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Special Monitoring and Coastal Environmental
Assessment Region Activity Centre



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Feasibility Study for Assessment of Seagrass Distribution in the NOWPAP Region



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columns)

Front cover: *Zostera marina* and sargassum beds in Nanao Bay, Japan

Taken by Genki Terauchi

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- **Executive summary**

Seagrasses provide important ecological functions and ecosystem services in coastal ecosystems. However, widespread and accelerated losses have been reported worldwide and some seagrass species are now under threat of extinction.

In the NOWPAP (Northwest Pacific Action Plan) region, coastal areas of northeast China, Japan, Korea and the Russian Far East are parts of the most densely populated areas in the world, and their coastal ecosystems including seagrass beds are under pressure from human activities. Although seagrasses have attracted much attention for their functions to maintain marine biodiversity and mitigate climate change, information on their distribution and threats in the NOWPAP region is very limited.

To help address these concerns, a feasibility study was conducted for the assessment of seagrass in the NOWPAP region in 2015 as an activity of the Special Monitoring and Coastal Environmental Assessment Regional Activity Center of NOWPAP. The objective of this activity was to investigate the usefulness of satellite images for the assessment of seagrass distribution in the NOWPAP region and identify obstacles and required resources and/or tasks for implementing the assessment.

Collection and review of the literature on seagrass distribution and threats to seagrass in each member state were first conducted by national experts nominated in each NOWPAP member state. Among the ten species of seagrasses reported in the NOWPAP region, 6 species were listed on the IUCN (International Union for Conservation of Nature) Red List of Threatened Species. More than 800 locations of seagrass observation records in the NOWPAP sea area were then mapped on a web-based GIS prototype developed by CEARAC.

From the case studies to map seagrass distribution with satellite images in selected sea areas in the NOWPAP member states, it was suggested to use standardized procedures in analyzing satellite images with a manual for the mapping of seagrass and seaweed beds distribution with satellite images in the NOWPAP and WESTPAC regions. The time and cost to analyze satellite images for mapping seagrass were then estimated based on case studies in selected sea areas in the NOWPAP member states, and it was concluded that the conventional processing method using software for analyzing satellite images is laborious and impractical to map seagrass distribution in the entire NOWPAP sea area. Use of cloud computing technology for the analysis of satellite images is recommended to reduce the time and cost required to map the distribution of seagrass in the NOWPAP region.

Introduction

Seagrass beds provide various ecological functions such as habitats, spawning and nursery and feeding grounds for aquatic biota (Beck et al., 2001). They also purify seawater by absorbing nutrients (nitrogen and phosphorus) and absorb and fix CO₂ in both plants and the sediment by photosynthesis (Hemminga and Duarte, 2000). However, widespread and accelerated losses of seagrasses have been reported (Waycott et al., 2009) and some seagrass species are under threat of extinction (Short et al., 2001).

The United Nations Environment Programme (UNEP) calls the carbon stored in the seas 'Blue Carbon', and its conservation, restoration and sustainable use is becoming well recognized among the public. Hence, as seagrasses are one of the coastal ecosystems that absorb a huge amount of carbon, they are subject to conservation for mitigating climate change under the Blue Carbon initiative, coordinated by Conservation International (CI), the International Union for the Conservation of Nature (IUCN) and the Intergovernmental Oceanographic Commission of the Educational, Scientific and Cultural Organization (IOC-UNESCO). The Blue Carbon Initiative currently focuses on carbon in coastal ecosystems - mangroves, tidal marshes and seagrasses. Recently, the creation of a global network of regional centers for blue carbon data and knowledge sharing has been announced as one of the main commitments of the United Nation Ocean Conference (5-9 June 2017, New York) toward the implementation of Sustainable Development Goal 14 for the conservation and and sustainable use of our oceans.

The Northwest Pacific region is one of the most densely populated areas of the world, and its coastal system was identified as one of regions highly impacted by human activities (Halpern et al., 2008). In this region, the Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the Northwest Pacific region (NOWPAP) of the UNEP was adopted in 1994. Within the framework of NOWPAP, the Special Monitoring and Coastal Environment Assessment Regional Activity Center (CEARAC) is responsible for the coordination of regional activities for monitoring and assessment of the state of the marine, coastal and associated freshwater environment and development of new monitoring techniques such as remote sensing.

Mapping seagrass by remote sensing is more difficult than mapping mangroves and tidal marshes due to water turbidity, color sun glint and the epiphytes that cover the blades of grass may dilute the spectral reflectance signal of seagrasses and hinder the ability of the instruments to see through the water (Howard et al., 2014). Then to clarify the usefulness and limitation of remote sensing for mapping seagrasses, a manual for mapping seagrass and seaweed beds distribution with satellite images was developed in 2015 (UNEP/NOWPAP/CEARAC/FPM 13/13 Annex XV) and case studies were carried out in selected sea areas in each NOWPAP member state (as presented in Chapter 3 of this report)

from 2015 to 2016. Since 2016, NOWPAP CEARAC has been conducting a feasibility study towards the assessment of seagrass distribution in the NOWPAP region.

This report presents the results of the feasibility study and identifies the resources and tasks required for the assessment of seagrass distribution in the NOWPAP region.

1. Data and method of the feasibility study

1.1. Collections of data

Although the mapping of seagrass with satellite images can provide large spatial-scale information, it requires precise geographical positions of seagrass species for the classifications of satellite images and evaluation of classified bottom substrate images (Sagawa et al., 2007). Therefore, it is important to collect information of seagrass species observed by field surveys. Based on the adopted workplan and budget for the feasibility study for the assessment of seagrass distribution in the NOWPAP region (UNEP/NOWPAP/CEARAC/FPM 14/9 Annex VIII), information of seagrass species in NOWPAP sea areas was collected from the literature by the national experts shown in Table 1. Literature written in English and the language of NOWPAP member states was collected and organized in tabular format by author name, year, title of publication, abstract, type of publication, name of journal, volume, pages, seagrass species, name of location, geographical coordinates, threats to seagrass and availability of GIS polygon data. CEARAC then constructed a seagrass database prototype based on the collected information (<http://map.nowpap3.go.jp/>). Estimation of the time and cost required to analyze satellite images to map the distribution of seagrass in the entire NOWPAP region was then carried out based on the case studies described in Chapter 3.

Table 1 List of national experts who conduct a review of the literature on seagrass distribution and threats to seagrass in the NOWPAP region

Country	Organization	Experts
China	State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, Chinese Academy of Sciences	Dr. Dingtian Yang
Japan	Faculty of Commerce, Yokohama College of Commerce	Dr. Teruhisa Komatsu
Korea	Korea Ocean Satellite Center, Korea Institute of Ocean Science and Technology	Dr. Jong-Kuk Choi
Russia	Pacific Geographical Institute, Far Eastern Branch of the Russian Academy of Sciences	Dr. Vasily Zharikov

1.2. Methodology of the feasibility study

The analysis of satellite images for mapping seagrass is a time-consuming process. To evaluate the feasibility to map the distribution of seagrass in the entire NOWPAP sea areas, it

is necessary to estimate the time and cost required to analyze satellite images. The entire processes of analyzing satellite images for mapping seagrass include selecting and obtaining satellite images from space agencies, carrying out sea truth surveys or collecting existing field data, preparing training data sets for classification, removing sun glint, correcting radiance by depth, classifying images and assessing the accuracy of the obtained classification results. We therefore decided to discuss the feasibility of mapping seagrass by using satellite images in the NOWPAP region in the form of a workshop to identify resources and streamline tasks required for the assessment of seagrass distribution in the NOWPAP region.

The first international workshop on the assessment of seagrass distribution in the NOWPAP region was held in Himi, Toyama, Japan on August 3, 2017 with researchers in and out of the NOWPAP region. Thirty people including local scientists, local government officers and NGO members who have been engaged in seagrass restoration projects attended the workshop. Dr. Maria Potouroglou of UNEP/GRID-Arendal gave a keynote speech titled “Carbon storage potential of blue forest: Prospects for developing blue carbon initiatives in the NOWPAP region”. Dr. Teruhisa Komatsu of Yokohama College of Commerce gave another keynote speech titled “Estimating candidate EBSA for seagrasses and projecting future distribution of seagrasses in Japan”. Country reports on the status of seagrass distribution and threats to seagrass in the NOWPAP region were presented by the nominated national experts who collected the literature in each NOWPAP member state. Dr. Tatsuyuki Sagawa of the Remote Sensing Technology Center of Japan presented “Large-scale seagrass mapping using satellite images in Japan” and Dr. Gregory N. Nishihara of Nagasaki University presented “Monitoring seagrass productivity using low-cost data logging technology”. At the end of the workshop, analysis of the time and cost required to analyze satellite images was presented by Dr. Genki Terauchi and a provisional table of contents of this feasibility study report was then discussed and finalized.

1.3. Flow of the feasibility study

The draft feasibility study report was first prepared by NOWPAP CEARAC and reviewed by experts who carried out the review of the literature on seagrass distribution and threats to seagrass in the NOWPAP region. To assure the quality of this feasibility study report, the report was then reviewed by CEARAC FPs and NOWPAP National Focal Points in accordance with the Guidance on the Quality of NOWPAP Technical Reports (UNEP/NOWPAP IG. 16/8/Rev.1).

2. Seagrass in the NOWPAP region

This chapter consists of two sections: 2.1 Seagrass species in the NOWPAP region, and 2.2 Threats to seagrass in the NOWPAP region. In the first section, seagrass species and their distributions in China, Japan, Korea and Russia are described. Information was collected through a literature review by the national experts in each NOWPAP member state nominated by CEARAC Focal Points. Table 2 shows the total number of literature, the ratios of literature in English and native languages and the ratios of papers or reports or books among the literature. Table 3 and Fig. 2 summarize the seagrass species and their occurrences with locations in the NOWPAP region reported in the literature. The occurrence of a specified seagrass species refers to the number of locations named in the literature. For example, in the case of *Zostera marina* of China, there are 21 locations named in the literature reviewed by the national expert of China. So the percentage of occurrence is 46.7%.

In addition, complementary information was collected from the “World Atlas of Seagrasses” (Green and Short, 2003) in the cases of Japan and Korea.

Table 2 Literature reviewed by national experts in each NOWPAP member state

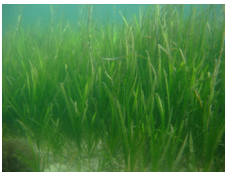



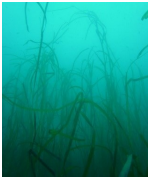


Country	Total No. of literatures	Ratio of literatures in English (%)	Ratio of literatures in native language (%)	Ratio of papers among literatures (%)	Ratio of reports among literatures (%)	Ratio of books among literatures (%)
China	20	0	100	95	0	5
Japan	28	7	93	14	82	4
Korea	13	46	54	92	0	8*
Russia	27	0	100	100	0	0
Total	88					
* Ph.D. dissertation						

Table 3 Seagrass species and their occurrences in the NOWPAP region reported in the literature

Country	Total No. of seagrass species reported	Seagrass species	Occurrences with locations reported in literatures *	
			Sub-total No. of occurrences	Percentage (%)
China	5	<i>Zostera marina</i>	21	46.7
		<i>Zostera japonica</i>	7	15.6
		<i>Zostera caespitosa</i>	6	13.3
		<i>Phyllospadix japonicus</i>	4	8.9
		<i>Phyllospadix iwatensis</i>	7	15.5
		Total	45	100.0
Japan	10	<i>Zostera marina</i>	341	45.7
		<i>Zostera japonica</i>	131	17.6
		<i>Zostera caespitosa</i>	73	9.8
		<i>Zostera asiatica</i>	17	2.3
		<i>Zostera caulescens</i>	10	1.3
		<i>Phyllospadix japonicus</i>	41	5.5
		<i>Phyllospadix iwatensis</i>	72	9.7
		<i>Halophila nipponica</i>	10	1.3
		<i>Halophila ovalis</i>	50	6.7
		<i>Halodule uninervis</i>	1	0.1
		Total	746	100.0
Korea	6	<i>Zostera marina</i>	28	59.6
		<i>Zostera japonica</i>	5	10.6
		<i>Zostera caespitosa</i>	1	2.1
		<i>Zostera asiatica</i>	1	2.1
		<i>Zostera caulescens</i>	6	12.8
		<i>Halophila nipponica</i>	6	12.8
Total	47	100.0		
Russia	4	<i>Zostera marina</i>	59	62.8
		<i>Zostera japonica</i>	11	11.7
		<i>Zostera asiatica</i>	20	21.3
		<i>Phyllospadix iwatensis</i>	4	4.2
Total	94	100.0		

* One species may be reported in multiple literatures.

Major seagrass species in the NOWPAP Region

 <p style="text-align: center;"><i>Zostera marina</i></p>	<p><i>Zostera marina</i> is a seagrass species widespread throughout the NOWPAP region and occurs throughout the coastal areas of China, Japan, Korea and the Russian Far East. <i>Zostera marina</i> is listed as a species of "Least Concern" on the IUCN Red List of Threatened Species.</p>
 <p style="text-align: center;"><i>Zostera japonica</i></p>	<p><i>Zostera japonica</i> occurs throughout the coastal areas of China, Japan, Korea and the Russian Far East. <i>Zostera japonica</i> is listed as a species of "Least Concern" on the IUCN Red List of Threatened Species.</p>
 <p style="text-align: center;"><i>Zostera caespitosa</i></p>	<p><i>Zostera caespitosa</i> occurs in the coastal areas of China, Japan and Korea. <i>Zostera caespitosa</i> is listed as a "Vulnerable" species on the IUCN Red List of Threatened Species.</p>
 <p style="text-align: center;"><i>Zostera asiatica</i></p>	<p><i>Zostera asiatica</i> occurs in the coastal areas of Japan, Korea and the Russian Far East. <i>Zostera asiatica</i> is listed as a "Near Threatened" species on the IUCN Red List of Threatened Species.</p>
 <p style="text-align: center;"><i>Zostera caulescens</i></p>	<p><i>Zostera caulescens</i> occurs in the coastal areas of Japan and Korea. <i>Zostera caulescens</i> is listed as a "Near Threatened" species on the IUCN Red List of Threatened Species.</p>
 <p style="text-align: center;"><i>Phyllospadix iwatensis</i></p>	<p><i>Phyllospadix iwatensis</i> occurs in the coastal areas of China, Japan and Korea. <i>Phyllospadix iwatensis</i> is listed as a "Vulnerable" species on the IUCN Red List of Threatened Species.</p>
 <p style="text-align: center;"><i>Halophila ovalis</i></p>	<p><i>Halophila ovalis</i> is a seagrass species widespread throughout the NOWPAP region and found throughout the coastal areas of China, Japan, Korea and the Russian Far East. <i>Halophila ovalis</i> is listed as a species of "Least Concern" on the IUCN Red List of Threatened Species.</p>

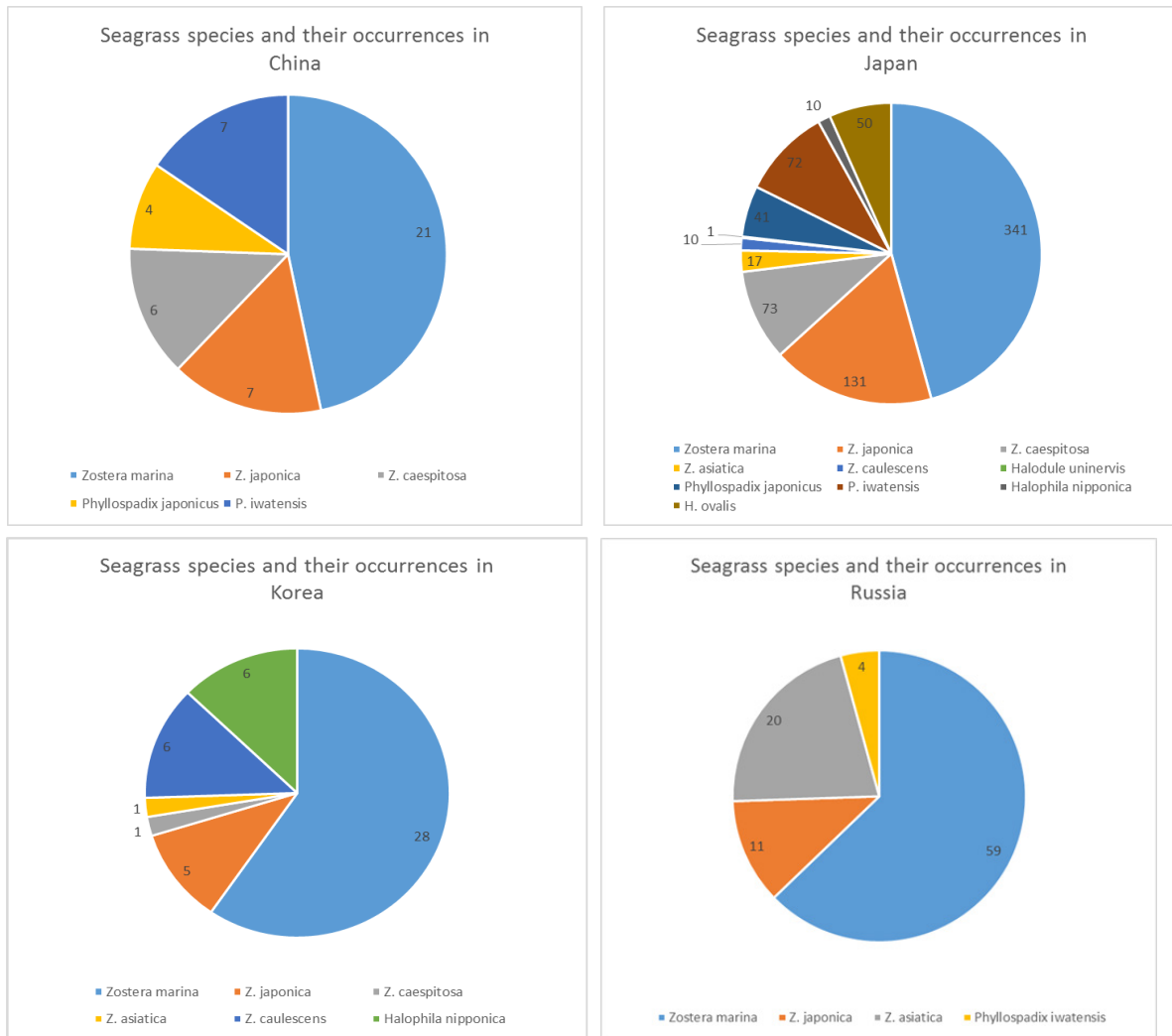


Figure 2 Seagrass species and their occurrences in the NOWPAP region

In the second section, threats to seagrass in China, Japan, Korea and Russia are described. Information was collected through the literature review by the national experts. Table 4 and Fig. 3 summarize the records of threats to seagrass in the NOWPAP region reported in the literature. Complementary information concerned with threats to seagrass was also collected from the “World Atlas of Seagrasses” in the cases of Japan and Korea.

Table 4 Records of threats to seagrass in the NOWPAP region reported in the literature

Country	Threats with locations reported in literatures*	Total No. of threats	Percentage (%)
China	YES	22	48.9
	NO	23	51.1
	Total	45	100.0
Japan	YES	63	8.4
	NO	683	91.6
	Total	746	100.0
Korea	YES	20	42.6
	NO	27	57.4
	Total	47	100.0
Russia	YES	4	4.3
	NO	90	95.7
	Total	94	100.0

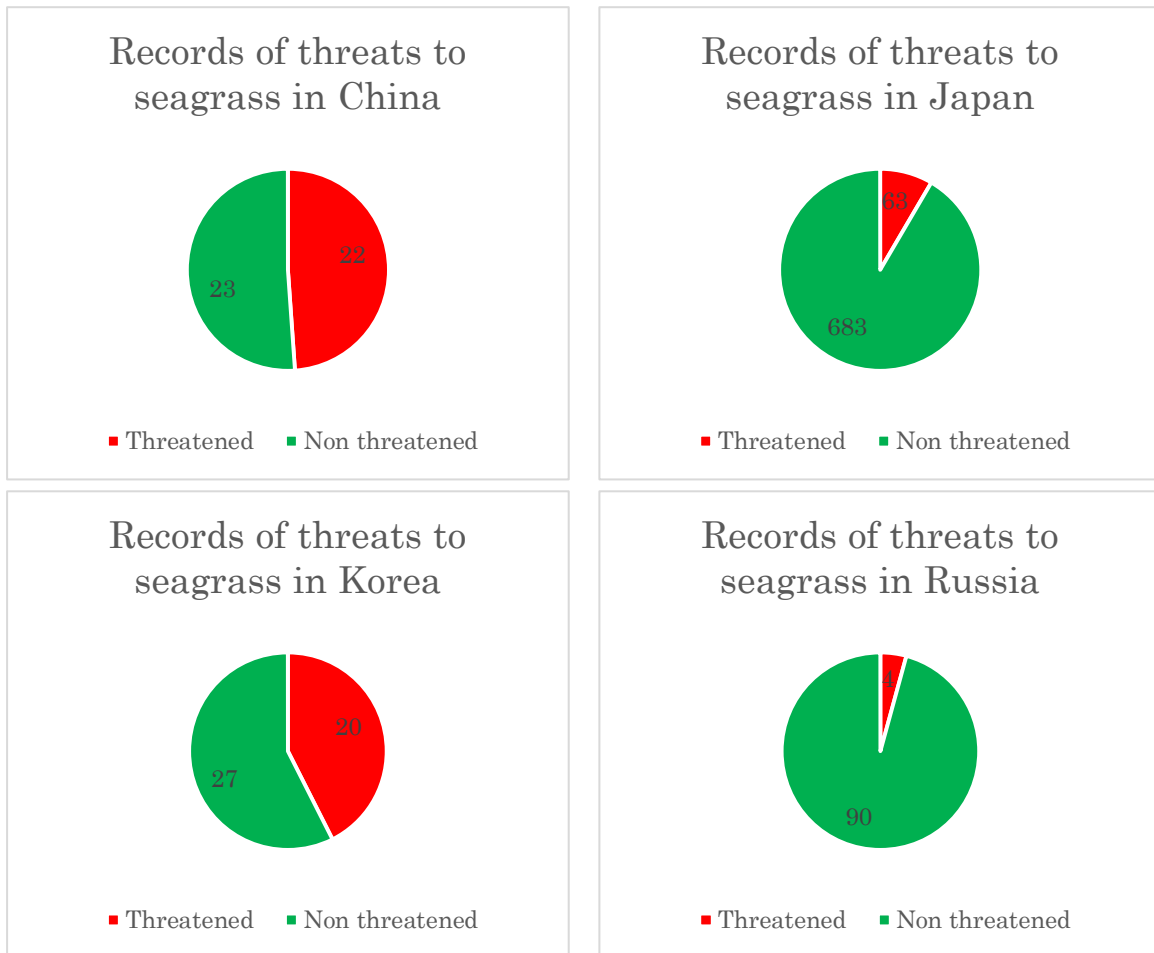


Figure 3 Records of threats to seagrass in the NOWPAP region

2.1. Seagrass species in the NOWPAP region

2.1.1. The seagrasses of China

SPECIES AND DISTRIBUTION

The literature reviewed by the national expert of China reported that five seagrass species are distributed in the NOWPAP region of China (Tables 3 and 5). *Zostera marina*, *Z. japonica*, *Z. caespitosa*, *Phyllospadix japonicus* and *P. iwatensis* are distributed along the coastal areas of Liaoning, Hebei and Shandong provinces (Zheng et al., 2013; Guo et al., 2010; Yang, 1979; Zhang et al., 2013; Yang, 2017). *Zostera* is the dominant species of most seagrass meadows. In addition, the distribution of *Z. japonica* is not limited to the northern coast of Liaoning, Hebei and Shandong, but also to the coast of Fujian, Taiwan, Guangxi, Hong Kong and even Hainan provinces (Zheng et al., 2013).

Zheng et al. detailed 22 seagrass species in China, including all five species shown in Table 3 and Table 5, and 17 other species (*Enhalus acoroides*, *Thalassia hemprichii*, *Halophila ovalis*, *H. minor*, *H. decipiens*, *H. beccarii*, *Cymodocea rotundata*, *C. serrulata*, *Halodule uninervis*, *H. pinifolia*, *Syringodium isoetifolium*, *Thalassodendron ciliatum*, *Zostera asiatica*, *Z. caulescens*, *Ruppia maritima*, *R. cirrhosa*, *R. megacarpa*). These 17 species are distributed in the South China Sea or East China Sea (Zheng et al., 2013).

Table 5 Seagrass species and their distribution in the NOWPAP region of China

Species	Distribution	Consistency with IUCN Red List (Category*)
Zosteraceae		
<i>Zostera marina</i>	Yellow Sea and Bohai Sea	
<i>Zostera japonica</i>	South China Sea, Yellow Sea and Bohai Sea	
<i>Zostera caespitosa</i>	Yellow Sea and Bohai Sea	
<i>Phyllospadix japonicus</i>	Yellow Sea and Bohai Sea	EN
<i>Phyllospadix iwatensis</i>	Yellow Sea and Bohai Sea	VU

* Category: Endangered (EN), Vulnerable (VU), Near Threatened (NT).

COMPARISON WITH IUCN RED LIST

A search of the IUCN (International Union for Conservation of Nature) Red List of Threatened Species website (<http://www.iucnredlist.org/search>) reveals that the distributions of the five species of seagrasses in China shown in Table 5 are consistent with the spatial distributions of the Red List. For example, the spatial distribution of *Phyllospadix iwatensis* is shown in light brown in

Fig. 4 (IUCN, 2017).

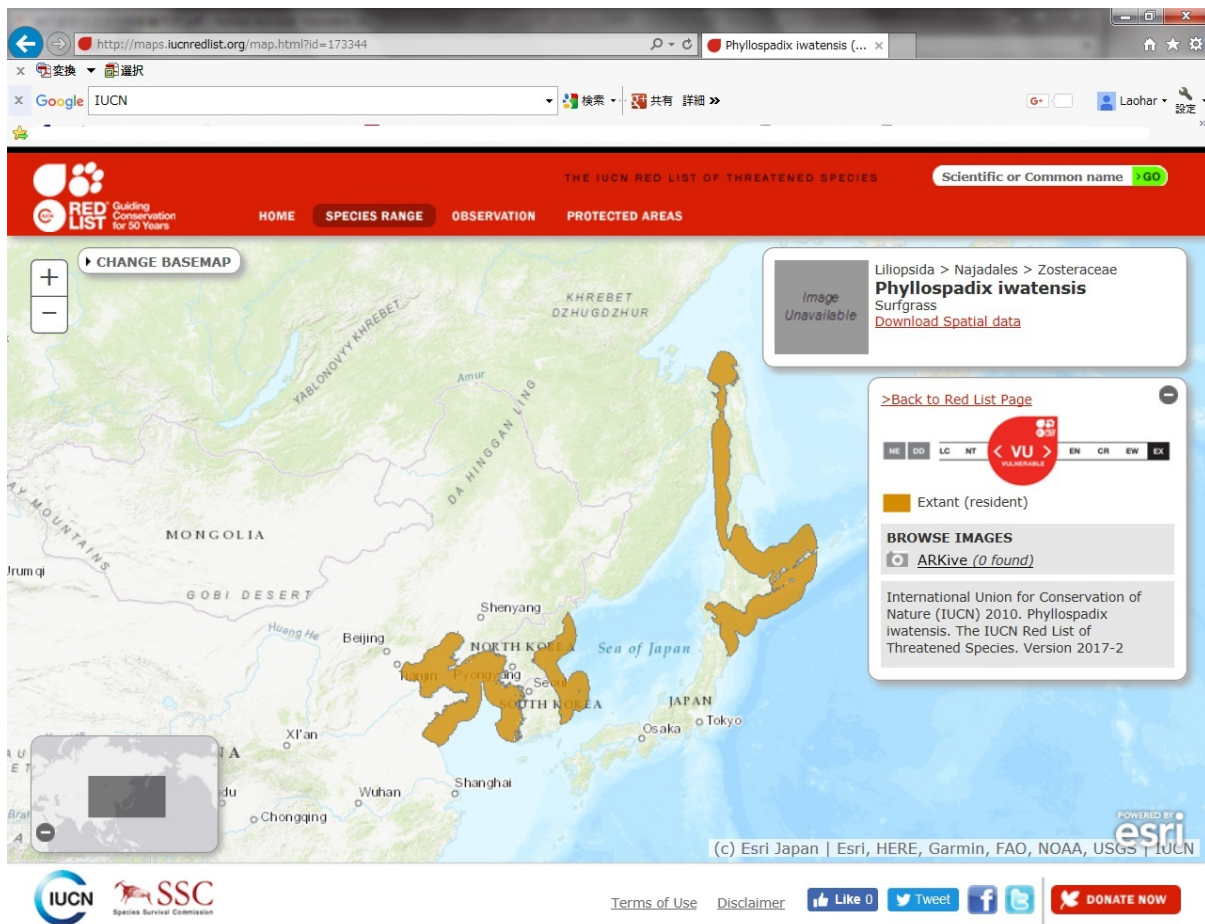


Figure 4 Spatial distributions of *Phyllospadix iwatensis* on the IUCN Red List.

In addition, by comparing with the 15 IUCN Red List seagrass species shown in Table 6, *Zostera caespitosa*, *Phyllospadix japonicus* and *P. iwatensis* occurring in the coastal waters of China are categorized as Endangered (EN) and Vulnerable (VU), respectively as shown in Table 5.

Table 6 IUCN Red List Category of seagrass species (Short et al., 2011)

Family	Species name	Red List Category*
ZOSTERACEAE	<i>Phyllospadix japonicus</i>	EN
ZOSTERACEAE	<i>Zostera chilensis</i>	EN
ZOSTERACEAE	<i>Zostera geojeensis</i>	EN
HYDROCHARITACEAE	<i>Halophila baillonii</i>	VU
HYDROCHARITACEAE	<i>Halophila beccarii</i>	VU
HYDROCHARITACEAE	<i>Halophila hawaiiiana</i>	VU
POSIDONIACEAE	<i>Posidonia sinuosa</i>	VU
ZOSTERACEAE	<i>Phyllospadix iwatensis</i>	VU
ZOSTERACEAE	<i>Zostera capensis</i>	VU
ZOSTERACEAE	<i>Zostera caespitosa</i>	VU
HYDROCHARITACEAE	<i>Halophila engelmanni</i>	NT
HYDROCHARITACEAE	<i>Halophila nipponica</i>	NT
POSIDONIACEAE	<i>Posidonia australis</i>	NT
ZOSTERACEAE	<i>Zostera asiatica</i>	NT
ZOSTERACEAE	<i>Zostera caulescens</i>	NT

*Category: Endangered (EN), Vulnerable (VU), Near Threatened (NT).

2.1.2. The seagrasses of Japan

SPECIES AND DISTRIBUTION

In 2003, Aioi and Nakaoka reported that 16 seagrass species, including seven temperate species (*Zosteraceae*) and nine tropical species (*Hydrocharitaceae* and *Cymodoceaceae*), occurred on the coasts of Japan, accounting for about 25% of seagrass species in the world (Aioi and Nakaoka, 2003). In 2007, Ohba and Miyata reported that 19 seagrass species were recorded from Rebun Island of Hokkaido Prefecture in the north of Japan to Ohmura Bay of Nagasaki Prefecture in the south of Japan (Ohba and Miyata, 2007). The northernmost spot on Rebun Island is located at latitude 45.4234588 degrees N and longitude 141.0293548 degrees E, and the southernmost spot on Ohmura Bay is located at latitude 33.0059639 degrees N and longitude 129.773949 degrees E. The Japanese Government conducted two large-scale surveys on seagrasses on the coasts of Japan. The Fisheries Agency of Japan conducted a “Study on technology development of seagrass bed creation considering biodiversity” from 2004 to 2006. The study consisted of “analysis on genetic diversity of seagrass species” and “a guideline for natural restoration of seagrass beds”. In the final report, the Fisheries Agency reported 14 seagrass species (Fisheries Agency of Japan, 2006), which were observed from Ezanodomari of Hokkaido to North Ohmura Bay of Nagasaki Prefecture. The northernmost spot on Ezanodomari of Hokkaido is located at latitude 45.445350 degrees N and longitude 141.643733 degrees E, and

the southernmost spot on North Ohmura Bay is located at latitude 33.090312 degrees N and longitude 129.764942 degrees E. From 2002 to 2007, the Ministry of Environment of Japan conducted surveys on the ecosystems in shallow waters in order to understand the present and the biological diversity of seagrass and seaweed beds in more than 120 places around the Japanese coast. The Ministry of Environment of Japan summarized the final report in 2008 (Ministry of Environment of Japan, 2008), in which 15 seagrass species were reported. Distributions of those 15 seagrass species were observed from Aomori Bay to Shishiki Bay of Nagasaki Prefecture. The northernmost spot on Aomori Bay is located at latitude 40.940490 degrees N and longitude 140.847470 degrees E, and the southernmost spot on Shishiki Bay is located at latitude 33.196000 degrees N and longitude 129.400370 degrees E.

The national expert of Japan reviewed the literature and defined that only ten species are distributed in the NOWPAP region of Japan shown in Tables 3 and 7.

Table 7 Seagrasses recorded in the NOWPAP region of Japan

Species	Consistency with IUCN Red List (Category* ¹)
Zosteraceae	
<i>Zostera marina</i>	
<i>Zostera japonica</i>	
<i>Zostera caespitosa</i>	VU
<i>Zostera asiatica</i>	NT
<i>Zostera caulescens</i>	NT
<i>Phyllospadix japonicus</i>	EN
<i>Phyllospadix iwatensis</i>	VU
Hydrocharitaceae	
<i>Halophila nipponica</i>	
<i>Halophila ovalis</i>	
Cymodoceaceae	
<i>Halodule uninervis</i>	

*¹ Category: Endangered (EN), Vulnerable (VU), Near Threatened (NT).

COMPARISON WITH IUCN RED LIST

A search of the IUCN Red List of Threatened Species reveals that the distributions of all species of seagrasses in Japan shown in Table 7 are consistent with the spatial distributions of the Red List (IUCN, 2017).

Also, according to Table 6, five of the 15 IUCN Red List seagrass species (*Zostera caespitosa*,

Z. asiatica, *Z. caulescens*, *Phyllospadix japonicus* and *P. iwatensis*) occur in coastal waters of Japan.

2.1.3. The seagrasses of Korea

SPECIES AND DISTRIBUTION

In the literature reviewed by the national expert of Korea, six seagrass species and their distributions in the NOWPAP region of Korea were described (Tables 3 and 8).

Lee et al. reported in 2016 that nine seagrass species of four genera, including five *Zostera* species (*Z. marina*, *Z. asiatica*, *Z. caespitosa*, *Z. caulescens* and *Z. japonica*), two *Phyllospadix* species (*P. iwatensis* and *P. japonicus*), *Ruppia maritima* and *Halophila nipponica* are distributed on soft sediments and rocky substrata from intertidal to a depth of approximately 15 m in coastal waters of Korea (Lee et al., 2016).

On the other hand, Lee and Lee (2003) reported that eight seagrass species are distributed in the coastal waters of Korea. According to Lee and Lee, *Zostera marina* is the dominant seagrass species widely distributed throughout all coastal areas forming relatively large meadows. *Z. asiatica* occurs on the east coast. The distribution of this species on the west and the south coasts of the Korean peninsula is not identified. *Z. caespitosa*, *Z. caulescens* and *Z. japonica* are found on all coasts of Korea. *Phyllospadix japonicus* occurs on all coasts of the peninsula, while *P. iwatensis* occurs on the east and west coasts. The distribution of *Ruppia maritima* in Korea has been reported from limited areas on the west and south coasts.

Table 8 Seagrass species distributed on the coasts of Korea

Species	Distribution	Consistency with IUCN Red List (Category*)
Zosteraceae		
<i>Zostera marina</i>	All coasts	
<i>Zostera japonica</i>	All coasts	
<i>Zostera caespitosa</i>	All coasts	VU
<i>Zostera asiatica</i>	East coast	NT
<i>Zostera caulescens</i>	All coasts	NT
Hydrocharitaceae		
<i>Halophila nipponica</i>	South coast	NT

*Category: Endangered (EN), Vulnerable (VU), Near Threatened (NT).

COMPARISON WITH IUCN RED LIST

A search of the IUCN Red List of Threatened Species reveals that the distributions of all species of seagrasses in Korea are consistent with the spatial distributions of the Red List (IUCN, 2017) (Table 8).

Also, according to Table 6, four of the 15 IUCN Red List seagrass species (*Zostera caespitosa*, *Z. asiatica*, *Z. caulescens* and *Halophila nipponica*) occur in the coastal waters of Korea.

2.1.4. The seagrasses of Russia

SPECIES AND DISTRIBUTION

There are four dominant species of seagrass distributed along the coasts of Russia in Peter the Great Bay, the Sea of Japan and the western coast of South Sakhalin Island (Paymeeva, 1973; Paymeeva, 1974; Vyshkvartsev and Peshehodko, 1982; Petrov, 2004) (Table 9).

Table 9 Seagrass species and their distributions in the NOWPAP region of Russia

Species	Distribution	Consistency with IUCN Red List (Category*)
Zosteraceae		
<i>Zostera marina</i>	Peter the Great Bay, Sea of Japan, Western coast of South Sakhalin Island	
<i>Zostera japonica</i>	Peter the Great Bay, Sea of Japan	
<i>Zostera asiatica</i>	Peter the Great Bay Sea of Japan	NT
Cymodoceaceae		
<i>Phyllospadix iwatensis</i>	Sea of Japan Western coast of South Sakhalin Island	VU

*Category: Endangered (EN), Vulnerable (VU), Near Threatened (NT).

COMPARISON WITH IUCN RED LIST

A search of the IUCN Red List of Threatened Species reveals that the distributions of all species of seagrasses in Russia are consistent with the spatial distributions of the Red List (IUCN, 2017) (Table 9).

Also, according to Table 6, two of the 15 IUCN Red List seagrass species, *Zostera asiatica*

and *Phyllospadix iwatensis*, occur in the coastal waters of Russia.

2.1.5. Summary

In summary, seagrass species reported in the NOWPAP region are listed in Table 10.

Table 10 Seagrass species in the NOWPAP region

Species	Distribution			
	China	Japan	Korea	Russia
Zosteraceae				
<i>Zostera marina</i>	✓	✓	✓	✓
<i>Zostera japonica</i>	✓	✓	✓	✓
<i>Zostera caespitosa</i>	✓	✓	✓	
<i>Zostera asiatica</i>		✓	✓	✓
<i>Zostera caulescens</i>		✓	✓	
<i>Phyllospadix japonicus</i>	✓	✓		
<i>Phyllospadix iwatensis</i>		✓	✓	✓
Hydrocharitaceae				
<i>Halophila nipponica</i>		✓	✓	
<i>Halophila ovalis</i>		✓		
Cymodoceaceae				
<i>Halodule uninervis</i>		✓		

2.2 Threats to seagrass in the NOWPAP region

2.2.1. Threats to seagrass in China

Based on the literature review by the national expert of China, records of threats to seagrass in China are summarized in Tables 4 and 11. According to Table 4, among 45 seagrass occurrences with locations, 22 threats were recorded as YES, accounting for 48.9% of the total seagrass occurrences.

Table 11 Records of threats to seagrass in China

Year	Location	Details of Threats	Causes
2010	Shandong Province	Not available	Human activities or natural environmental change
2010	Lidao, Shandong	Not available	Aquaculture and land reclamation
2012	Shandong Peninsula	Damage & degradation	Land reclamation, coastal overdevelopment
2013	Sanggou Bay	Not available	Monsoon storm tide, typhoon, land reclamation, sand digging
2016	Caofeidian, Bohai Sea	Decreases of meadows	Sea fish catch, oil exploitation, land reclamation, sand digging
2017	Swan Lake	Not available	Human activities or natural environmental change, typhoon

The main reason for the degradation of seagrasses in China is man-made interference, which is characterized by destructive digging and aquaculture activities in seagrass meadows, as well as land reclamation activities in seagrass habitats and surroundings. Destructive digging of worms and trawling of shellfish, electric fishing, fencing and other man-made behaviors destroy seagrass meadows directly (Zheng et al., 2013; Guo et al., 2010; Liu et al., 2016; Liu et al., 2013).

Large-scale aquacultures of seaweeds, fish, crabs, shellfish and other economic flora and fauna will cause water pollution and poor water exchange. Seaweed aquaculture may compete for nutrients with seagrass resources, which will threaten the survival of seagrasses (Zheng et al., 2013; Yu et al., 2007; Guo et al., 2010).

Port construction, land reclamation, oil exploitation and coastal overdevelopment etc. directly occupy the shallow waters of seagrass meadows forcing the loss of the best growing habitats of many seagrasses (Zheng et al., 2013; Liu et al., 2016; Guo et al., 2010; Liu et al., 2012). An investigation carried out in November 2012 in Beihai City, Guangxi found that port construction directly occupied an area of more than 0.2 km² in which seagrass meadows had been distributed (Zheng et al., 2013).

In addition, the existing studies have shown that land-based fish culture, industrial and domestic sewage, etc. also affect water quality and sediments, which cause degradation of seagrass meadows. Global climate change is also considered as a reason for seagrass degradation (Zheng et al., 2013). Typhoons directly destroy seagrass meadows (Zheng et al., 2013; Yang, 2017), for example in Sanggou Bay of Shandong Province (Liu et al., 2013).

2.2.2. Threats to seagrass in Japan

Seagrasses have been disappearing rapidly due to industrial development in the coastal regions of Japan. Major threats for further decline in present seagrass coverage include land reclamation, environmental deterioration such as worsening water quality and a rise in water temperature and water level due to global warming (Komatsu, 1997; Aioi and Nakaoka, 2003).

Based on the literature review by the national expert of Japan, records of threats to seagrass in Japan are summarized in Tables 4 and 12. According to Table 4, among 746 seagrass occurrences with locations, 63 threats were recorded as YES, accounting for only 8.4% of the total seagrass occurrences.

As early as in 1983, Nabata and Matsuda (1983) reported the disappearance of *Phyllospadix iwatensis* resulting from removing seagrasses with chains in kelp farms around Rishiri Island, Hokkaido. Kunii (2001) reported that seagrasses grow in waterways in reclaimed land. As time passed, salinity decreased. A decrease in salinity in waterways might lead to the disappearance of seagrasses. Nishigaki et al. (2005) reported that the increase in suspended matter covering seagrass leaves lowers the limit of seagrass distributions through the reduction of PAR by coverage of sediment on the leaves. Decreases of seagrass meadows were also reported in Yomogida Fishery Port, Aomori Prefecture and other locations, where broad seagrass meadows remained until 2000 and there were only a few patches of seagrass meadows in 2006. Threats were recorded in several places, but the causes were unknown (Fisheries Agency of Japan, 2006). The Ministry of Environment of Japan reported that feeding of herbivorous fishes on *Zostera caulescens* are a cause of its decrease (Ministry of Environment of Japan, 2008).

Table 12 Records of threats to seagrass in Japan

Year	Location	Details of Threats	Causes
1983	Rishiri Island, Hokkaido	Seagrass disappearance	Removing seagrasses with chains in kelp farms
2001	Lakes Shinji & Nakaumi	Seagrass disappearance	Decreasing salinity
2005	Maizuru Bay	Seagrass growth affected	Increase in suspended matter
2006	Yomogida Fishery Port Aomori Pref.	Decreases of meadows	Not available
2006	Toyoda, Niigata Pref.	Not available	Not available
2006	Ishida, Toyama Pref.	Seagrass disappearance	Not available
2006	Kyouden, Toyama Pref.	Seagrass disappearance	Not available
2006	Shishizaki, Kyoto Pref.	Decreases of meadows	Not available
2006	Haji, Kyoto Pref.	Decreases of meadows	Not available
2006	Kanzaki, Kyoto Pref.	Decreases of meadows	Not available
2006	Tai, Kyoto Pref.	Decreases of meadows	Not available
2006	Hamasakiimazu, Fukuoka Pref.	Decreases of meadows	Not available
2008	Uchiura, Ishikawa Pref.	Decreases of meadows	Feeding damage of herbivorous fish
2008	Nanao Bay, Ishikawa Pref.	Seagrass disappearance	Reclamation and repair of piers
2008	Ohashi River Estuary, Shimane Pref.	Seagrass disappearance	Not available
2008	Yuya Bay, Yamaguchi Pref. Shimane Pref.	Seagrass disappearance	Not available
2008	Shishiki Bay, Nagasaki Pref.	Decreases of meadows	Not available

Zostera caulescens occurs in the coastal areas of Japan and Korea. *Zostera caulescens* is listed as a "Near Threatened" species on the IUCN Red List of Threatened Species.

2.2.3. Threats to seagrass in Korea

Seagrasses in Korea have been severely impacted by coastal eutrophication, land reclamation, aquaculture and fishing activities, and these threats still exist. Since the majority of Korean seagrasses are cold water species, global warming appears to be a new threat to seagrasses in Korea (Lee and Lee, 2003).

Based on the literature review by the national expert of Korea, records of threats to seagrass in Korea are summarized in Tables 4 and Table 13. According to Table 4, among 47 seagrass occurrences with locations, 20 threats were recorded as YES, accounting for 42.6% of the total seagrass occurrences.

In 2002, a die-off of seagrass beds caused by red-tide was observed in Jindong Bay (Lee et al., 2007). Impacts by land reclamation are reported in Kwangyang Bay in the south of Korea (Kim et al., 2008), in Deukryang Bay on the southwest coast of Korea (Kim et al., 2009) and in the Nakdong River estuary on the south coast of Korea (Park et al., 2009). Impacts on seagrass beds by typhoons are reported. A die-off of seagrass beds was observed in September 2012 after the Bolaven, Tembin and Sanba typhoons consecutively passed the study site in Jangheung (Kim et al., 2015).

Table 13 Records of threats to seagrass in Korea

Year	Location	Details of Threats	Causes
2002	Jindong Bay	Seagrass die-off	Red-tide
2008	Namhae Island	Not available	Land reclamation, construction
2009	Goheung & Jangheung	Not available	Land reclamation
2009	Nakdong River estuary	Decreases of meadows	Land reclamation
2015	Jangheung	Seagrass die-off	Typhoons

2.2.4. Threats to seagrass in Russia

Based on the literature review by the national expert of Russia, records of threats to seagrass in Russia are summarized in Tables 4 and Table 14. According to Table 2.3, among 94 seagrass occurrences with locations, four threats were recorded as YES, accounting for only 4.3% of the total seagrass occurrences.

Progressing irreversible degeneration of the spatial structure of the seagrass ecosystem of Alekseev cove (Popov Island, Peter the Great Bay) under the influence of activity on breeding aquaculture of sea scallops and mussels is reported (Zharikov and Preobrazhensky, 2010). Large populations of *Zostera marina* located within the port area in Sovetskaya Gavan Bay are subject to significant anthropogenic pollution (Dulenin, 2012). Threats by a typhoon to the seagrasses in Srednaya Bay (Zharikov et al., 2015), threats by the development of ports, pollution and aquaculture to the seagrasses in Severnaya Bay (Zharikov et al., 2016) and threats by the development of ports and pollution to the seagrasses in Tokarevsky Koshka (Eastern Bosphorus Strait) (Kalita and Scriptsova, 2017) are reported.

Table 14 Records of threats to seagrass in Russia

Year	Location	Details of Threats	Causes
2010	Popov Island, Peter the Great Bay	Progressing irreversible degeneration of spatial structure of ecosystem	Aquaculture
2012	Sovetskaya Gavan Bay	Not available	Development of port, pollution
2015	Srednaya Bay	Not available	Typhoon
2016	Severnaya Bay	Not available	Development of port, pollution, aquaculture
2017	Eastern Bosphorus Strait	Not available	Development of port, pollution

2.2.5. Summary

In summary, threats to seagrass habitats in the NOWPAP region have been reported due to both anthropogenic and natural disturbances, such as land reclamation, port construction, destructive digging, aquaculture, oil exploitation and typhoons. Quantitative analysis of the threats to seagrass from the collected literature was not possible. Even though Coles et al. (2013) reported that (1) urban/port infrastructure development, (2) changes in surface temperature and (3) sea level rise in that order are major disturbances that threaten the seagrass communities and habitats in the temperate North Pacific, there are no observation data and reports on the threat caused by “(2) changes in surface temperature” and “(3) sea level rise” according to Tables 11, 12, 13 and 14, in which the records are based on the literature review by the national experts in each NOWPAP member state.

3. Case studies of mapping seagrass distribution by satellite images in the NOWPAP region

3.1. A manual for mapping of seagrass and seaweed bed distribution with satellite images

The mapping of seagrass and seaweed bed distribution with satellite images has been conducted by scientists since the launch of a satellite sensor into space (e.g. Komatsu et al., 2012; Noiraksar et al., 2014). While the Remote Sensing Handbook for Tropical Coastal Management (Green et al., 2000) provides basic guidelines on the use of satellite images for mapping seagrass, rapid and remarkable progress has been made in the development of satellite remote sensing sensors in the past two decades. In particular after the opening of the Landsat archive free of charge was announced in 2008, there has been an accelerated use of satellite images for monitoring of the environment.

A proposal to conduct case studies on seagrass and seaweed mapping in selected sea areas in the NOWPAP region was presented at the 11th CEARAC Focal Points Meeting (Toyama, Japan) in September 2013, then adopted in 2014 with the revision of mapping only seagrass. The proposal included the development of a manual for mapping distributions of seagrass and seaweed beds with a remote sensing approach using satellite images. The manual was then developed by Dr. Teruhisa Komatsu under a Memorandum of Understanding with CEARAC. The development of the manual aimed at standardizing the methodology of mapping seagrass and seaweed beds in the NOWPAP region considering the latest development in satellite remote sensing sensors. The developed manual includes theories of optics for remote sensing, a summary of satellite images capable of detecting seagrass and seaweed beds, the availability of satellite images and software, guidance in the collection of ground truthing data and procedures to analyze satellite images including the classification of images and validation of accuracy. The developed manual was shared among the national experts nominated by CEARAC Focal Points to carry out case studied in selected sea areas in each NOWPAP member state (UNEP/NOWPAP/CEARAC/FPM 13/13 Annex XV) then the developed manual was submitted to Coastal Marine Science in early 2018 for peer review.

3.2. Summary of case studies in the 2014-2015 biennium

National experts were nominated by CEARAC FPs to carry out case studies in selected sea areas in the NOWPAP member states with the developed manual (Table 15). This chapter introduces the summary of the case studies in each selected sea area.

Table 15 Nominated experts and selected sea areas for the seagrass mapping case studies in the NOWPAP region.

Country	Experts	Selected sea areas
China	State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, Chinese Academy of Sciences Dr. Yang Dingtian	Swan Lake (Head of the Shandong Peninsula)
Japan	Northwest Pacific Region Environmental Cooperation Center Dr. Tsuneo Maeda, Dr. Wataru Matsumura and Dr. Genki Terauchi	West part of Toyama Bay (Himi), Nanao Bay (West Bay area)
Korea	Korea Ocean Satellite Center, Korea Institute of Ocean Science and Technology Dr. Keunyong Kim and Dr. Jong-Kuk Choi	Deukryang Bay (Jangheung Province)
Russia	Pacific Geographical Institute, Far Eastern Branch of the Russian Academy of Sciences Dr. Vasily Zharikov	Eastern section of the Far Eastern Marine Reserve (Southwest coastal area out of Peter the Great Bay)

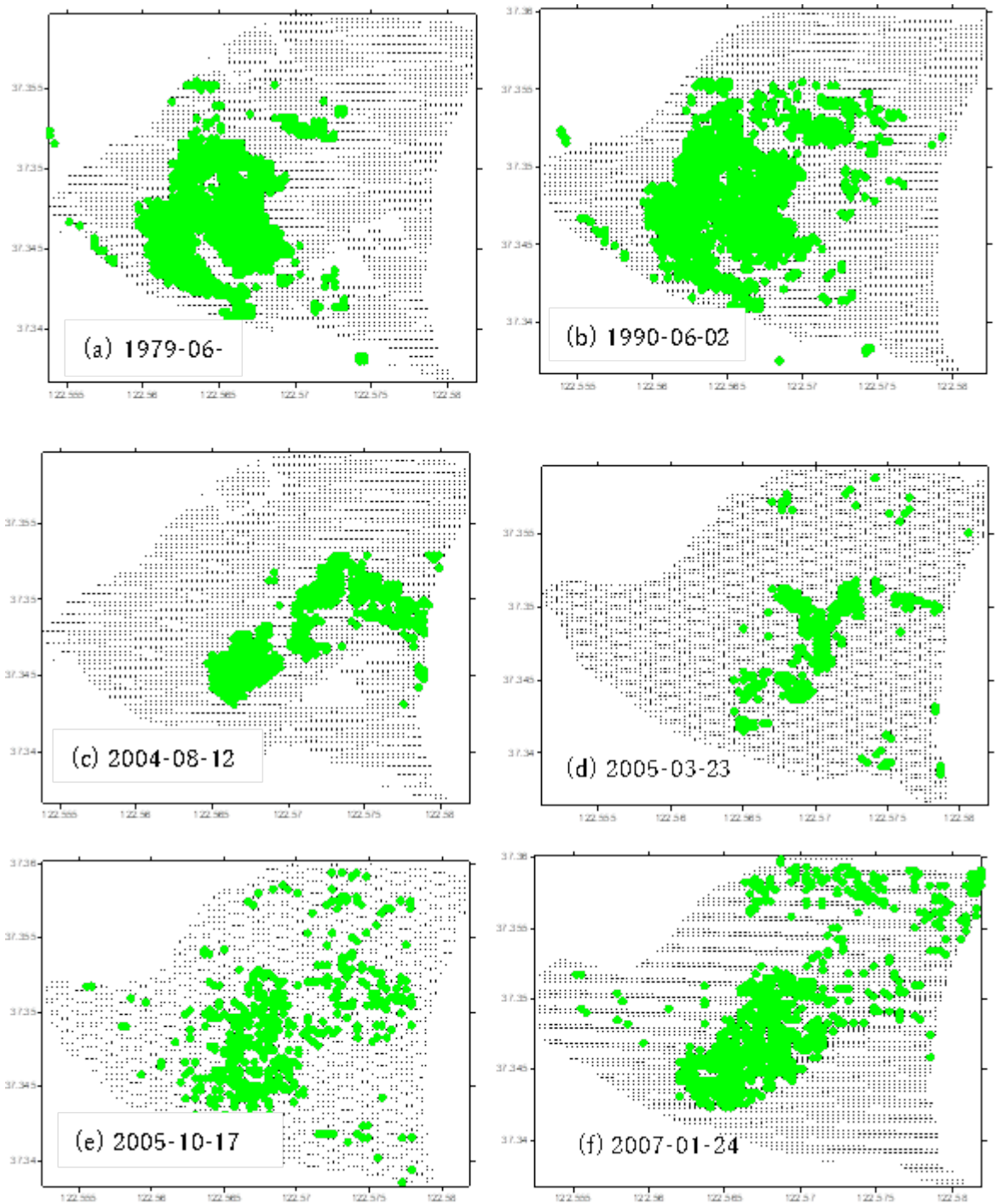
3.2.1. Swan Lake, China

Seagrass and attached bio-resources are very important for swans' overwintering in Swan Lake, located at the head of Shandong Peninsula, China. The satellite remote sensing data of the Landsat series in the late spring, summer, autumn and early winter from 1979 to 2010 were analyzed using ground truthing data to retrieve the temporal change in the spatial distribution of seagrass beds in Swan Lake. The band ratio of red and green for Landsat MSS and blue and green for TM and ETM+ was used for correction of the water column by Lyzenga's method. The ratio of red and green for MSS and blue and green for Landsat TM and ETM+ with a range greater than 4.5 was determined as seagrass.

The seagrass occurred mainly in the central area to the southwest and east of Swan Lake at a distance of tens of meters from the bank. Although seagrass density was found to be dense in the main seagrass bed, seagrass distributions with different densities are distributed outside the central area of the main seagrass bed. Results demonstrate that seagrass appeared in the southeastern and central areas of Swan Lake in 1979 and 1989 (Fig. 5). Significant loss of seagrass occurred in the southeastern area from 1990 to 2004 leaving seagrass beds only in the central and central-eastern areas of the Lake. By 2009, the area of seagrass distribution had

expanded and showed recovery in the western and northern part of the Lake.

Analyzing the reasons for seagrass distribution change showed that human activities, especially dam and fish pond construction caused their loss from 1990 to 2004. However, it showed recovery towards 2009 with the raising of awareness of seagrass importance and protective activities such as seagrass transplant, change of solid waste landfill site and construction of a sewage treatment plant. Nevertheless, human activities such as aquaculture, shellfish digging, pollution and fish pond construction remain as threats to seagrass in Swan Lake.



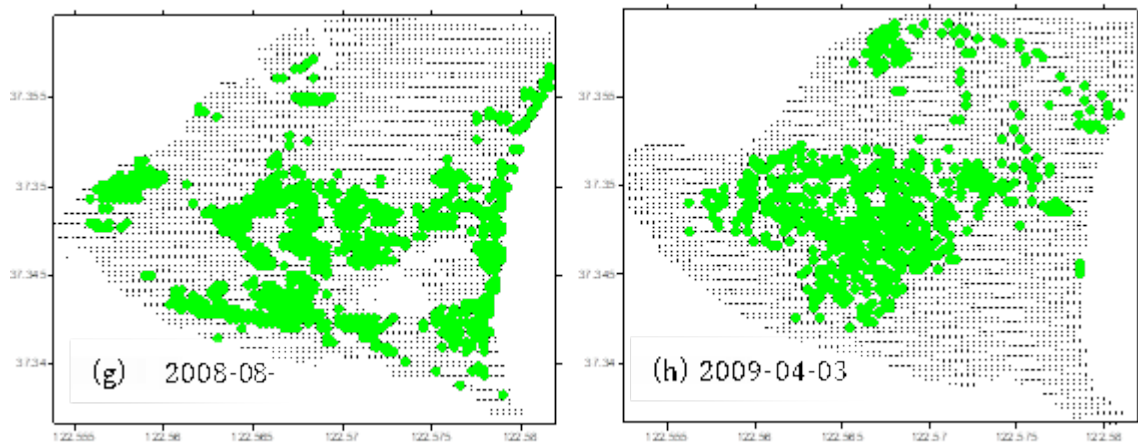


Figure 5 Seagrass (green spots in the figures) distributions inferred from the satellite remote sensing data in Swan Lake on (a) 12 June 1979, (b) 6 June 1990, (c) 12 August 2004, (d) 23 March 2005; (e) 17 October 2005, (f) 24 January 2007, (g) 7 August 2008 and (h) 3 April 2009.

3.2.2. Toyama Bay and Nanao Bay, Japan

Toyama Bay is a deep-water bay located at the eastern foot of Noto Peninsula. The total surface area of Toyama Bay is approximately 2,120 km² and the maximum water depth is 1,250 m (Imamura et al., 1985). In contrast, Nanao Bay is a shallow bay located westward of the bend of the Noto Peninsula. Nanao Bay consists of three small bays: north bay, west bay and south bay with a total surface area of approximately 183 km² and the maximum water depth is 60 m at its north bay entrance. The innermost parts of Toyama Bay and Nanao Bay are designated as Ecologically and Biologically Significant Marine Areas by the central government of Japan, in line with scientific criteria of the Convention on Biological Diversity. Dense seagrass distributions have been observed in the western part of the Himi area in Toyama Bay and the west bay area in Nanao Bay. These areas were selected for the case studies of CEARAC on seagrass mapping with satellite images in Japan.

In the Himi area of Toyama Bay, satellite remote sensing data of GeoEye-1 of November 22, 2014 and RapidEye of March 17, 2016 were used to map seagrass beds. Water column correction of the Bottom Reflectance Index (BRI) method proposed by Sagawa et al. (2010) was applied to the GeoEye-1 image of November 22, 2014 for supervised classification by the maximum likelihood. The obtained results of bottom substrate classification using the BRI corrected Green and Blue bands indicated that seagrasses were widely distributed from Shimao Beach to Ao around Himi Harbor located in the northern part of the study area at a depth of 3-11 m (Fig. 6). Overall accuracy of the classification results around Himi Harbor was 0.61 and the tau coefficient was 0.47, which was not very high. In particular, user accuracy of seagrasses was 0.20, which means that only 20% of the areas classified as seagrass beds were correctly identified by ground truth data obtained on November 2 to 4, 2015. As one of the possibilities for the mis-match between the classification results and ground truth data, it was suggested that the seagrass

habitat had decreased during 1 year after the GeoEye-1 sensor observed this area in November 2015. To fill in this temporal gap, a RapidEye image of March 17, 2016 was then used for classification of the sea bottom from Blue, Green and Red bands corrected with a radiometric correction method of BRI. The obtained classification results showed a similar pattern of seagrass distribution in comparison with the classification results of the GeoEye-1 of November 22, 2014 with improved accuracy: overall accuracy of 0.64 and tau coefficient of 0.54 (Fig. 7). Improved user accuracy of the seagrasses to 0.72 indicated 72% of areas classified as seagrass were consistent with the field survey. The field survey of seagrass by observation on the sea bottom with a camera lowered from a boat from 2015 to 2016 indicated that seagrass beds distributed from 6 to 13 m deep were annual and disappeared after flowering season in early summer until the production of seedling in winter. Ralph et. al (2007) reported that the distribution of seagrass, especially at the deepest edge of the meadow, was controlled by light availability. In the coastal zones of Himi, the increase of phytoplankton biomass towards summer with fresh water discharge was temporarily observed from 1998 to 2014 by remotely sensed chlorophyll-a concentration (Terauchi et al., 2014). The penetration of light in seawater is prevented by turbidity caused by the increase of phytoplankton biomass (Nixon, 1995). Light penetration is also controlled by inorganic suspended materials and yellow substances discharged from rivers (IOCCG, 2000). Thus, it was considered that the location of seagrass deeper than 6 m in the coastal zones of Himi may vary every year possibly due to the availability of light which depends on factors including the amount of phytoplankton biomass, suspended materials and yellow substances discharged from rivers, which may relate to land use.

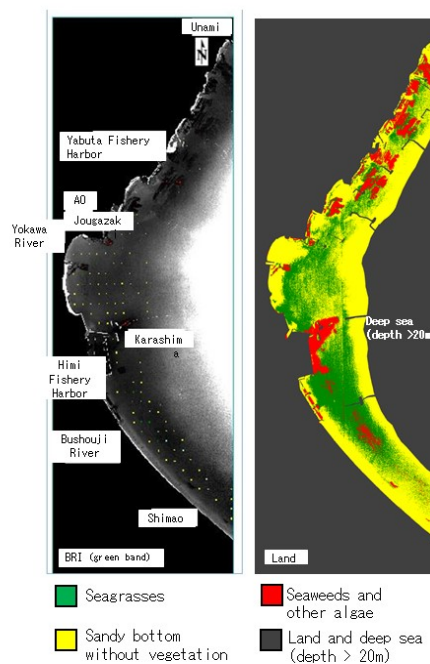


Figure 6. Seagrass distributions detected by the supervised classification with blue and green

bands of GeoEye-1 taken on November 22, 2014 corrected with a radiometric correction method of the BRI band. BRI corrected green band (left) and classification results of bottom substrates (right).

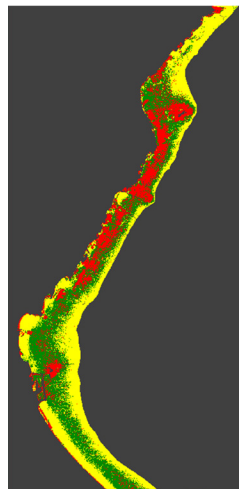


Figure 7 Seagrass distributions detected by the supervised classification of blue, green bands of RapidEye taken on March 17, 2016 corrected with a radiometric correction method of the BRI method.

In Nanao Nishi Bay located in the west area of Nanao Bay, the Landsat OLI image of June 1, 2016 was used for detecting seagrass beds. The field survey with an underwater video camera was carried out on June 1, 2 and 16 in 2016. Dense seagrasses were mostly observed at areas at bottom depths less than 5 m by the field survey. In a shallow zone where the bottom depth is less than 2 m, seagrass coexisted with *Sargassum* species covering the sea surface with a canopy of matured colored leaves. Six classes of training data were then prepared for classifying the Landsat OLI image: dense seagrass, dense seagrass with *Sargassum*, *Sargassum*, sandy bottom, mud and exposed sand. Since the spatial resolution of Landsat is 30 x 30 m per pixel, ground truth data of dense seagrass beds larger than 30 x 30 m were allocated to a seagrass class. Those of seagrass beds smaller than 30 x 30 m and sandy bottom without vegetation were allocated to a sandy bottom class. Supervised classification of the bottom substrates was carried out by the maximum likelihood method using bands of Red, Green and Blue or band ratios of Green/Blue, Green/Red, Blue/Red and Green/Coastal bands corrected with a radiometric correction method of the Depth Invariant Index (DII) developed by Lyzenga (1978) consisting of atmospheric and water column corrections. The obtained results of bottom substrate classification (Fig. 8) were consistent with the ground truth data reserved for the accuracy evaluation, and

accuracy assessment shows better results in the DII corrected band ratios: overall accuracy of 0.73 and tau coefficient of 0.66. The area of seagrass was estimated as 846.6 ha which was calculated by the sum of seagrass with sargassum and dense seagrass classes. Ikemori et al. (2016) reported areas of seagrass as 1042 ha in the west bay area of Nanao Bay in 2011, based on a scuba diving survey in December. Considering that smaller spatial seagrass beds (patches less than 30 x 30 m spatial resolution) were not included in the estimation of seagrass areas with the Landsat OLI image and differences in timing and methods of observations by Ikemori et al. (2016), the estimated area of seagrass was sufficiently close.

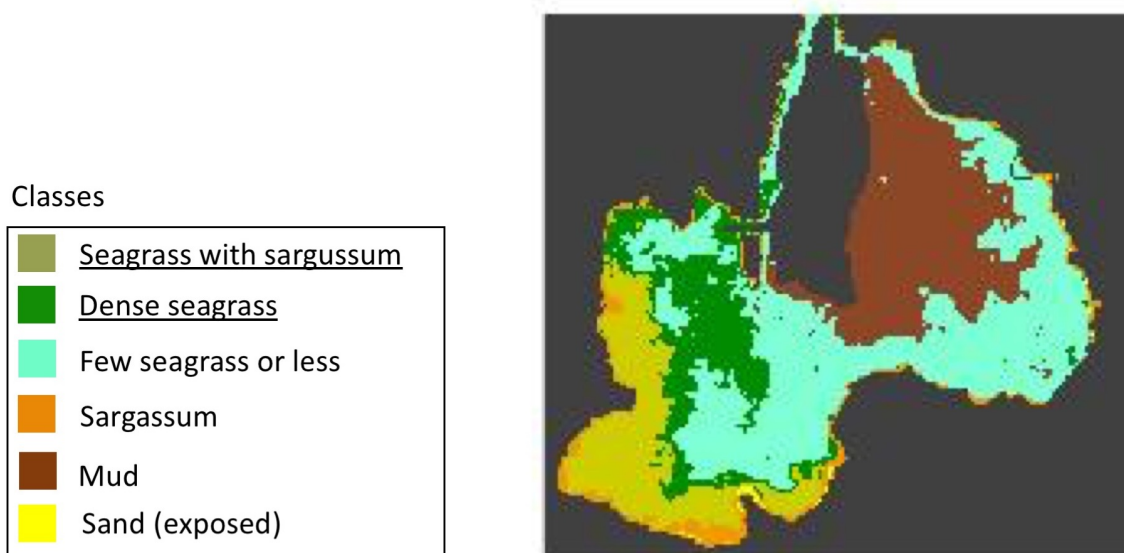


Figure 8 Results obtained by the supervised classification of band ratios of Green/Blue, Green/Red, Blue/Red and Green/Coastal corrected with a radiometric correction method of the Depth Invariant Index (DII) of Landsat 8 OLI on June 1, 2015.

Ikemori et al. (2016) indicated the disappearance of seagrass from late summer to early autumn in 2016 due to high sea water temperature in summer. If seagrass disappears and its root dies, seed germination of seagrass occurs from the winter to the spring season in Japan (Aioi and Nakaoka, 2015). To verify whether the reported disappearance of seagrass from late summer is an annual event before 2016, past Landsat archive data were analyzed to detect a seasonal pattern of seagrass distribution in Nanao-Nishi Bay. Since field data collected were not sufficient for classification of the past Landsat archive data, K means unsupervised classification was used for mapping the seagrass distribution using Red, Green and Blue bands without water column corrections. We classified pixels of the Landsat OLI image of June 1, 2016 into six classes. Cloud free past Landsat archive images were collected and analyzed by the K means unsupervised

classification. Classification results of the Landsat OLI image of June 1, 2015 were used as a reference to determine seagrass distribution as it had good compliance with the ground truth data. Two classes of unsupervised classification corresponded to a distribution pattern consisting of dense seagrass and dense seagrass with *Sargassum* of ground truthing data. We then merged the two classes into a class of seagrass distribution. A comparison of seasonal patterns of seagrass distribution estimated by the unsupervised classification of satellite images from November 22, 1991 to June 1, 1992 (Fig. 9) and from November 21, 2014 to June 1, 2015 (Fig. 10) showed a seasonal pattern similar to that in 2016. This indicates that a large-scale disappearance of seagrass distribution in autumn might have occurred in the past.

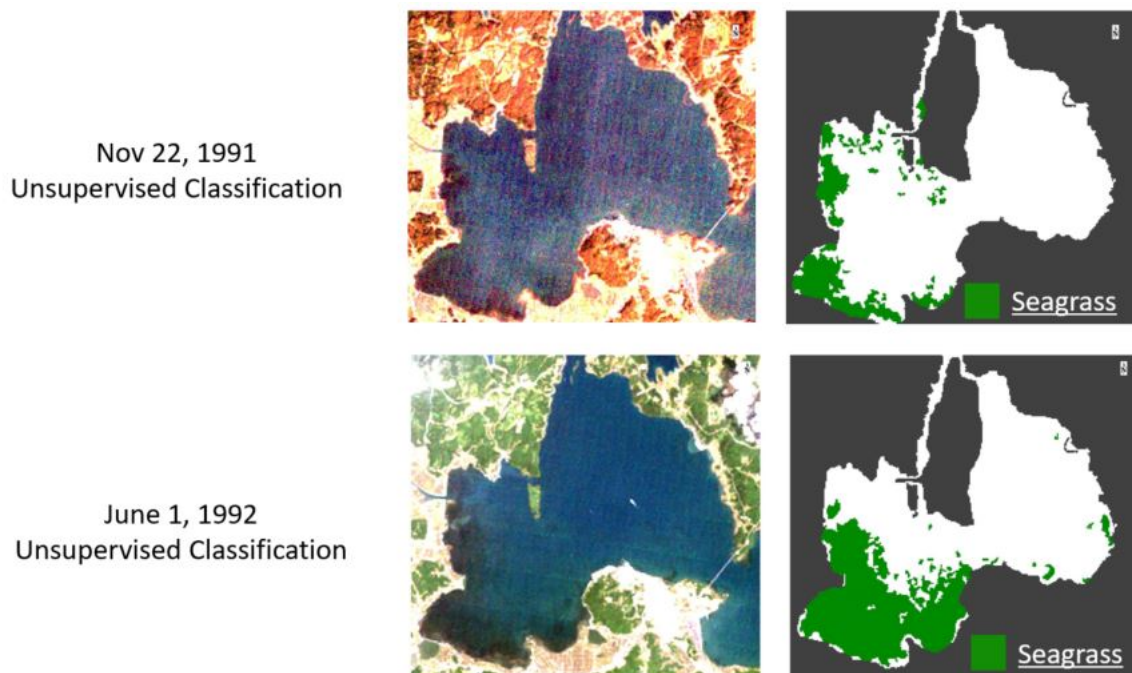


Figure 9 Comparison of seasonal pattern of seagrass distribution from November 22, 1991 to June 1, 1992.

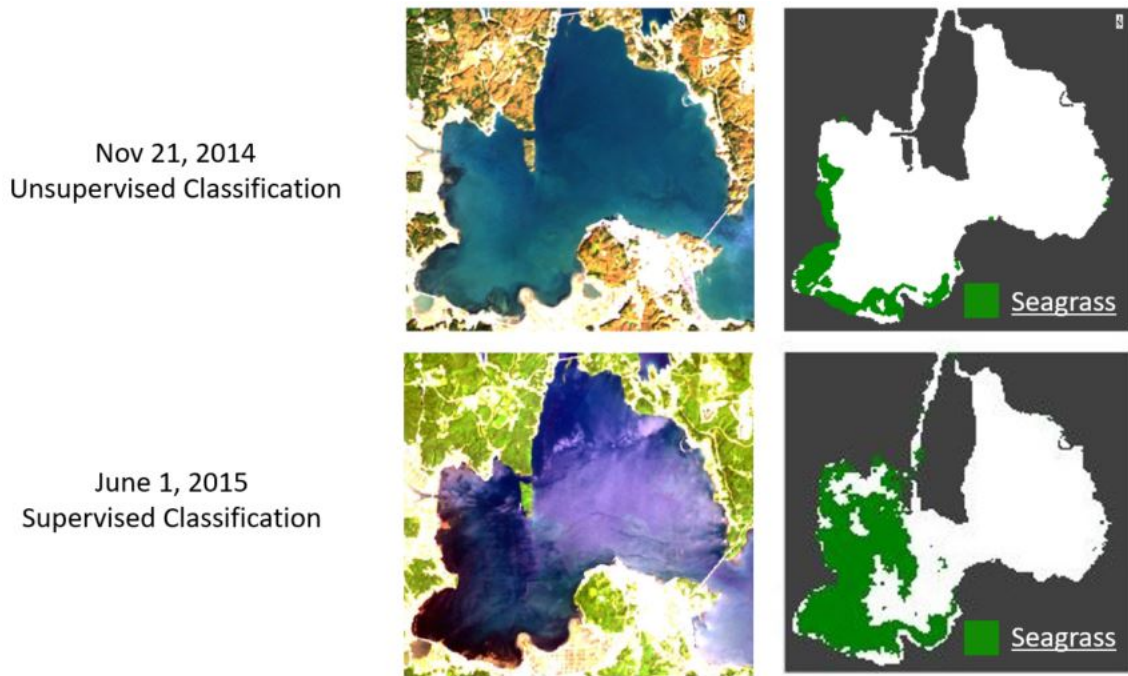
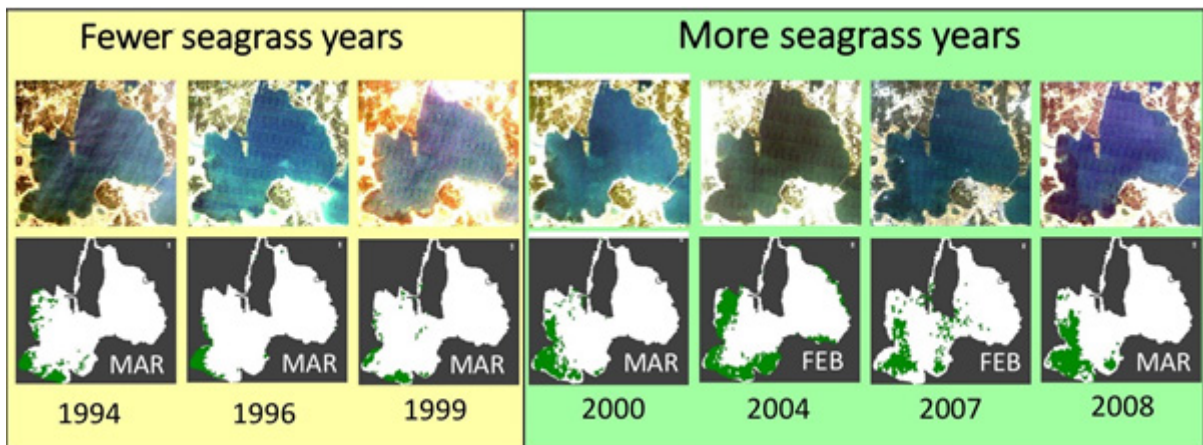


Figure 10 Comparison of seasonal pattern of seagrass distribution from November 21, 2014 to June 1, 2015.



In Japan, *Zostera marina* seeds germinate from November to February in Yanai Bay west of Honshu Island (Kawabata et al., 1990). Thus, it is also true that the germination of *Z. marina* occurs in this period. Past Landsat images in February to March corresponding to the *Z. marina* seed germination period and following small seedling period was then classified by the same K mean unsupervised classification to verify whether there is any interannual variability in seagrass distribution from February to March. The obtained results showed that there are fewer seagrass years (1994, 1996 and 1999) and more seagrass years (2000, 2004, 2007 and 2008), indicating the survival rate of seagrass varied depending on the year (Fig. 11).

Figure 11. Interannual variability of seagrass distribution in February and March from 1994 to 2008 mapped by unsupervised classification

3.2.3. Deukryang Bay, Korea

Deukryang Bay is located on the southern coast of the Korean peninsula and surrounded by small villages. *Zostera marina* dominates at the bay, while lesser amounts of *Z. caulescens* and *Halophila nipponica* are also distributed in this area. Satellite remote sensing data of KOMPSAT-2 and Landsat TM/ETM+ images were analyzed to detect the seagrass distribution of Deukryang Bay. The radiometric correction of DII was applied to all the collected images and the results showed that accuracies of any classification methods increased when DII was applied to the satellite image data. Among the several classification methods applied to the KOMPSAT-2 image of January 7, 2012, the object-based classification algorithm showed the highest overall accuracy (0.92) and the Mahalanobis distance method showed the second highest (0.87) with the radiometric correction of DII. Although the object-based classification algorithm is effective for the high spatial resolution images to map precise habitats, consequently it is not suitable for lower spatial resolution data such as Landsat images. Thus, the Mahalanobis distance method, which is applicable to freely available medium spatial resolution Landsat images, was used for detecting temporal and spatial change in seagrass distribution with a time-series of multiple Landsat images from 1990 to 2012. This study revealed that the distribution of seagrass in the study area did not change much during the past 20 years (Fig. 12). Long-term changes in sea surface temperature, daylight hours and precipitation were also studied, but no significant relation with the changes in the spatial distribution of seagrass beds was observed.

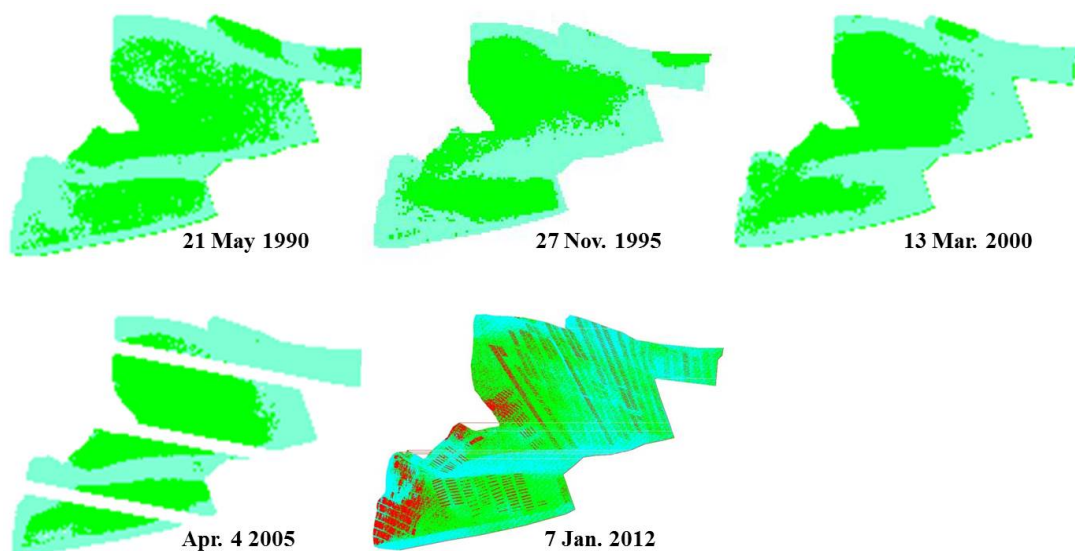


Figure 12 Changes in the spatial distribution of seagrass beds in the study area from 1990 to 2012 mapped with Landsat TM/ETM+. Light green indicates the distribution of seagrass and red indicates aquaculture rafts.

3.2.4. Eastern section of the Far Eastern Marine Reserve, Russia

Peter the Great Bay is located in the Far Eastern part of Russia. Three species of seagrasses: *Zostera Marina*, *Zostera asiatica* and *Zostera japonica* have been observed in this region. The most common species in the Peter the Great Bay is *Z. marina*. Satellite remote sensing data of Landsat ETM+ and OLI were analyzed to detect seagrass distribution in the eastern section of the Far Eastern Marine Reserve. Two radiometric corrections of DII and BRI were applied in the Eastern section of the Far Eastern Marine Reserve, Russia, and the classified seagrass distribution map with the BRI method showed better consistency with the sea truth data. The BRI method was then applied to three satellite images of 2001, 2013 and 2014 applying a supervised classification of maximum likelihood to the corrected image data (Fig. 13). Areas occupied by seagrass were 286 ha and 316 ha in 2013 and 2014, respectively. The distribution pattern of seagrass in these two years was similar in shape and it coincided with the survey conducted by the laboratory of underwater landscapes of the Pacific Geographical Institute. In 2001 areas occupied by seagrasses were 98 ha and were much smaller than in 2013 and 2014. Since the mapped area was located far from cities, anthropogenic impacts on this area were considered negligible. Presumably, the smaller area of seagrass distribution in 2001 was due to natural disturbances such as typhoons or low-pressure storms. Although they destroy seagrass beds, seagrasses can recover autonomously (e.g. Sugimoto et al., 2008). As most of the sparse beds were distributed in open areas, it was considered that hydrodynamics action, which depends on the frequency and magnitude of low-pressure storms and typhoons, determined the survival rate of seagrasses in this region.

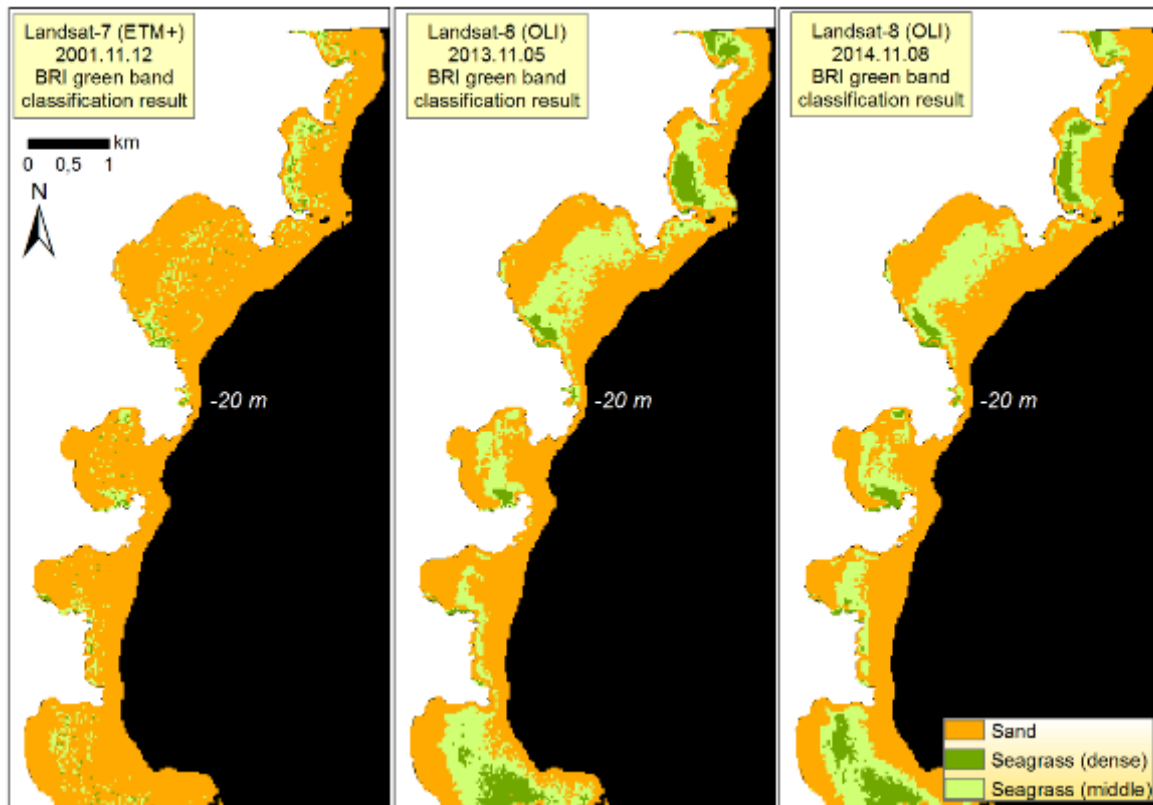


Figure 13 Maps showing distributions of seagrasses in 2001, 2013 and 2014 obtained by applying radiometric correction based on the Bottom Reflectance Index method.

4. Towards mapping of seagrass distribution in the entire NOWPAP region

4.1. Available satellite images and tools for analysis

For mapping seagrass, multiband satellite images that include multiband data generally composed of blue, green, red and near infrared layers are used. It is better to use finer spatial resolution of satellite images than an actual seagrass patch. The spatial resolution of satellite images varies in each sensor mounted on a satellite. Spatial resolutions of commercial satellite sensors are usually finer than those of non-commercial satellite sensors. While satellite images taken by commercial satellites are costly, most non-commercial satellite images are free of charge. The list of multiband satellite images available is summarized in Table 16. Satellite images obtained by commercial satellite sensors can be purchased from distributors in each country. However, satellite images obtained by non-commercial satellite sensors such as Landsat 8 OLI and Sentinel-2 MSI are freely available from various sources via the Internet. The use of Landsat archive data has radically increased since 2008 after the United States Geological Survey (USGS) opened the Landsat archive at no charge via the Internet (Loveland and Dwyer, 2012).

These satellite images have often been analyzed by expensive commercial software such as ENVI, ERDAS and ArcGIS. Recently, new platforms to analyze and visualize the satellite images are available from private companies. Goggle Earth Engine is a free tool that combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities and makes it available for scientists, researchers and developers to detect changes, to map trends and to quantify differences on the Earth's surface (Gorelick et al., 2016). Landsat 8 OLI and Sentinel-2 MSI images are also available from Amazon Web Service (AWS) free of charge and anyone can use their on-demand computing resources to perform analysis and create new products without worrying about the cost of storing Landsat data or the time required to download them.

Table 16 List of satellite multispectral sensors that can be used for mapping seagrass. Their spatial resolutions, swath width, band spectral ranges in nm of sensors and panchromatic bands, average revisit days and dynamic ranges are presented.

Satellite	Spatial resolution (m)	Swath width (km)	Multi and panchromatic bands (nm)	Average revisit and dynamic range
WorldView-2 WorldView-3	WV-2 Pan 0.46 Multi 1.85	WV-2 16	Coastal 400 - 450 Blue 450 - 510 Green 510 - 580 Yellow 585 - 625	WV-2 3.7 days 11 bit pixels
	WV-3 Pan 0.34 Multi 1.38	WV-3 13	Red 630 - 690 Red Edge 705 - 745 NIR1 770 - 895 NIR2 860 - 1040 Pan 450 - 800	WV-3 4.5 days 11 bit pixels
GeoEye-1	Pan 0.41 Multi 1.64	15.2	Blue 450 - 510 Green 520 - 580 Red 655 - 690 NIR 780 - 920 Pan 450 - 900	3 days 11 bit pixels
Quick Bird-2	Pan 0.61 Multi 2.4	16.5	Blue 450 - 520 Green 520 - 600 Red 630 - 690 NIR 760 - 900 Pan 450 - 900	3.5 days 11 bit pixels
IKONOS	Pan 1 Multi 4	11.3	Blue 450 - 530 Green 520 - 610 Red 640 - 720 NIR 760 - 860 Pan 450 - 900	3 days 11 bit pixels
Pleiades-1 Pleiades-2	Pan 0.5 Multi 2.8	20	Blue 450 - 530 Green 510 - 590 Red 620 - 700 NIR 775 - 915 Pan 480 - 820	4 days 12 bit pixels
Spot-6 Spot-7	Pan 1.5 Multi 8	60	Blue 455 - 525	26 days 12 bit pixels
			Green 530 - 590	
			Red 625 - 695	
			NIR 760 - 890	
			Pan 455 - 745	

Satellite	Spatial resolution (m)	Swath width (km)	Multi and panchromatic bands (nm)	Average revisit and dynamic range
LANDSAT 8 OLI	Pan 15	180	New Deep Blue (Coastal) 433 - 453	16 days
	Multi 30		Blue 450 - 515 Green 525 - 600 Red 630 - 680 NIR 845 - 885 Pan 500 - 860	12 bit pixels
LANDSAT ETM+	Pan 15	180	Blue 450 - 520	16 days
	Multi 30		Green 530 - 610 Red 630 - 690 NIR 780 - 900 Pan 520 - 900	8 bit pixels
ALOS AVNIR-2 (Multi) PRISM (Pan)	Pan 2.5	70	Blue 420 - 500	46 days
	Multi 10		Green 520 - 600 Red 610 - 690 NIR 760 - 890 Pan 520 - 770	8 bit pixels
Sentinel-2 A & B	Pan	70	Blue 490 (center bandwidth)	46 days
	Multi 10		Green 560 (center bandwidth) Red 665 (center bandwidth) NIR 842 (center bandwidth) Pan (center bandwidth)	8 bit pixels

4.2 Estimation of cost to obtain and analyze satellite images

CEARAC has estimated the cost of analyzing satellite images in case studies in the selected sea areas in the 2014-2015 biennium (Annex). To carry out the case studies in the selected sea areas, close to USD 12,000 of satellite images were purchased and the ship-chartered fee was estimated as USD 6,400. Moreover, scientists spent several months in each case study site to analyze the satellite images with field data for classifying sea floor substrates.

The analysis of satellite images is a long-term process. The entire processes include selecting and obtaining satellite images from space agencies, carrying out a field survey or collecting existing field data, preparing training data sets for classification, removing sun glint and the effect

of water column from satellite images, classifying satellite images and assessing the accuracy of the obtained classification results. Taking into account the time and costs spent in the case studies in the selected sea areas, it is unrealistic to apply the same method to map the distribution of seagrass in the entire NOWPAP coastal zones. Then, we decided to look for other solutions to save time and cost in analyzing satellite images for mapping the distribution of seagrass on a larger scale.

At the first international workshop on the assessment of seagrass distribution in the NOWPAP region held in Himi, Japan on August 3, 2017, Dr. Tatsuyuki Sagaga proposed the use of Google Earth Engine and Amazon Web Services, cloud computing services, for mapping seagrass to analyze satellite images in order to save time and money. Cloud computing has already been used for the terrestrial application of remote sensing. Hansen et al. (2013) mapped global forest changes by using global Landsat data at a 30-meter spatial resolution and characterized forest extent, loss and gain from 2000 to 2012 using Google Earth Engine. They filtered out 654,178 scenes from 1.3M Landsat scenes then further screened these images by clouds, cloud shadows and water to convert them into normalized top of atmosphere reflectance for mapping global forest changes. The entire process of analyzing satellite images took only a few days with the Google Earth Engine in which a single computer would have taken 15 years.

While the cost of purchasing some satellite images of commercial satellite sensors is expensive, satellite images taken by non-commercial satellite sensors such as Landsat Thematic Mapper, Enhanced Thematic Mapper Plus and Operational Land Imager and Sentinel-2 MSI are freely available. Therefore, it is suggested to start using these freely available satellite images first before purchasing expensive images taken by commercial satellite sensors. Free satellite images were used in the case studies in Swan Lake, Nanao Bay, Deukryang Bay and the eastern section of the Far Eastern Marine Reserve in Russia. Although the spatial resolution of these Landsat optical sensors is 30 m, the case studies demonstrated that freely available Landsat sensors can detect seagrass beds distributed on a large scale. Moreover, the spatial resolution of freely available satellite sensors has improved up to 10 m with the advent of the Multispectral Imager (MSI) on board the Sentinel-2 satellite of the European Space Agency that has similar wavelengths and the same geographic coordinate system as the Landsat optical sensors. Topouzelis et al. (2016) has demonstrated the use of the MSI for mapping seagrass in the Kalloni Gulf in Greece.

Thus, using the freely available satellite sensors in conjunction with the cloud computing services is expected to start for mapping the distribution of seagrass in the NOWPAP region.

4.3 Potential collaborators

Mapping the distribution of seagrass is a monumental task. Therefore, it is ideal to have a collaborative framework by stakeholders to improve efficiency in the process of mapping the distribution of seagrass. The stakeholders can be voluntary citizen groups, NPOs and NGOs

working on the conservation and restoration of seagrass at international, regional, national and local levels.

Seagrass-Watch established in 1998 is the largest scientific, non-destructive seagrass assessment and monitoring program in the world. This program aims to raise awareness on the condition and trends of nearshore seagrass ecosystems and provide an early warning of major coastal environment changes. Manuals for monitoring and assessment of seagrass are available on the Seagrass-Watch website. In addition, Project Seagrass is an environmental charity devoted to the conservation of seagrass ecosystems through education, influence, research and action. Seagrass Spotter is a tool developed by Project Seagrass and it is available for the public to collect field data of seagrass on a worldwide scale using smart phones. These organizations are potential collaborators in collecting and exchanging field data of seagrass. In the NOWPAP region, CEARAC has constructed the prototype of a seagrass database on the regional scale (<http://map.nowpap3.go.jp/>). The prototype database aggregates field data of seagrass to help reduce the time spent on the collection of field data containing the collected information on seagrass distribution through the literature reviews in the NOWPAP member states. CEARAC is expecting to establish a collaborative network with national and local organizations to enrich the database.

The analysis of satellite images for mapping the distribution of seagrass requires knowledge of remote sensing. The developed manual for mapping of seagrass and seaweed bed distribution with satellite images contributed to standardizing the procedures in analyzing satellite images. However, for disseminating the use of the developed manual, it is necessary to carry out capacity building activities such as the organization of training courses. CEARAC has conducted a series of training courses on remote sensing for marine environment conservation in the NOWPAP region with international, regional and national partners such as IOC/WESTPAC, PICES, YSLME, JAXA, KIOST and national universities in the NOWPAP member states. It is suggested to continue similar training courses collaboratively in the future to disseminate the use of satellite images for mapping the distribution of seagrass in the NOWPAP region.

4.4. Possible funding options

Although some satellite images for mapping the distribution of seagrass are becoming freely available today, the analysis of those images still requires manpower which often depends on funding resources. The conservation of seagrass habitats is related to two conventions: the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC).

CBD provides a list of potential funding sources in the “Catalogue of Funding Sources” on the website. These funding sources can be used for activities related to biodiversity conservation. The development of a practical mapping tool for using freely available satellite images or carrying out

capacity building activities of CEARAC is also conservation-related. However, the use of UNFCC related funds is likely to be limited to blue carbon accounting. Therefore, the latter funds require a methodology to estimate carbon storage and emission from the seagrass system through seagrass mapping in NOWPAP.

5. Conclusion and recommendation

5.1. Conclusions

The feasibility of assessment of seagrass distribution in the entire NOWPAP region was evaluated in 2016-2017 biennium as one of CEARAC's specialized projects.

To grasp the availability of field data on seagrass, which is helpful for mapping the distribution of seagrass by using satellite images, literature reviews were first carried out by the national experts in each NOWPAP member state. Through this process, seagrass species observed in the NOWPAP region were listed up and threats to seagrass in the NOWPAP region were reviewed.

Case studies carried out in the selected sea areas in the NOWPAP member states indicated that freely available Landsat optical sensors data were useful for monitoring seagrass beds and the application of water column correction methods of DII and BRI methods improved the accuracy of the results. Consolidation of the classification method was also suggested to estimate seagrass distribution.

From the analysis of cost to map seagrass distributions by using satellite images in the selected sea areas in the NOWPAP region, it is unrealistic to take the conventional approach for obtaining and analyzing satellite images to map seagrass distributions in the entire NOWPAP coastal zones. Instead, it is suggested to use cloud computing services and freely available satellite images for mapping seagrass distributions in the NOWPAP region to save the time and money required to analyze satellite images.

5.2. Recommendations

- Use of freely available multi-spectral satellite images such as Landsat 8 OLI and Sentinel-2 MSI is encouraged.
- Collection and maintenance of field database of seagrass is essential and needs to be continued to help prepare training data for classifying satellite images.
- Use of a standardized procedure in analyzing satellite images with the manual developed under CEARAC activity is necessary.
- Use of cloud computing technology for analysis of satellite images is recommended to reduce the time and cost required to map the distribution of seagrass.
- Development of a web-based common tool to map the distribution of seagrass is expected.
- Mapping of seagrass can be enhanced through capacity development activities for young scientists and the public.

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