shrimp aquaculture has caused deforestation of mangrove [5]. Coastal ecosystems, however, have to be conserved and maintained for sustainable development of fisheries and society. Thus it is necessary to monitor present coastal ecosystems and fishing activities, and to establish databases and information networks to share and disseminate their data to manage them for their sustainable development [1].

We are conducting researches on mapping of coastal ecosystems [6, 7, 8, 9] including aquaculture by using satellite data [10]. We are interested in not only spatial distributions of natural coastal ecosystems such as mangrove, tidal flats, coral reefs, seagrass meadows and seaweed, but also fisheries related facilities and infrastructures such as aquaculture rafts, set nets, fishing ports, roads, fish markets, villages etc. Final goal of our study is to make clear possibilities of use of satellite data for integrated coastal management and monitoring of different types of coastal areas. Since characteristics of coastal ecosystems depend on climate, we select study areas from boreal to tropical waters through temperate ones.

ALOS launched on by 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 that have spatially more precise than those of LANDSAT 7 ETM allow us to map coastal areas with various ecosystems and fishing activities. Therefore we use ALOS AVNIR-2, PRISM and PALSAR imageries as data for remote sensing of coastal areas to map and monitor them.

During this ALOS project, we studied mapping on seagrass and seaweed beds distributed from boreal to tropical waters as study sites because seagrass beds are very important for fisheries and biodiversity as habitats of marine organisms.

We also challenged mapping aquaculture facilities set in coastal waters because Integrated Coastal Area Management needs information on distribution of fisheries gears influencing environments. Decision makers don't have such information.

This paper reported the results obtained by our ALOS projects briefly.

2. SEAGRASS AND SEAWEED MAPPING

2.1 AKKESHI LAKE IN BOREAL WATERS

Akkeshi Lake is located in Hokkaido Island northern part of Japan facing the Pacific Ocean (Fig. 1). The maximum bottom depth was 9 m. The seawater comes into the lake by tidal current through the narrow bay mouth (400 m wide). Since Environmental Agency of Japan [11] reported that broad seagrass, Zostera marina L., was distributed in this lake, it is suitable for examining possibility of AVNIR-2 imagery to map seagrass beds in shallow waters. Inside the lake, aquaculture of oysters has been developed since 1930. Seagrass beds are an important source of particulate organic matter as foods for oysters. Therefore conservation of seagrass beds is needed for sustainable aquaculture.

An imagery of ALOS AVNIR-2 sensor taken on 29 September 2006 was analyzed with image processing software, TNT mips (Microimage Inc., USA). Pixels inside the lake were classified into seagrass bed, sand bed, turbid water and tidal flat with supervised classification (maximum likelihood method) after masking land area. Ground truth of sand and seagrass beds was conducted in August 2007 and September 2008. A researcher observed bottom feature from the boat localizing survey points with a portable GPS.

Enhanced imagery of AVNIR-2 was shown in Fig. 2. Bands of NIR, R and G were allocated to red, green and blue colors. Field survey revealed that the seagrass beds were distributed in the areas of dark blue (seagrass) and grey colors (dense seagrass). Turbid water, tidal flats and sand beds were reddish, brighter grey and purple, respectively. Using the distribution information, supervised classification was conducted. The result demonstrated that classification well corresponded to ground truth data (Fig. 5). Overall accuracy of seagrass and sand beds was about 95%. ALOS AVNIR-2 could detect seagrass beds in Akkeshi Bay. Shallow water depth, clear water in the lake and healthy seagrass leaves with less epiphytic algae lead successful classification of seagrass beds. We also analyzed IKONOS multiband imagery of Akkeshi Lake whose spatial resolution is 4 m x 4 m with the same method of this report. The result of IKONOS was nearly identical to that of this report. Therefore, ALOS multiband imagery, AVNIR-2, is very practical for mapping seagrass beds with spatial scale of Akkeshi Lake located in boreal waters.

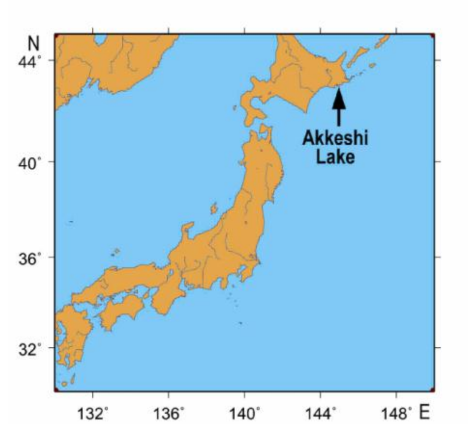

Fig. 1 Map showing locations of Akkeshi Lake in Hokkaido Island, Japan

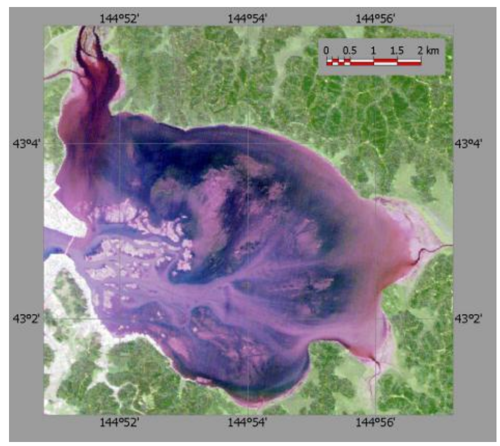

Fig. 2 Enhanced AVNIR-2 imagery of Akkeshi Lake

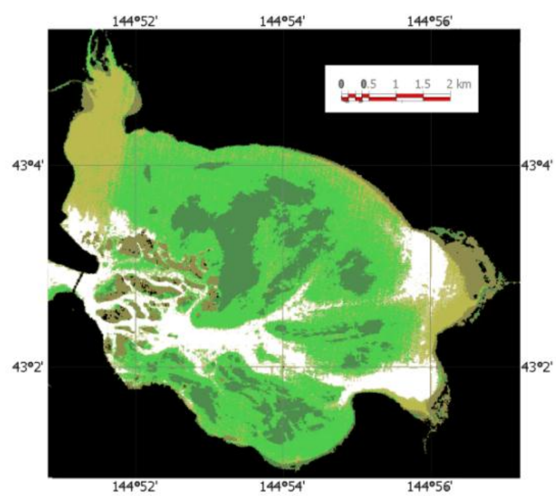

Fig. 3 Supervised classification result of Akkeshi Lake. Dark green, green, ocher, brown, white and black were dense seagrass, seagrass, turbid water, tidal flat, sand bed and land, respectively

2.2 SOUTH OF GOLF OF GABES IN TEMPERATE WATERS

Golf of Gabes is located in southern Tunisia facing Mediterranean Sea (Fig. 4) belonging to temperate waters.

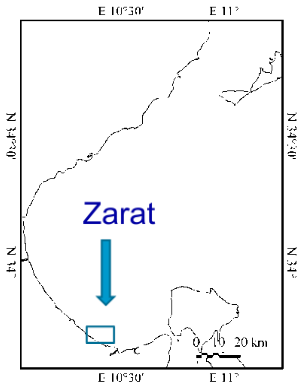

Fig. 4 Map showing locations of Zarat, Golf of Gabes, Tunisia

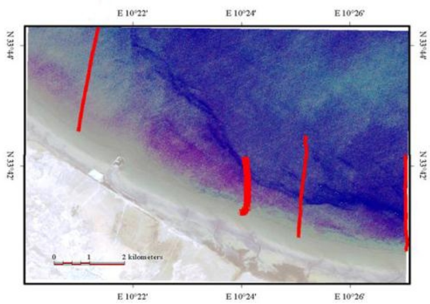

Fig. 5 Enhanced AVNIR2 imagery of Zarat and sidescan sonar survey lines (red) to obtain ground truth

Golf of Gabes has broad seagrass beds mainly composed of *Posidonia oceanica* L. *P. oceanica* is very important species in Mediterranean Sea because it supplies important habitats for fisheries resources. However, increasing economic activity along the coast has been damaging *P. oceanica* meadows. Therefore it is necessary to map seagrass beds in Golf of Gabes where fisheries are very important local industry.

An imagery of ALOS AVNIR-2 sensor taken in February 2008 was analyzed with image processing software, TNT mips. Pixels inside the imagery were classified into seagrass bed and sand bed with supervised classification (maximum likelihood method) after masking land area using intensity of near infrared. Ground truth of sand and seagrass beds was conducted from 3 to 11 November 2005. A researcher dived to verify bottom feature where geographical position was measured with a portable GPS on the boat. A sidescan sonar (SIS1624, Benthos) was used for obtaining ground truth data with broad area coverage of bottom substrates because the sidescan sonar can obtain area information of sand and seagrass [12]. The navigation chart (Service hydrographique de la Marine, 1889) was used to estimate bottom depth of pixel in the imagery.

Sidescan sonar image showed that it could identify sand and *P. oceanica* beds clearly as other seagrasses pointed out by Sagawa et al. [12]. Thus we used sidescan sonar images as seatruth data according to Sagawa et al. [12]. Training and validation data corresponding to two classes, sand and seagrass, were obtained from sonar images along the survey lines (Fig. 5). Supervised classification was applied to AVNIR-2 imagery (Fig. 5). The result indicated that seagrass area was overestimated (Fig. 6). Overall accuracy of classification was 64.2%.

A method of radiometric correction, BR index, proposed by Sagawa et al. [13] was applied to extract bottom reflectance information. BR index [13] is based on the Lyzenga's model [14] expressed by the following equation.

$$Li = Lsi + Ai \cdot Ri \cdot \exp(-Ki \cdot \mathrm{F} \cdot Z) \quad (1)$$

Where Li, Lsi, Ai, Ri and Z are radiance of i band on a pixel of multi-band imagery from the sea bottom, radiance of i band from atmosphere including that reflected by the sea surface, radiance at the sea surface, bottom reflectance of i band, attenuation coefficient of i band, geometrical parameter of light pass under the sea and bottom depth. Lyzenga [15] proposed a depth invariant index (DI index) by canceling term including a parameter of bottom depth, Z. Using the bottom depth data from the chart, BR index is expressed as Eq. 2 through transforming Eq. 1.

$$BR = (Li - Lsi) / \exp(-Ki \cdot \mathrm{F} \cdot Z) \quad (2)$$

Where BR is BR index and directly related to bottom reflectance as the following equation from Eqs. 1 and 2 .

$$BR = Ai \cdot Ri \quad (3)$$

We applied this radiometric correction to AVNIR-2 imagery off Zarat to enhance bottom signature under relatively turbid water. After radiometric correction, we applied supervised classification.

Radiometric correction showed that BR index could correct signals in deeper bottom (Fig. 6). Supervised classification was applied to radiometric correction imagery. Result showed that lower depth limit of seagrass beds (Fig. 6) appeared after correction. Overall accuracy of supervised classification was increased to 71.8 %.

Jerlov Water Type (JWT) of Zarat was estimated from attenuation coefficient, K. It was classified as JWT III, which means transparency was about 10 m. In this water type area, radiometric correction contributes to extract bottom reflectance information. In most of temperate waters, transparency of water is less than in tropical waters where sea water is generally oligotrophic, BR index is practical tool to make radiometric correction if data of bottom depth distribution are available. It is indicated that AVNIR-2 data can be used for mapping seagrass beds in temperate waters if radiometric correction is applied.

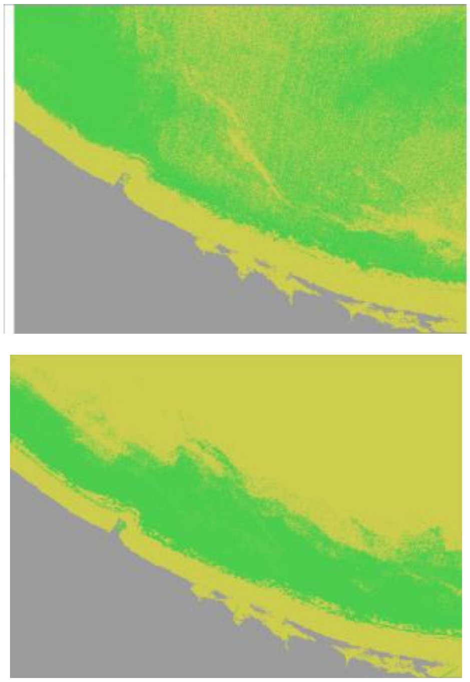

Fig. 6 Results of supervised classification applied to AVNIR-2 imagery (upper) and that corrected with BR index (lower) of Zarat. Grey, green and ocher colors represent land, seagrass and sand, respectively

2.3. BARRANG LOMPO ISLAND IN SPERMONDE ARCHIPELAGO IN TROPICAL WATERS

Spermonde Archipelago is located off south Sulawesi, Indonesia belonging to tropical waters (Fig. 7). The islands of Spermonde Archipelago are encircled with coral reefs. Inhabitants of archipelago depends on fish resources strongly connecting to the coral reef ecosystem composed of coral reef and seagrass beds around the lagoon. Population has been increasing in the archipelago. Human activity such as destructive fisheries threatens coral reef ecosystem. Global warming is a cause of bleaching of live coral due to increase in water temperature. Therefore it is urgently needed to develop a method to map coral reef and seagrass beds in a lagoon around the island in tropical waters where marine environments have been changing.

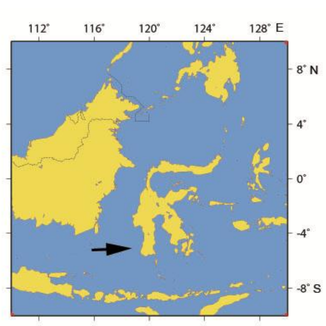

Fig. 7 Map showing Spermonde Archipelago (arrow) in south Sulawesi, Indonesia

An imagery of ALOS AVNIR-2 sensor taken in June 2007 was analyzed with image processing software, TNT mips. Supervised classification (maximum likelihood method) classified pixels into four classes, seagrass bed, live coral, dead or bleached coral and sand or rubble, after masking land area. Ground truth data were obtained through diving, walking during low tide and observing from the boat in July 2008. Bottom depths were measured by echosounder during the visual observation from the boat.

Around Barrang Lompo Island four species of seagrass were identified: *Enhalus acroides*, *Thalasia hemprichii*, *Syringodium isoetifolium* and *Halophila ovalis*. Shoots of the former two species were about 30 to 70 cm in length. Their distributions were easily distinguished. *S. isoetifolium* appeared with *T. hemprichii. H. ovalis* was small and not dense. Corals were classified into live coral, dead or bleached corals and rubble that was fragments of dead corals. In many cases, rubble appeared with sand and its color was also sandy one. Then we grouped rubble and sand into one class. Finally we used four classes: seagrass, live coral, dead or bleached coral (DBC), and sand or rubble (SR). Live coral was distributed along reefs which encircled the island. Their distribution extended in horizontal scale of several hundred meters. Other classes, especially DBC and SR, were patchily distributed in horizontal scale of several tens meters.

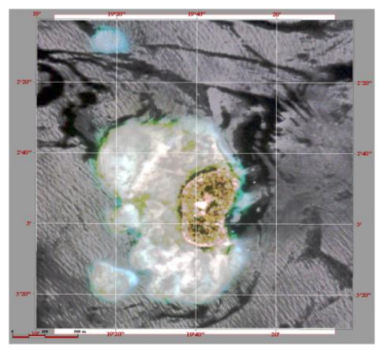

Fig. 8 Enhanced AVNIR-2 imagery (RGB) around Barrang Lompo Island

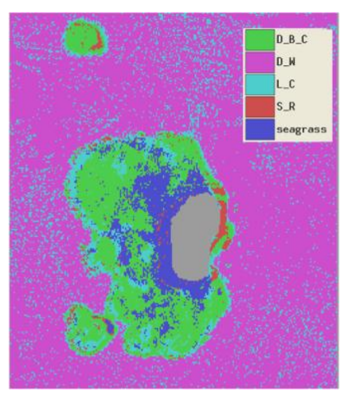

Fig. 9 Result of supervised classification of waters around Barrang Lompo Island with (left) and without deep water (right). DBC, DW, LC, SR and seagrass were classes of dead or bleached coral, deep water, live coral and seagrass, respectively

Since AVNIR-2 imagery included deep waters around Barrang Lompo Island (Fig. 8), we added a class, deep water. Result of supervised classification showed that area with bottom depths greater than 20 m was classified into deep water or live coral (Fig. 9). The reason of misclassification of deep water as live coral is due to low DN of pixels distributed in the deep water area that were very similar to those of live coral class. The other problem was another misclassification of live coral as DBC. Therefore overall accuracy of supervised classification was very low, 41.2 %.

Then we applied supervised classification to lagoon area around Barrang Lompo Island shallower than 20 m to remove deep water class. Result of classification was ameliorated (Fig. 10). User accuracy of live coral classification attained to 79.6 % while those of seagrass, DBC and SR were 58.2, 21.3 and 14.3 %, respectively. Overall accuracy became 60.1 %.

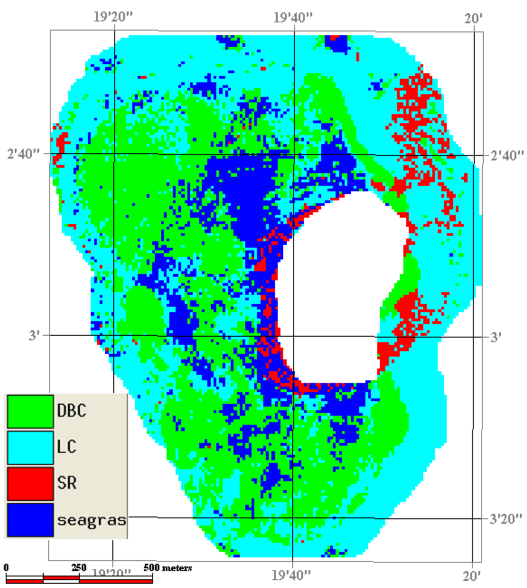

Fig. 10 Result of supervised classification of waters around Barrang Lompo Island without deep water. DBC, DW, LC, SR and seagrass were classes of dead or bleached coral, deep water, live coral and seagrass, respectively

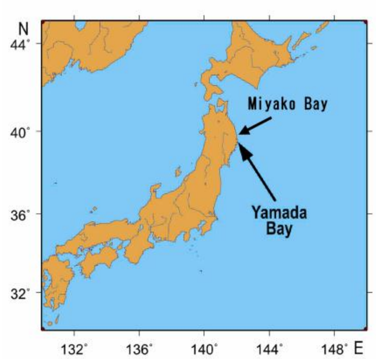

Fig. 11 Map showing locations of Yamada and Miyako Bays

3. AQUACULTURE FACILITIES

3.1 AQUACULTURE FACILITIES IN YAMADA BAY

Yamada Bay is located in Sanriku Coast. The bay is one of the rias-type ones in Sanriku Coast facing the Pacific Ocean (Fig.11). There are a lot of aquaculture facilities in the bay. Thus the bay is suitable for the study site.

Imageries of ALOS and PRISM taken on 10 September 2006, respectively, were used for producing pansharpened RGB imagery with the image processing software (TNT mips, Microimage Inc.). Enhanced pansharpened imagery was used to detect aquaculture facilities (Fig. 12).

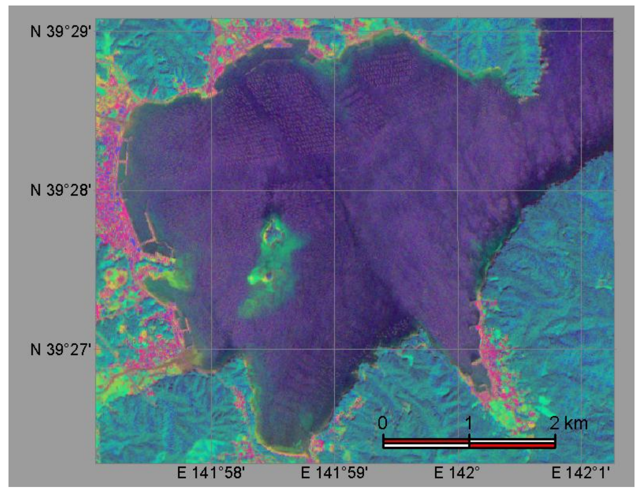

Fig. 12. Enhanced pansharpened true color AVNIR2 imagery of Yamada Bay

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 aquaculture. 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.

Pansharpened AVNIR2 true color imagery couldn't distinguish wood-raft type aquaculture facilities from the sea. However, enhanced imagery could show rafts distributions around north and west sides of the bay (Fig. 12). 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 imagery of the whole bay to extract rafts from the seasurface at once. Then we divided the imagery of the bay into several sections with similar radiance of rafts. The sections were enhanced to examine rafts distributions. One of example was shown in Fig. 13. Radiance of wood rafts was greater than those of the seasurface because the rafts were completely exposed on the sea surface. Then they were

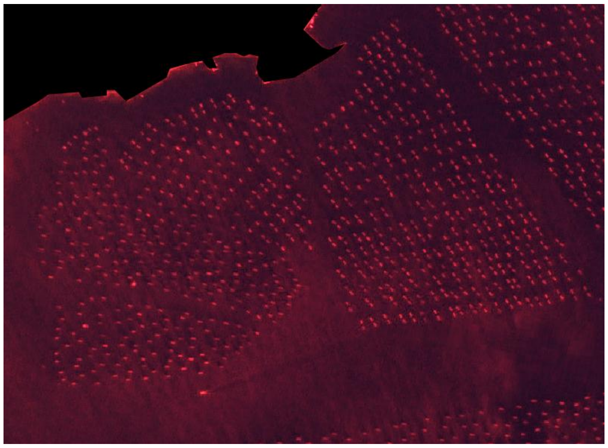

Fig. 13 Pansharpened imagery of the northwest area of Yamada Bay of which red color was enhanced

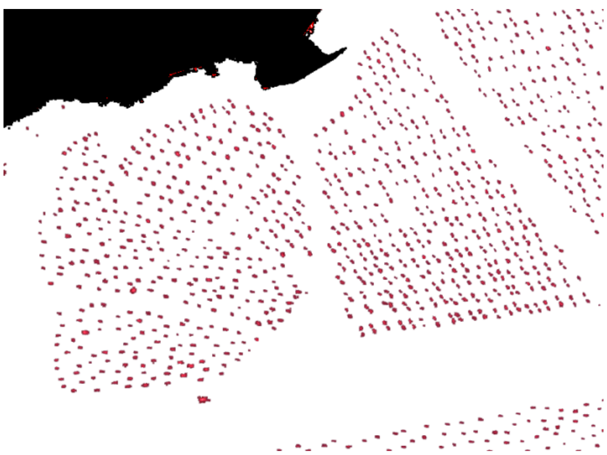

Fig. 14 Extracted rafts in northwest area of Yamada Bay

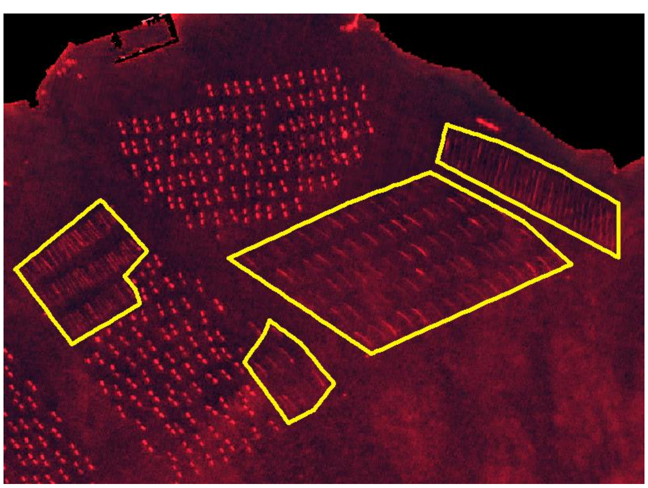

Fig. 15 Pansharpened imagery of the north area of Yamada Bay of which red color was enhanced

Fig. 16 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, respectively

extracted from the imagery (Fig. 14). All the wood rafts in the bay were shown in Fig. 16.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 imagery is enough accurate for practical use.

The license of Iwate Prefecture determined the size of raft was 48 m2 (12m x 4m). Since the resolution of one pixel of ALOS pansharpened imagery is 2.5x2.5 m^2, one raft is consisted of about 2 x 6 pixels. In reality, wood rafts on the imagery were consisted more than 12 pixels. It is known that image analysis of satellite imagery 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.

Buoy-and-rope type aquaculture facilities in Fig. 15 were clearer than those in Fig. 12 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. 16). The other buoy-and-rope facilities were distributed in southeast area of the bay. Although a buoy-and-rope type aquaculture facility had many buoys for getting buoyancy, it was difficult to identify the length of this type with image analysis. 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. It is very difficult to measure the surface area occupied by this type facilities due to pixels with low radiance (yellow area in Fig. 16). Surface area occupied by the buoy-and-rope type aquaculture facilities were summarized in Fig. 16.

The results above-shown well corresponds to those of image analysis of IKONOS pansharpened multispectral imagery with 1 m spatial resolution [16]. Therefore this method mapping aquaculture facilities in Yamada Bay using ALOS imagery is very practical and useful for management of coastal aquaculture activity like as IKONOS imagery.

3.2 AQUACULTURE FACILITIES IN MIYAKO BAY

Miyako Bay is located in Sanriku Coast. The bay is one of the rias-type ones in Sanriku Coast facing the Pacific Ocean (Fig.11). There are a lot of aquaculture facilities in the bay. Thus the bay is suitable for the study site. In this bay, aquaculture facilities consisted of only buoy and rope-type aquaculture rafts. Targets of aquaculture are grouped into two groups: one is seaweed, *Laminaria japonica* and *Undaria pinnatifida*, and the other is shells, scallops and oysters.

Imageries of ALOS and PALSAR taken in February and May 2010, respectively, were used for analysis with the image processing software (TNT mips, Microimage Inc.).

Enhanced ALOS AVNIR 2 in February showed the distribution of aquaculture rafts in the inner part of the bay (Fig. 17). Although we examined AVNIR 2 image in May, we couldn't identify distributions of aquaculture facilities. The difference in images of ALOS AVNIR 2 between February and May is due to those of transparency. We estimate that the increase in turbidity in Miyako Bay from February to May owes to phytoplankton blooming.

PALSAR images were fine mode HH poralimetric data with 7 m spatial resolution. We could identify artificial objects on the sea (Fig. 18). Ground surveys clarified that the aquaculture facilities identified by PALSAR image were for shell aquaculture and had much bigger buoys than those of seaweed aquaculture facilities. Therefore back-scattering from the shell aquacultures were scanned by the PALSAR sensor but that from seaweed aquacultures. AVNIR 2 identified both aquaculture facilities for seaweeds and shells with AVNIR 2 images. Thus we can identify two kinds of buoy and rope type aquaculture facilities. This information is very useful for the integrated coastal management.

4. CONCLUSION

ALOS optical sensors, AVNIR-2 and PISM are very practical tool for mapping coastal ecosystem, especially seagrass beds from boreal to tropical waters and live coral in tropical waters. In tropical waters, it was difficult to evaluate the performance of AVNIR-2 imagery because ground truth data didn't correspond to pixel size. It is necessary to make ground truthing that surveys area of bottom substrate at a reference point to resolve this problem. Fusion of AVNIR-2 with PISM is very practical to identify aquaculture facilities. We will use ALOS optical sensors and also PALSAR to coastal waters in Southeast Asia and North Africa with SAR (PALSAR) in the near future.

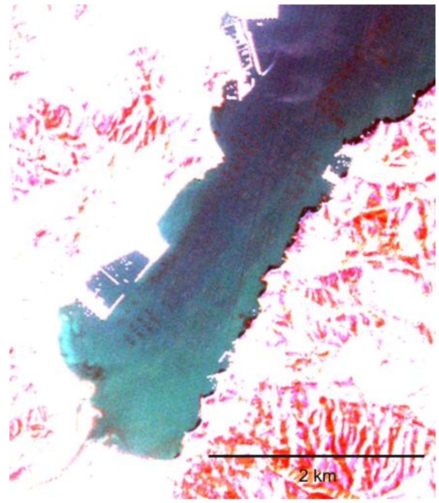

Fig. 17 Enhanced image of ALOS AVNIR 2 in February 2010. Blue and white areas are land and sea. Bar-like lines are buoy and rope rafts

Fig. 18 Enhanced image of ALOS PALSAR HH in February 2010. White bar-like lines in the bay are buoy and rope rafts for shell aquaculture

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] A.B. Smith, C.D. Jones, and E.F. Roberts, “Article Title,” *Journal*, Publisher, Location, pp. 1-10, Date.

[1] T. Komatsu, K. Tatsukawa, K. Ishida, C. Igarashi, S. Sultana, M. Takahashi, and Y. Matsuoka, (2002). “Development of methods mapping coastal zone along Sanriku Coast using satellite imagery and acoustic survey,” In ‘*Conserving our coastal environment: man and the ocean. UNU-ORI-Iwate Symposium Marine Ecology and Environment*’, United Nations University, Tokyo, Japan, pp.33-47, 2002.

[2] T. Komatsu, U. Umezawa, M. Nakaoka, C. Supanwanid and Z. Kanamoto, “Water flow and sediment in Enhalus acoroides and other seagrass beds in the Andaman Sea, off Khao Bae Na, Thailand,” *Coastal Marine Science*, 29, pp. 63-38, 2004.

[3] T. Komatsu and S. Murakami, “Influence of a Sargassum forest on the spatial distribution of water flow,” *Fisheries Oceanography*, 3, pp. 256-266, 1994.

[4] T. Komatsu, “Long-term changes in the Zostera bed area in the Seto Inland Sea (Japan), especially along the coast of the Okayama Prefecture,” *Oceanologica Acta*, 20, pp. 209-216, 1997.

[5] M. Huitric, C. Folke and N. Kautsky, “Development and government policies of the shrimp farming industry in Thailand in relation to mangrove ecosystems,” *Ecological Economcs*, 40, pp. 441-455, 2002.

[6] T. Komatsu, C. Igarashi, K. Tatsukawa, S. Sultana, Y. Matsuoka and S. Harada, “Use of multi-beam sonar to map seagrass beds in Otsuchi Bay, on the Sanriku Coast of Japan,” *Aquatic Living Resources*, 16, pp. 223-230, 2003.

[7] A. Mikami, T. Komatsu, M. Aoki and T. Sagawa, “Biomass estimation of a mixed-species Sargassum forest using aerial photography, field survey and Geographical Information Systems,” In ‘*GIS/spatial analyses in fisheries and aquatic sciences Volume 3*’ (Eds. T. Nishida, P.J. Kaiola & A.E. Caton), Fishery-Aquatic GIS Research Group, Saitama, Japan, pp. 147-160, 2007.

[8] T. Sagawa, A. Mikami, T. Komatsu, N. Kosaka, A. Kosako, S. Miyazaki and M. Takahashi, M, “Mapping seagrass beds in Funakoshi Bay (Sanriku Coast, Japan), by high precision multi-spectral image of IKONOS and side scan sonar technique,” In ‘*GIS/spatial analyses in fisheries and aquatic sciences Volume 3*’ (Eds. T. Nishida, P.J. Kaiola, & A.E. Caton), Fishery-Aquatic GIS Research Group, Saitama, Japan, pp. 85-96, 2007.

[9] T. Komatsu, Y. Matsuoka, K. Shibata, T. Ikemori and N. Ohkei, “Mapping and quantifying a Sargassum forest off Ossaka (Toyama Bay, the Sea of Japan) by using narrow multibeam sonar and GIS,” In ‘*GIS/spatial analyses in fisheries and aquatic sciences Volume 3*’ (Eds. T. Nishida, P.J. Kaiola, & A.E. Caton), Fishery-Aquatic GIS Research Group, Saitama, Japan, pp. 97-114, 2007.

[10] T. Komatsu, M. Takahashi, K. Ishida, T. Suzuki and H. Tameishi, “Mapping aquaculture facilities in Yamada Bay in Sanriku Coast, Japan, by IKONOS satellite imagery,” *Fishieries Science*, 68(sup. I), pp. 584-587, 2002.

[11] Anonymous, “The Report of the Marine Biotic Environment Survey in the 4th National Survey on the Natural Environment, Vol. 2. Algal and Sea-Grass Beds,” Nature Conservation Bureau and Environment Agency and Marine Parks Center of Japan, Tokyo, 1994

[12]T. Sagawa, A. Mikami, T. Komatsu, N. Kosaka, A. Kosako, S. Miyazaki and M. Takahashi, “Mapping seagrass beds using IKONOS satellite image and side scan sonar measurements: a Japanese case study,” *International Journal of Remote Sensing*, 29, 281-291, 2008.

[13] T. Sagawa, E. Boisnier, T. Komatsu, K. Ben Mustapha, A. Hattour, N. Kosaka and S. Miyazaki, “Using bottom surface reflectance to map coastal marine areas: a new application method for Lyzenga’s model,” *International Journal of Remote Sensing*, 31, pp. 3051-3064, 2010.

[14] D. R. Lyzenga, “Passive Remote-Sensing Techniques for Mapping Water Depth and Bottom Features,” *Applied Optics*, 17, pp. 379-383, 1978.

[15] D. R. Lyzenga, (1981). Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. *International Journal of Remote Sensing*, 10, pp. 53-69, 1981.

[16] T. Komatsu, K. Takahashi, K. Ishida, T. Suzuki and H. Tameishi, “Mapping aquaculture facilities in Yamada Bay in Sanriku Coast, Japan, by IKONOS satellite imagery,” *Fisheries Science*, 68, sup. I, pp. 584-587, 2002.