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Feasibility Study for Assessment of Seagrass Distribution in the NOWPAP Region

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Front cover photo:
Zostera marina and *sargassum* beds in Nanao Bay, Japan taken by Genki Terauchi

Photos of major seagrass species in the NOWPAP region (Page 8):
Photos of *Zostrera marina*, *Zostera japonica*, *Zostera caespitosa* and *Phyllospadix iwatensis* were taken by Genki Terauchi. Photos of *Zostera asiatica* and *Zostera caulescens* were provided by Teruhisa Komatsu. Photo of *Halophila ovalis* was taken by Wataru Matsumura.

Table of Contents of the Feasibility Study for
Assessment of Seagrass Distribution in the NOWPAP Region

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 Northwest Pacific 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 Centre of NOWPAP (NOWPAP CEARAC). The objective of this activity was to investigate the usefulness of satellite images for the assessment of seagrass distribution in the NOWPAP region and to 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 11 species of seagrasses reported in the NOWPAP region, six species were categorized as either threatened or near threatened in the IUCN 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 NOWPAP 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 IOC/WESTPAC regions. The time and cost to analyze satellite images for mapping seagrass were then estimated based on the case studies in the 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 carbon dioxide 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 are becoming well recognized among the public. Hence, 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 Conservation of Nature (IUCN) and the Intergovernmental Oceanographic Commission of the United Nations 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 Nations Ocean Conference (June 5-9, 2017, New York) toward the implementation of Sustainable Development Goal 14 for the conservation 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 Centre (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 seagrass, a manual for seagrass and seaweed beds distribution mapping 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 from 2015 to 2016 (as presented in

Chapter 3 of this report). 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. Collection 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 towards assessment of seagrass distribution in the NOWPAP region (UNEP/NOWPAP/CEARAC/FPM 14/9 Annex VIII), information of seagrass species in the NOWPAP sea area was collected from the literature by the national experts shown in Table 1. Literature written in English and the languages of the NOWPAP member states was collected and organized in a 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. NOWPAP 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 conducted 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 area, it is necessary to estimate the time and cost required to analyze satellite images. The entire process of analyzing satellite images for mapping seagrass includes 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 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 Ecologically or Biologically Significant marine Areas (EBSAs) 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 of NOWPAP CEARAC, 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 the 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 Focal Points (FPs) and NOWPAP National Focal Points (FPs) 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 the literature review by the national experts in each NOWPAP member state nominated by CEARAC FPs. Table 2 shows the total number of literatures, the ratios of literature in English and native languages and the ratios of papers, reports or books among the literature. Table 3 and Figure 1 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% (Table 3). In addition, complementary information was collected from the “World Atlas of Seagrasses” (Green and Short, 2003) in the cases of Japan and Korea.

The information of collected seagrass species in the NOWPAP region was then compared with the category in the IUCN Red List of Threatened Species (IUCN Red List).

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

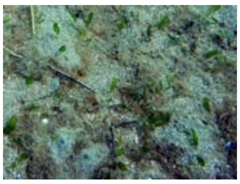
Country	Total No. of literatures	Ratio of literatures in English (%)	Ratio of literatures in native languages (%)	Ratio of papers among literatures (%)	Ratio of reports among literatures (%)	Ratio of books among literatures (%)
China	20	0	100	95	0	5
Japan	28	7	93	14	82	4
Korea	13	46	54	92	0	8
Russia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

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	*Zostera marina*	21	46.7
		Zostera japonica	7	15.6
		Zostera caespitosa	6	13.3
		Phyllospadix japonicus	4	8.9
		Phyllospadix iwatensis	7	15.5
		Total	45	100.0
Japan	10	*Zostera marina*	341	45.7
		Zostera japonica	131	17.6
		Zostera caespitosa	73	9.8
		Zostera asiatica	17	2.3
		Zostera caulescens	10	1.3
		Phyllospadix japonicus	41	5.5
		Phyllospadix iwatensis	72	9.7
		Halophila nipponica	10	1.3
		Halophila ovalis	50	6.7
		Halodule uninervis	1	0.1
		Total	746	100.0
Korea	6	*Zostera marina*	28	59.6
		Zostera japonica	5	10.6
		Zostera caespitosa	1	2.1
		Zostera asiatica	1	2.1
		Zostera caulescens	6	12.8
		Halophila nipponica	6	12.8
		Total	47	100.0
Russia	4	*Zostera marina*	59	62.8
		Zostera japonica	11	11.7
		Zostera asiatica	20	21.3
		Phyllospadix iwatensis	4	4.2
		Total	94	100.0

* One species may be reported in multiple literatures.

Major seagrass species in the NOWPAP Region.

 *Zostera marina*	*Zostera marina* is a seagrass species widespread throughout the NOWPAP region and occurs throughout the coastal areas of China, Japan, Korea and the Russian Far East. *Zostera marina* is listed as a species of "Least Concern" on the IUCN Red List.
 *Zostera japonica*	*Zostera japonica* occurs throughout the coastal areas of China, Japan, Korea and the Russian Far East. *Zostera japonica* is listed as a species of "Least Concern" on the IUCN Red List.
 *Zostera caespitosa*	*Zostera caespitosa* occurs in the coastal areas of China, Japan and Korea. *Zostera caespitosa* is listed as a "Vulnerable" species on the IUCN Red List.
 *Zostera asiatica*	*Zostera asiatica* occurs in the coastal areas of Japan, Korea and the Russian Far East. *Zostera asiatica* is listed as a "Near Threatened" species on the IUCN Red List.
 *Zostera caulescens*	*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.
 *Phyllospadix iwatensis*	*Phyllospadix iwatensis* occurs in the coastal areas of China, Japan and Korea. *Phyllospadix iwatensis* is listed as a "Vulnerable" species on the IUCN Red List.
 *Halophila ovalis*	*Halophila ovalis* is a seagrass species widespread throughout the NOWPAP region and found throughout the coastal areas of China, Japan, Korea and the Russian Far East. *Halophila ovalis* is listed as a species of "Least Concern" on the IUCN Red List.

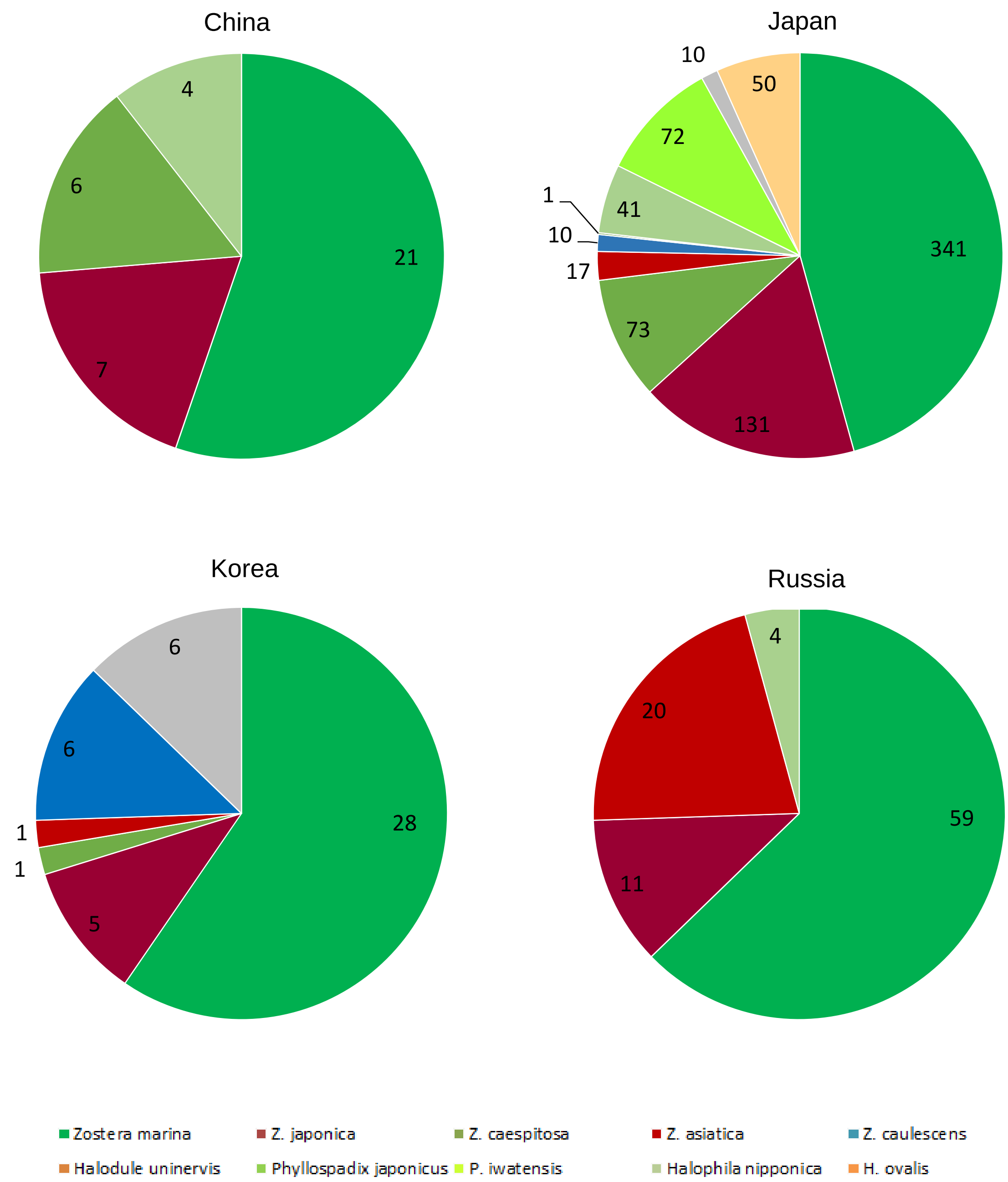


Figure 1 Seagrass species and their occurrences in the NOWPAP region.

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 Figure 2 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 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

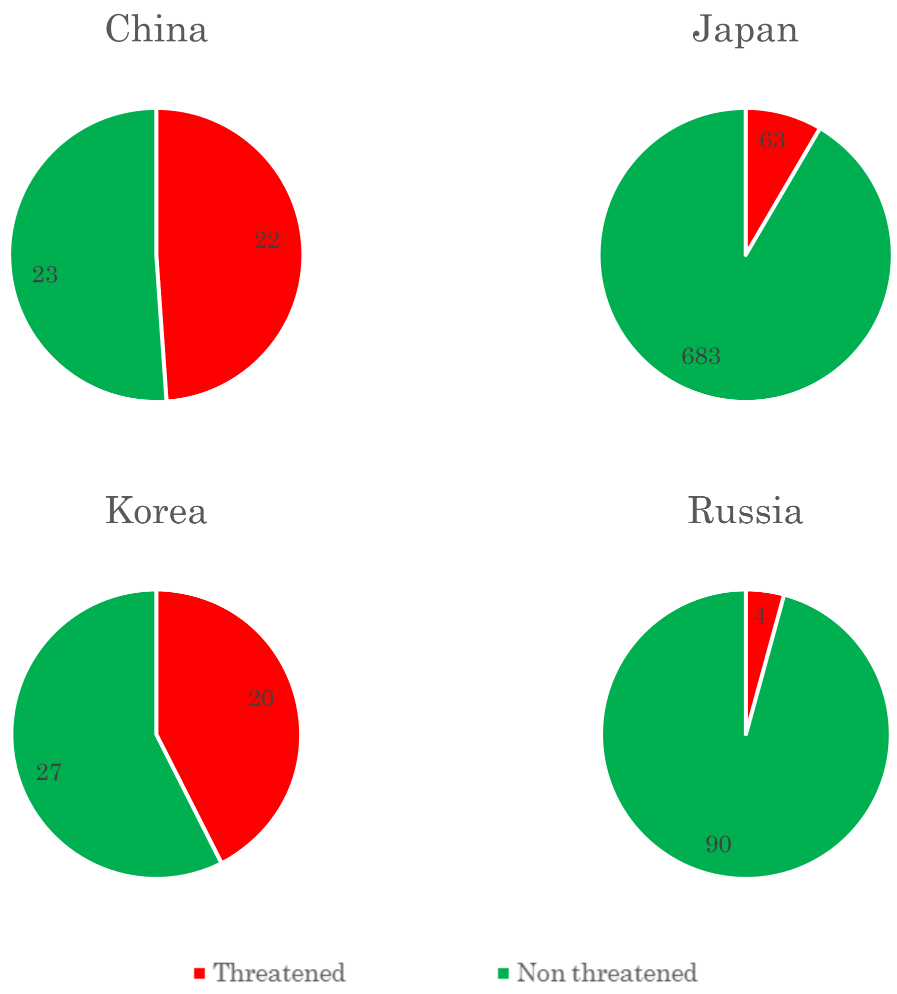


Figure 2 Records of threats to seagrass in the NOWPAP region.

2.1. Seagrass species in the NOWPAP region

2.1.1. 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.

It is worth to mention that Zheng *et al*. (2013) detailed 22 seagrass species in China, including all five species shown in Table 3 and Table 5.

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

Species	**Distribution**	**Category* in the IUCN Red List**
Zosteraceae		
Zostera marina	Yellow Sea and Bohai Sea	LC
Zostera japonica	South China Sea, Yellow Sea and Bohai Sea	LC
Zostera caespitosa	Yellow Sea and Bohai Sea	VU
Phyllospadix japonicus	Yellow Sea and Bohai Sea	EN
Phyllospadix iwatensis	Yellow Sea and Bohai Sea	VU

* Category: Least Concern (LC), Endangered (EN), Vulnerable (VU).

COMPARISON WITH THE IUCN RED LIST

It was revealed that the distributions of the five species of seagrasses in China shown in Table 5 are consistent with the spatial distributions of the IUCN Red List. For example, the spatial distribution of *P. iwatensis* is shown in light brown in Figure 3 (IUCN, 2017).

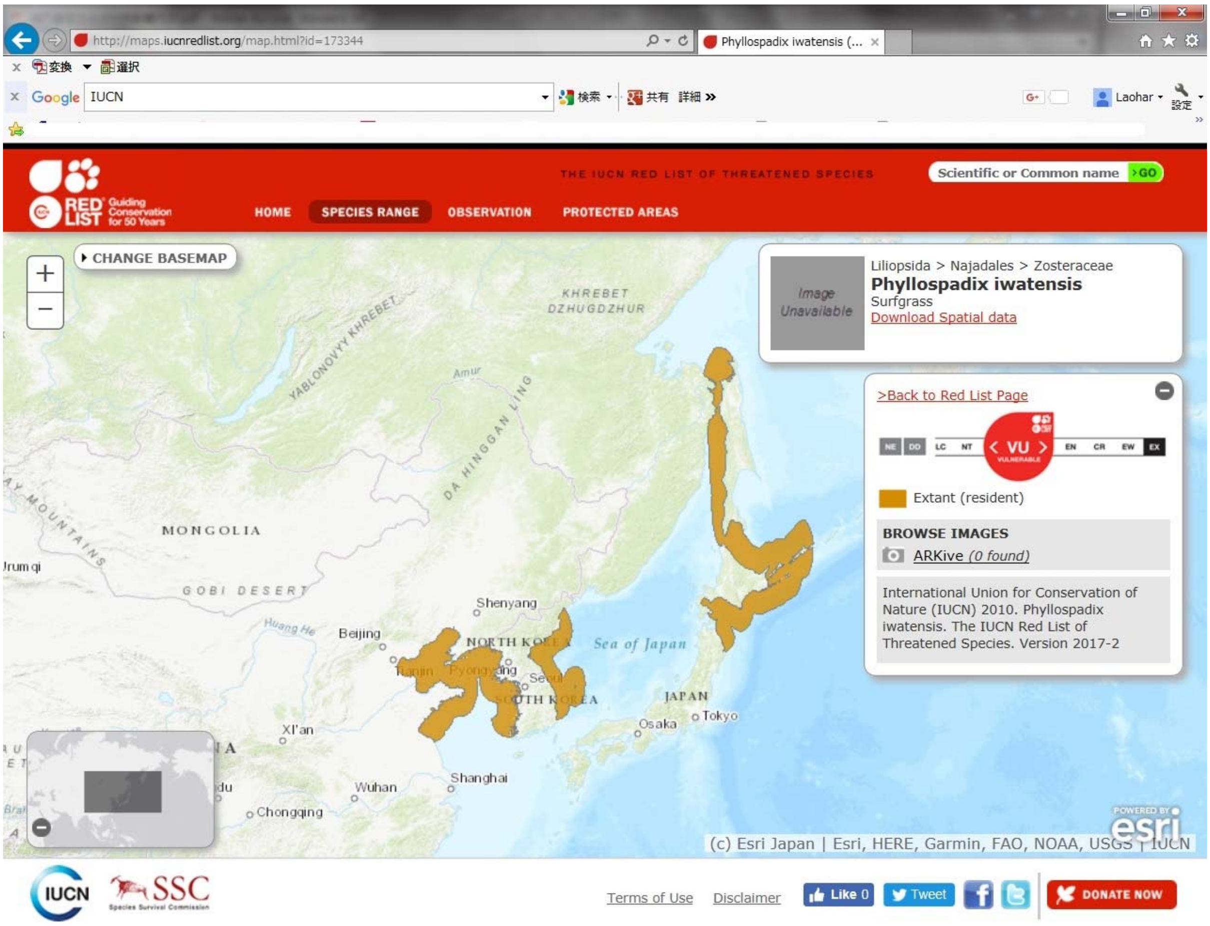


Figure 3 Spatial distributions of *Phyllospadix iwatensis* in the IUCN Red List.

In addition, by comparing with the 15 seagrass species categorized as threatened (EN: Endangered or VU: Vulnerable) or near threatened (NT) in the IUCN Red List shown in Table 6, *Z. caespitosa, P. japonicus* and *P. iwatensis* occurring in the coastal waters of China are categorized either Endangered (EN) or Vulnerable (VU) as shown in Table 5.

Table 6 15 Seagrass species categorized as either threatened (EN: Endangered or VU: Vulnerable) or near threatened (NT) in the IUCN Red List of the Threatened Species (Short *et al.*, 2011).

Family	Species name	Category* in the IUCN Red List
ZOSTERACEAE	*Phyllospadix japonicus*	EN
ZOSTERACEAE	*Zostera chilensis*	EN
ZOSTERACEAE	*Zostera geojeensis*	EN
HYDROCHARITACEAE	*Halophila baillonii*	VU
HYDROCHARITACEAE	*Halophila beccarii*	VU
HYDROCHARITACEAE	*Halophila hawaiiana*	VU
POSIDONIACEAE	*Posidonia sinuosa*	VU
ZOSTERACEAE	*Phyllospadix iwatensis*	VU
ZOSTERACEAE	*Zostera capensis*	VU
ZOSTERACEAE	*Zostera caespitosa*	VU
HYDROCHARITACEAE	*Halophila engelmanni*	NT
HYDROCHARITACEAE	*Halophila nipponica*	NT
POSIDONIACEAE	*Posidonia australis*	NT
ZOSTERACEAE	*Zostera asiatica*	NT
ZOSTERACEAE	*Zostera caulescens*	NT

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

2.1.2. 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 the Environment of Japan conducted surveys on the ecosystems in shallow waters in order to understand the presence and the biological diversity of seagrass and seaweed beds in more than 120 places around the Japanese coast. The Ministry of the Environment of Japan summarized the final report in 2008 (Ministry of the Environment of Japan, 2008), in which 15 seagrass species were reported. Distributions of those 15 seagrass species were observed from Aomori Bay of Aomori Prefecture 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	**Category* in the IUCN Red List**
Zosteraceae	
Zostera marina	LC
Zostera japonica	LC
Zostera caespitosa	VU
Zostera asiatica	NT
Zostera caulescens	NT
Phyllospadix japonicus	EN
Phyllospadix iwatensis	VU
Hydrocharitaceae	
Halophila nipponica	NT
Halophila ovalis	LC
Cymodoceaceae	
Halodule uninervis	LC

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

COMPARISON WITH THE IUCN RED LIST

It was revealed that the distributions of all species of seagrasses in Japan shown in Table 7 are consistent with the spatial distributions of the IUCN Red List (IUCN, 2017).

Also, according to Table 6, six threatened or near threated seagrass species (*Z. caespitosa, Z. asiatica, Z. caulescens, P. japonicas*, *P. iwatensis and Halophila nipponica*) occur in coastal waters of Japan.

2.1.3. 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 (Table 3).

Nevertheless, 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 (*Phyllospadix 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.

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, *Z. 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. *P. 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

COMPARISON WITH THE IUCN RED LIST

It was revealed that the distributions of all species of seagrasses in Korea are consistent with the spatial distributions of the IUCN Red List (IUCN, 2017) (Table 8).

Also, according to Table 6, six threatened or near threatened seagrass species (*Z caespitosa, Z. asiatica, Z. caulescens, P. japonicus, P. iwatensis* and *H. nipponica*) occur in the coastal waters of Korea.

Table 8 Seagrass species and their distribution in the NOWPAP region of Korea.

Species	Distribution	Category* in the IUCN Red List
Zosteraceae		
Zostera marina	All coasts	LC
Zostera japonica	All coasts	LC
Zostera caespitosa	All coasts	VU
Zostera asiatica	East coast	NT
Zostera caulescens	All coasts	NT
Phyllospadix japonicus	All coasts	EN
Phyllospadix iwatensis	East and West coasts	VU
Hydrocharitaceae		
Halophila nipponica	South coast	NT
Ruppiaceae		
Ruppia maritima	West and south coasts	LC

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

2.1.4. Seagrasses of Russia

SPECIES AND DISTRIBUTION

There are four dominant seagrass species distributed along the coasts of Peter the Great Bay of Russian Far East 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 distribution in the NOWPAP region of Russia.

Species	Distribution	Category* in the IUCN Red List
Zosteraceae		
Zostera marina	Peter the Great Bay, Russian Far East, Western coast of South Sakhalin Island	LC
Zostera japonica	Peter the Great Bay, Russian Far East	LC
Zostera asiatica	Peter the Great Bay, Russian Far East	NT
Phyllospadix iwatensis	Russian Far East, Western coast of South Sakhalin Island	VU

*Category: Least Concern (LC), Vulnerable (VU), Near Threatened (NT).

COMPARISON WITH THE IUCN RED LIST

It was revealed that the distributions of all species of seagrasses in Russia are consistent with the spatial distributions of the IUCN Red List (IUCN, 2017) (Table 9).

Also, according to Table 6, two threatened or near threatened seagrass species (*Z. asiatica* and *P. 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				
Zostera marina	✓	✓	✓	✓
Zostera japonica	✓	✓	✓	✓
Zostera caespitosa	✓	✓	✓	
Zostera asiatica		✓	✓	✓
Zostera caulescens		✓	✓	
Phyllospadix japonicus	✓	✓	✓	
Phyllospadix iwatensis	✓	✓	✓	✓
Hydrocharitaceae				
Halophila nipponica		✓	✓	
Halophila ovalis		✓		
Cymodoceaceae				
Halodule uninervis		✓		
Puppiaceae				
Ruppia maritima			✓	

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 cause water pollution and poor water exchange. Seaweed aquaculture may compete for nutrients with seagrass resources, which leads to threatening 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 and such 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).

In addition, the existing studies have shown that land-based fish culture, industrial and domestic sewage, and so on also affect water quality and sediments, which cause degradation of seagrass meadows. Global climate change is also considered as another 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 the 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 *P. iwatensis* resulting from removing seagrasses with chains in kelp farms around Rishiri Island, Hokkaido Prefecture. Kunii (2001) reported that seagrasses grow in waterways in reclaimed land. As time passed, salinity decreased. 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 Photosynthetically Active Radiation (PAR) by coverage of sediment on the leaves. Decrease of seagrass meadows was 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 the Environment of Japan reported that feeding of herbivorous fishes on *Z. caulescens* are a cause of the decrease (Ministry of the Environment of Japan, 2008).

Table 12 Records of threats to seagrass in Japan.

Year	Location	Details of Threats	Causes
1983	Rishiri Island, Hokkaido Pref.	Seagrass disappearance	Removing seagrasses with chains in kelp farms
2001	Lakes Shinji & Nakaumi, Shimane Pref.	Seagrass disappearance	Decreasing salinity
2005	Maizuru Bay, Kyoto Pref.	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

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 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 in Jangheung 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 14. According to Table 4, 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 in aquaculture of sea scallops and mussels is reported (Zharikov and Preobrazhensky, 2010). Large populations of *Z. 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

Threats to seagrass 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 selected sea areas in the NOWPAP region

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

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. 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 NOWPAP 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 collection of ground truthing data and procedures to analyze satellite images including classification of images and validation of accuracy. The developed manual was shared among the national experts nominated by CEARAC FPs to carry out case studies 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

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.

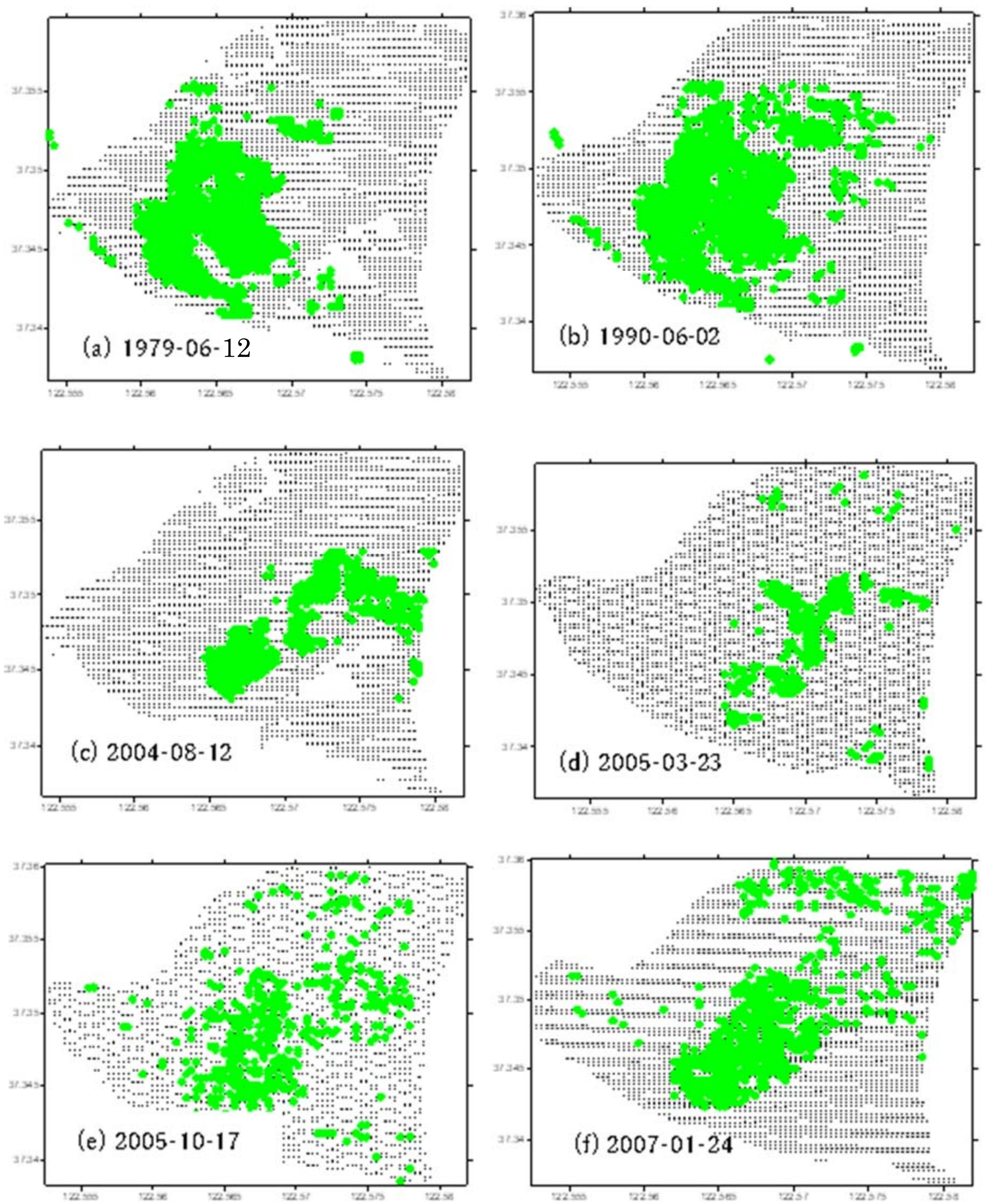
Country	Experts	Selected sea areas
China	State Key Laboratory of Tropical Oceanography, South China Sea Institute of Oceanology, Chinese Academy of Sciences Dr. Dingtian Yang	Swan Lake (Head of the Shandong Peninsula)
Japan	Northwest Pacific Region Environmental Cooperation Center Dr. Tsuneo Maeda, Dr. 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 the 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 Multi Spectral Scanner (MSS) and Blue and Green for Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) was used for correction of the water column by Lyzenga's method (Lyzenga, 1978, 1981). 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.

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 dense seagrass was found in the central area of the Swan Lake, it was rather sparse in other areas. Case study results demonstrate that seagrass appeared in the southeastern and central areas of Swan Lake in 1979 and 1989 (Figure 4). 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 loss of seagrass 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.



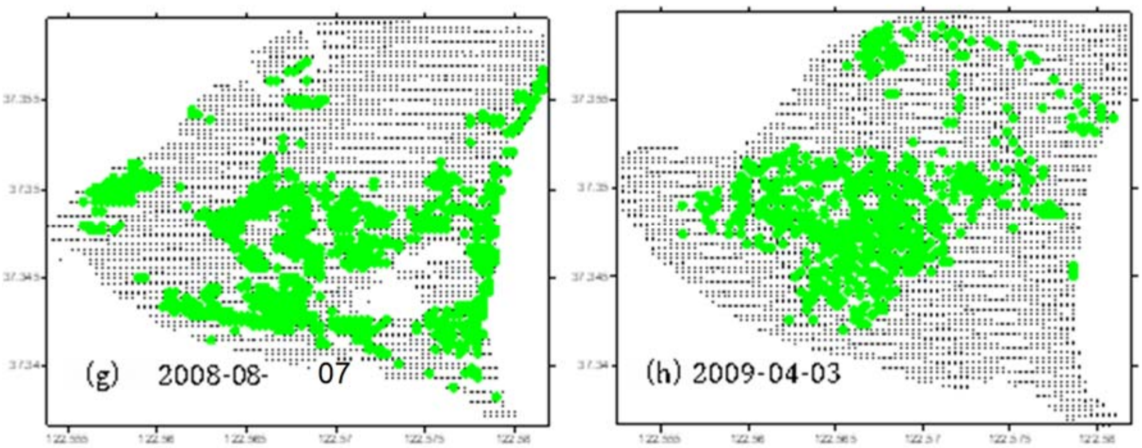


Figure 4 Seagrass (green spots in the figures) distributions inferred from the satellite remote sensing data in Swan Lake on (a) June 12, 1979, (b) June 2, 1990, (c) August 12, 2004, (d) March 23, 2005; (e) October 17, 2005, (f) January 24, 2007, (g) August 7, 2008 and (h) April 3, 2009.

3.2.2. Toyama Bay and Nanao Bay, Japan

Toyama Bay is a deep-water bay located at the eastern foot of the Noto Peninsula. The total surface area of Toyama Bay is approximately 2,120 km^2 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 km^2 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 (CBD). Dense seagrass distributions have been observed in the western part of Himi area in Toyama Bay and the west bay area in Nanao Bay. These areas were selected for the case studies of NOWPAP CEARAC on seagrass mapping with satellite images in Japan.

In 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, 2012) 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 (Figure 5). 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 for a year after the GeoEye-1 sensor observed this area on November 2, 2014. 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 the 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 (Figure 6). 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). 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 locations 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.

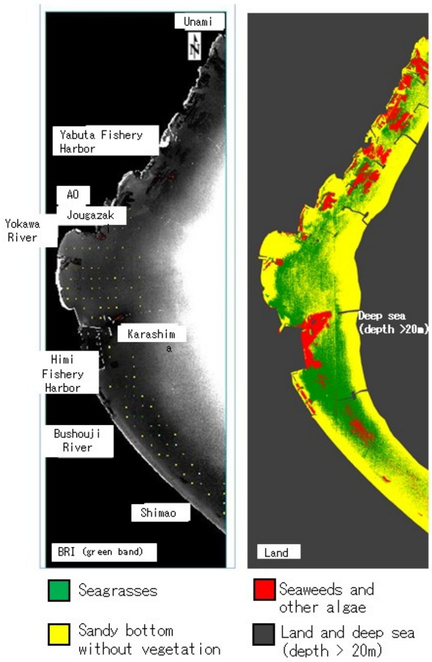


Figure 5 Seagrass distributions detected by the supervised classification with Blue and Green bands of GeoEye-1 taken on November 22, 2014 corrected with the radiometric correction method of the BRI band. The BRI corrected green band (left) and classification results of bottom substrates (right).

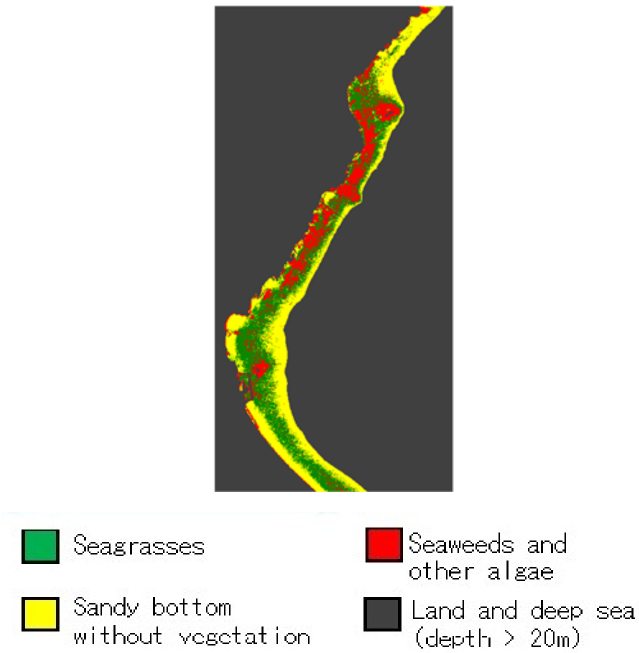


Figure 6 Seagrass distributions detected by the supervised classification of Blue and Green bands of RapidEye taken on March 17, 2016 corrected with the radiometric correction method of the BRI method.

In Nanao Nishi Bay located in the west area of Nanao Bay, the Landsat Operational Land Imager (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 the seagrass class. Seagrass beds smaller than 30 x 30 m and sandy bottom without vegetation were allocated to the 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 the radiometric correction method of the Depth Invariant Index (DII) (Lygenga, 1981; Mumby and Edwards, 2000) consisting of atmospheric and water column corrections. The obtained results of bottom substrate classification (Figure 7) 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 1,042 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.

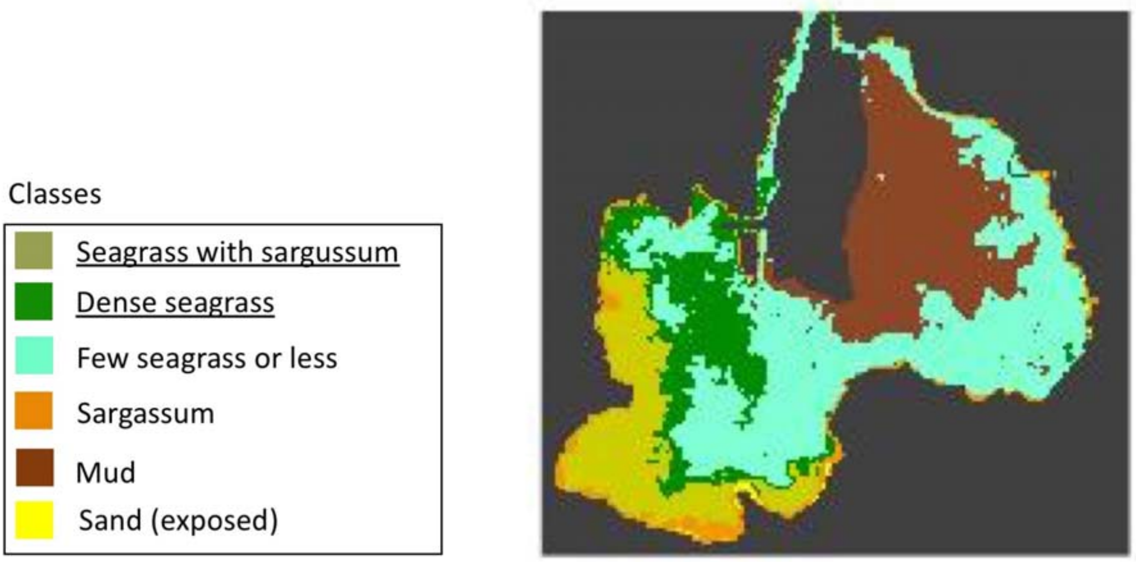


Figure 7 Results obtained by the supervised classification of band ratios of Green/Blue, Green/Red, Blue/Red and Green/Coastal corrected with a radiometric correction method of the Depth Invariant Index (DII) of Landsat 8 OLI on June 1, 2015.

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, 2003). 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, the K means unsupervised classification was used for mapping the seagrass distribution using Red, Green and Blue bands without water column corrections. Pixels of the Landsat OLI image of June 1, 2016 were then classified 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 distributions 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 one 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 (Figure 8) and from November 21, 2014 to June 1, 2015 (Figure 9) 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.

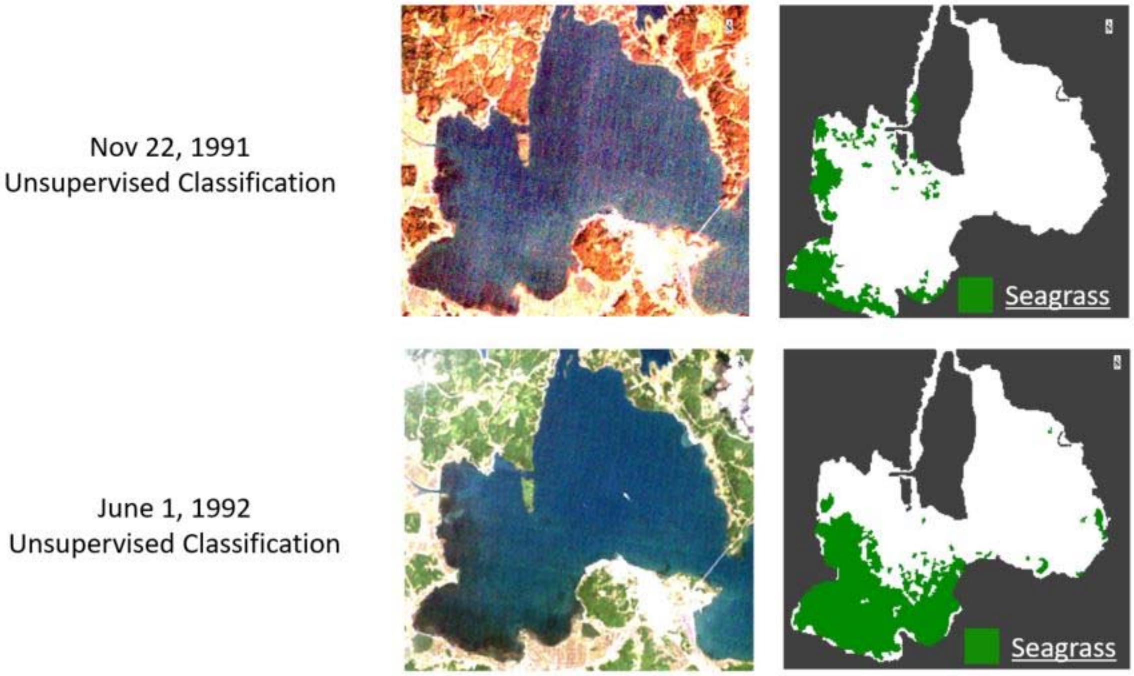


Figure 8 Comparison of seasonal patterns of seagrass distribution from November 22, 1991 to June 1, 1992.

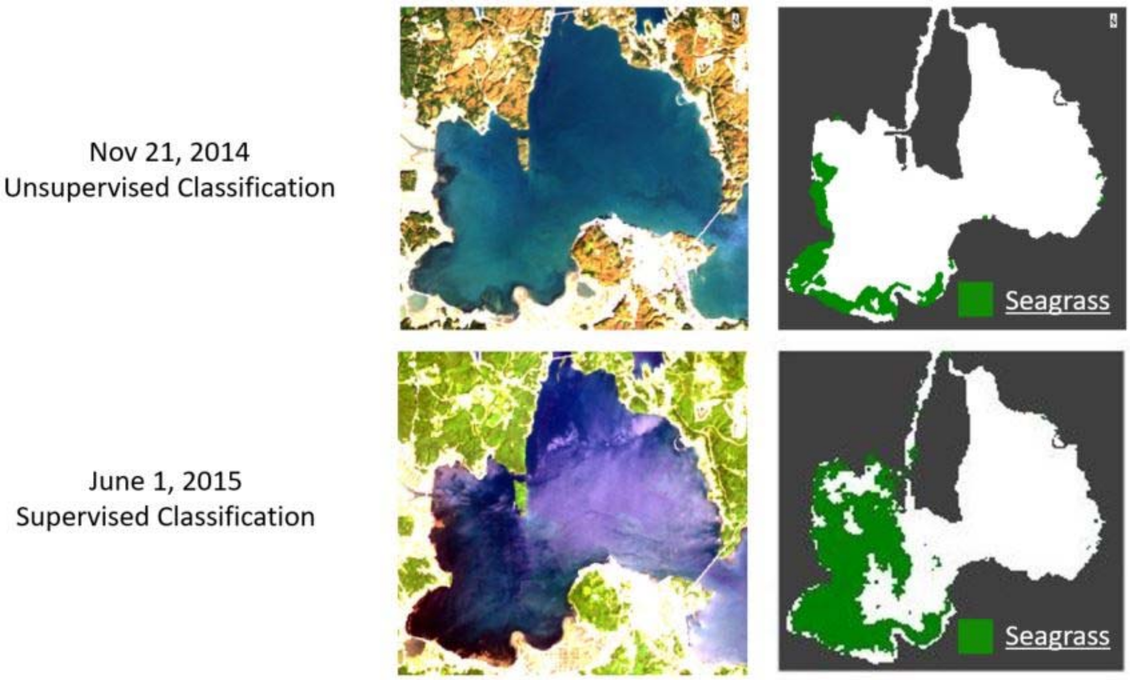


Figure 9 Comparison of seasonal patterns of seagrass distribution from November 21, 2014 to June 1, 2015.

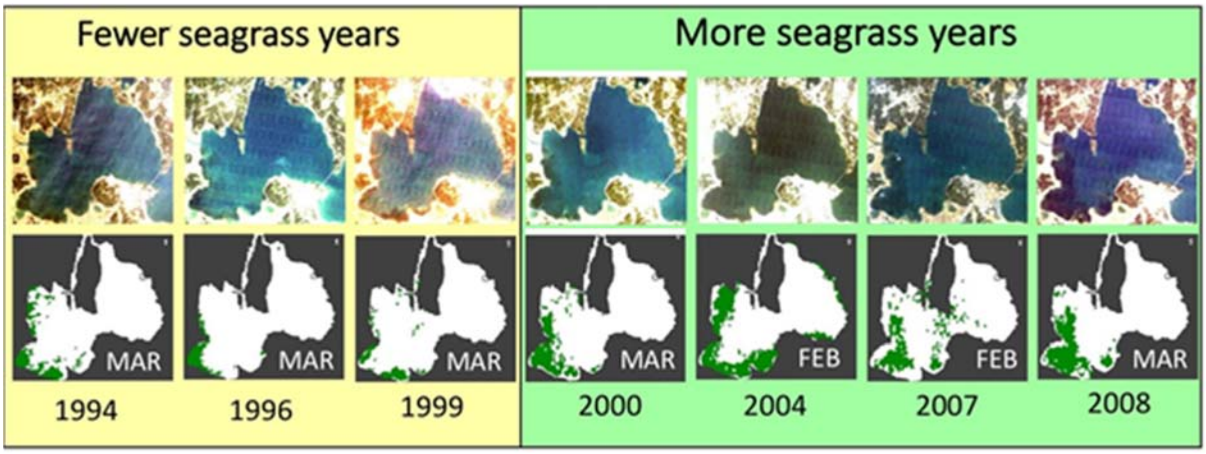


Figure 10 Interannual variability of seagrass distribution in February and March from 1994 to 2008 mapped by unsupervised classification.

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 distributions 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 (Figure 10).

3.2.3. Deukryang Bay, Korea

Deukryang Bay is located on the southern coast of the Korean Peninsula and surrounded by small villages. *Z. 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 and ETM+ images were analyzed to detect the seagrass distribution of Deukryang Bay. The radiometric correction of the DII was applied to all the collected images and the results showed that accuracies of any classification methods increased when the 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 the 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 changes 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 (Figure 11). 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.

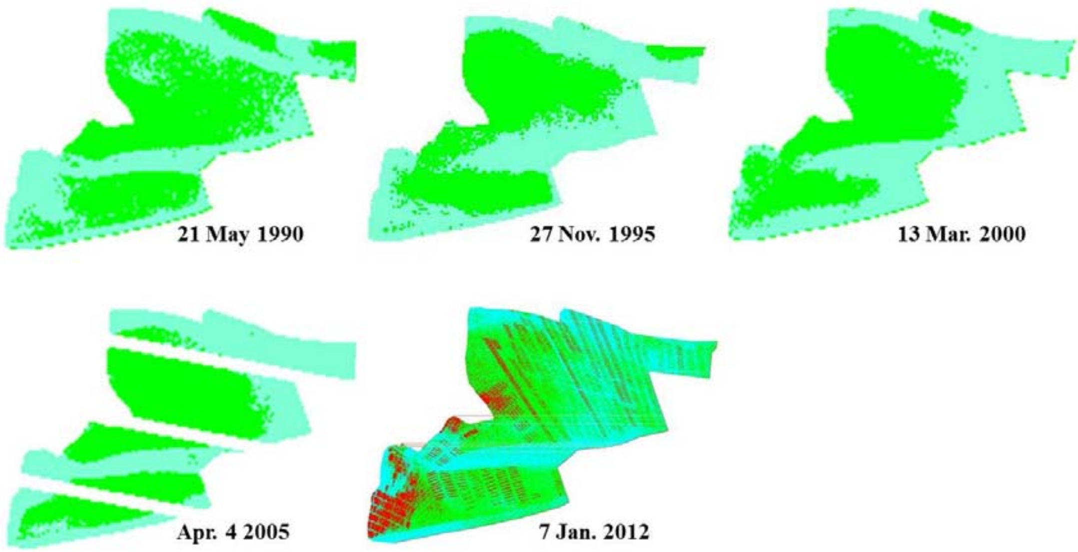


Figure 11 Changes in the spatial distribution of seagrass beds in the study area from 1990 to 2012 mapped with Landsat TM/ETM+. Light green indicates the distribution of seagrass and red indicates aquaculture rafts.

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: *Z. marina*, *Z. asiatica* and *Z. 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 the DII and the BRI were applied in the eastern section of the Far Eastern Marine Reserve 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 (Figure 12). 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 the areas occupied by seagrasses were 98 ha and were much smaller than those 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 (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.

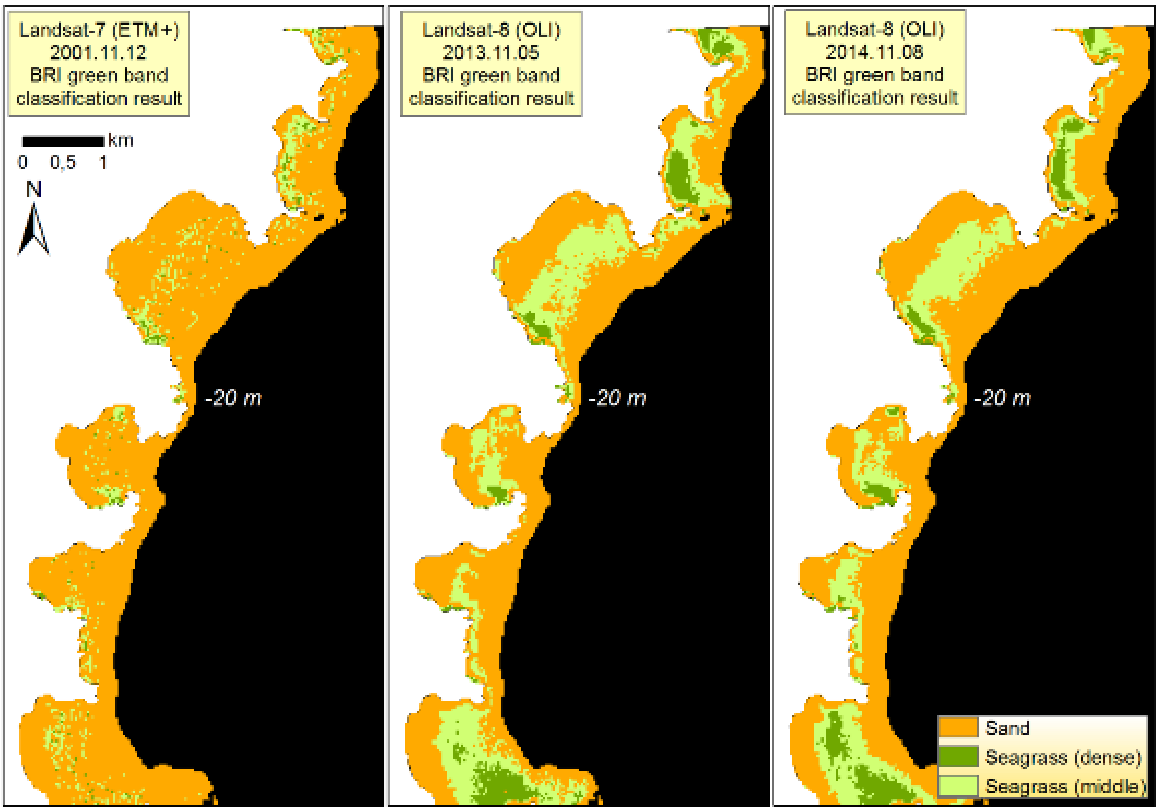


Figure 12 Maps showing distributions of seagrasses in 2001, 2013 and 2014 obtained by applying radiometric correction based on the Bottom Reflectance Index method.

4. For 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 a 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 Sentinnel-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 satellite images are available from private companies. Google Earth Engine (GEE) 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 trends and quantify differences on the Earth's surface (Gorelick *et al.*, 2016). Landsat 8 OLI and Sentinnel-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-3 Pan 0.34 Multi 1.38	WV-2 16 WV-3 13	Coastal Blue Green Yellow Red Red Edge NIR1 NIR2 Pan	400 - 450 450 - 510 510 - 580 585 - 625 630 - 690 705 - 745 770 - 895 860 - 1040 450 - 800	WV-2 3.7 days 11 bit pixels WV-3 4.5 days 11 bit pixels
GeoEye-1	Pan 0.41 Multi 1.64	15.2	Blue Green Red NIR Pan	450 - 510 520 - 580 655 - 690 780 - 920 450 - 900	3 days 11 bit pixels
Quick Bird-2	Pan 0.61 Multi 2.4	16.5	Blue Green Red NIR Pan	450 - 520 520 - 600 630 - 690 760 - 900 450 - 900	3.5 days 11 bit pixels
IKONOS	Pan 1 Multi 4	11.3	Blue Green Red NIR Pan	450 - 530 520 - 610 640 - 720 760 - 860 450 - 900	3 days 11 bit pixels
Pleiades-1 Pleiades-2	Pan 0.5 Multi 2.8	20	Blue Green Red NIR Pan	450 - 530 510 - 590 620 - 700 775 - 915 480 - 820	4 days 12 bit pixels
Spot-6 Spot-7	Pan 1.5 Multi 8	60	Blue Green Red NIR Pan	455 - 525 530 - 590 625 - 695 760 - 890 455 - 745	26 days 12 bit pixels

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	12 bit pixels
			Red	630 - 680	
			NIR	845 - 885	
			Pan	500 - 860	
LANDSAT ETM+	Pan 15	180	Blue	450 - 520	16 days
	Multi 30		Green	530 - 610	8 bit pixels
			Red	630 - 690	
			NIR	780 - 900	
			Pan	520 - 900	
ALOS AVNIR-2 (Multi) PRISM (Pan)	Pan 2.5	70	Blue	420 - 500	46 days
	Multi 10		Green	520 - 600	
			Red	610 - 690	8 bit pixels
			NIR	760 - 890	
			Pan	520 - 770	
Sentinel-2 A & B	Pan	70	Blue	490 (center bandwidth)	46 days
	Multi 10		Green	560 (center bandwidth)	
			Red	665 (center bandwidth)	8 bit pixels
			NIR	842 (center bandwidth)	
			Pan	(center bandwidth)	

4.2 Estimation of cost to obtain and analyze satellite images

NOWPAP CEARAC has estimated the cost of analyzing satellite images in the case studies in the selected sea areas in the 2014-2015 biennium. To carry out the case studies in the selected sea areas, close to 12,000 US dollars of satellite images were purchased and the ship-chartered fee was estimated as 6,400 US dollars. Moreover, the national experts of the NOWPAP member states 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 process includes 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 costs in analyzing satellite images for mapping the distribution of seagrass on a larger scale.

At the first international workshop on assessment of seagrass distribution in the NOWPAP region held in Himi, Japan on August 3, 2017, Dr. Tatsuyuki Sagaga proposed the GEE and the AWS, 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 the GEE. 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 GEE in which a single computer would have taken 15 years.

While the cost of purchasing some satellite images of commercial satellite sensors is high, satellite images taken by non-commercial satellite sensors such as Landsat TM, ETM+ and OLI and Sentinel-2 Multispectral Imager (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 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) have 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 (www.seagrasswatch.org/). In addition, Project Seagrass (https://www.projectseagrass.org/) 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 can be potential collaborators in collecting and exchanging field data of seagrass. In the NOWPAP region, NOWPAP 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 collection of field data containing the collected information on seagrass distribution through the literature reviews in the NOWPAP member states. NOWPAP CEARAC is expecting to establish a collaborative network with national and local organizations to enrich the database.

An analysis of satellite images for mapping the distribution of seagrass requires knowledge of remote sensing. The developed manual for mapping of seagrass and seaweed beds 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. NOWPAP 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 the IOC Sub-Commission for the Western Pacific (IOC/WESTPAC), the North Pacific Marine Science Organization, the Yellow Sea Large Marine Ecosystem Project, Japan Aerospace Exploration Agency, Korea Institute of Ocean Science and Technology 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. 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. Development of a practical mapping tool for using freely available satellite images or carrying out capacity building activities of NOWPAP CEARAC is also conservation-related. However, the use of UNFCCC 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 region.

5. Summary and recommendations

5.1. Conclusions

The feasibility of assessment of seagrass distribution in the entire NOWPAP region was evaluated in the 2016-2017 biennium as one of NOWPAP 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 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 concluded 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 Sentinnel-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 a NOWPAP 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.

References

Aioi K, Nakaoka M (2003) The seagrasses of Japan. In: Green, E.P., Short, F.T. (Eds.), World Atlas of Seagrasses. University of California Press, pp. 185-192

Beck MW, Heck KL, J, Able KW, Childers DL, Eggleston DB, Gillanders BM, Halpern B, Hays CG, Hosahino K, Minello TJ Orth RJ, Sheridan PF, Weinstein MP (2001). The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51(8): 633-641

Coles R, Grech A, McKenzie L (2013) Seagrass under pressure. Seagrass-Watch 47, 2-6

Dulenin AA (2012) Resources and distribution of commercial macrophytes in the western Tartar Strait (Khabarovsk Territory). Izvestia TINRO 170, pp.17-29

Fisheries Agency of Japan (2006) Final report of the project "Studies on technology development of seagrass bed creation considering biodiversity: analysis on genetic diversity of seagrass species. Report

Green EP, Mumby PJ, Clark CD, Edwards TM (2000) Remote sensing handbook for tropical coastal management. Coastal Management Sourcebooks, 3. UNESCO Publishing: Paris, pp. 316

Green EP, Short FT (2003) World Atlas of Seagrass. Prepared by the UNEP World Conservation Monitoring Centre, University of California Press, pp.332

Gorelick N, Hancher M, Dixon M, Ilyushchenko S, Thau D, Moore R (2016) Google earth engine: Planetary-scale geospatial analysis for everyone. Remote Sens. Environ. 202: 18-27

Guo D, Zhang P, Zhang, X, Li W, Zhang X, Yuan Y (2010) Preliminary investigation and study on seagrass species of inshore areas in Shandong province. Transactions of Oceanology and Limnology 2: 17-21.

Guo D, Zhang P, Zhang X, Li W, Zhang X (2010) Ecological study on eelgrass of inshore areas in Lidao Town of Rongcheng City. Periodical of Ocean University of China, 40(9): 51-55.

Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert, Fox HE (2008) A global map of human impact on marine ecosystems. Science, 319: 948-952

Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, *et al.* (2013) High-resolution global maps of 21st-century forest cover change. Science, 342: 850-853

Hemminga MA, Duarte CM (2000) Seagrass Ecology, Cambridge University Press, pp.99-136

Howard J, Hoyt S, Isensee K, Telszewski M, Pidgeon E (2014) Coastal blue carbon: methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature, Arlington, Virginia, USA, pp.180

Ikemori T, Higashide Y, Sakai K (2016). Distribution and seasonal characteristics of Zostera in Nanao Sei-Wan Bay, Ishikawa Prefecture, Sea of Japan. Japan Sea Research, 47: 29-33

International Union for the Conservation of Nature [IUCN] (2017) IUCN Red List of Threatened Species. www.iucnredlist.org. Accessed 30 March 2018

IOCCG (2000) Remote sensing of ocean colour in coastal, and other optically-complex, waters. In: Sathyendranath S (ed) Reports of the International Ocean-Colour Coordination Group, No. 3, IOCCG, Dartmouth, pp. 5–21

Kalita TL, Scriptsova AV (2017) The modern state of *Zostera marina* community at Tokarevsky Koshka (The Sea of Japan), Russian Journal of Marine Biology (in press).

Kawabata T, Hasegawa T, Tomita N (1990) Growth of eelgrass (Zostera marina) and an attempt at the development of eelgrass bed in Yanai Bay (Symposium: Restoration of Submerged Vegetation in the Marine Environment). Bulletin on Coastal Oceanography 27: 146-156

Komatsu T (1997) 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: 209-216

Komatsu T, Sagawa T, Sawayama S, Tanoue H, Mohri A, Sakanishi Y (2012) Mapping is a key for the sustainable development of coastal waters: examples of seagrass beds and aquaculture facilities in Japan with use of ALOS images. In Sustainable Development-Education, Business and Management-Architecture and Building Construction-Agriculture and Food Security. In Tech. pp. 145-146 https://www.intechopen.com/download/pdf/29276. Accessed 30 March 2018

Kim K, Kim J-H, Kim KY (2008) Using a digital echosounder to estimate eelgrass (*Zostera marina L.*) cover and biomass in Kwangyang Bay. Algae 23(1): 83-90 (in Korean with English abstract)

Kim JB, Park J-I, Lee K-S (2009) Seagrass distribution in Deukryang Bay. The Korean Society of Fisheries and Aquatic Science, 42(5): 509-517

Kim K, Choi J-K, Ryu J-H, Jeong HJ, Lee K, Park MG, Kim KY (2015) Observation of typhoon-induced seagrass die-off using remote sensing. Estuarine, Coastal and Shelf Science, 154: 111-121

Kunii H (2001) Distribution of endangered aquatic macrophytes in Lakes Shinji and Nakaumi. Laguna 8: 95-100

Lee K-S, Kim SH, Kim YK (2016) Current status of seagrass habitat in Korea. In: Finlayson, C.M. *et al.* (Eds). Wetland Book. Springer Netherlands, pp.1-8

Lee K-S, Park J-I, Kim YK, Park SR, Kim J-H (2007) Recolonization of *Zostera marina* following destruction caused by a red tide algal bloom: the role of new shoot recruitment from seed banks. Marine Ecology Progress Series 342: 105-115

Lee KS, Lee SY (2003) The seagrasses of the Republic of Korea. In: Green, E.P., Short, F.T. (Eds.), World Atlas of Seagrasses. University of California Press, pp.193-198

Liu H, Huang X, Wang Y, Liang Z, Gu B, Su J (2016) Newly discovered seagrass bed and its ecological characteristics in the coastal area of Caofeidian, Bohai Sea. Chinese Journal of Ecology 35(7): 1677-1683

Liu B, Zhou Y, Liu X, Liu, P, Zhang X (2013) Ecological characteristics research of *Zostera marina* L. in Sanggou Bay. Marine Sciences 31, 42-48

Liu K, Liu F, Wang F, Sun X, Wang W, Ding C, Liang Z, Li T (2012) Survey and identification of *Zosteraceae* along Shandong Peninsula coast. Progress in Fishery Sciences, 33(6): 99-105

Loveland TR, Dwyer JL (2012) Landsat: Building a strong future. Remote Sens. Environ. 122: 22-29

Lyzenga DR (1978) Passive remote sensing techniques for mapping water depth and bottom Features, APPLIED OPTICS 17: 379-383

Lyzenga DR (1981) Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. International Journal of Remote Sensing, 2, 71–82.

Ministry of Environment of Japan (2008) The Report of the Marine Biotic Environment Survey in the 7th National Survey on the Natural Environment. Report

Mumby PJ and EDWARDS AJ (2000) Water column correction techniques. In Remote Sensing Handbook for Tropical Coastal Management, A.J. Edwards (Ed.), pp. 121–128 (Paris: UNESCO).

Nabata S, Matsuda H (1983) Removal of *Phyllospadix iwatensis* in kelp beds around Rishiri Island with the use of chain. Monthly report of Hokkaido Fisheries Experimental Station 40: 249-269

Nishigaki T, Yatsuya K, Itani T, Wada Y (2005) Relationship between underwater light condition and lower depth limit of *Zostera marina* in coastal area of Kyoto Prefecture. Bulletin of Kyoto Prefectural Marine Research Center, 27: 35-36

Nixon SW (1995) Coastal marine eutrophication: A definition, social causes, and future concerns, Ophelia 41: 199-219

Noiraksar T, Sawayama S, Phauk S, Komatsu T (2014) Mapping sargassum beds off the coast of Chon Buri Province, Thailand, using ALOS AVNIR-2 satellite imagery. Botanica Marina 57(5): 367-377

Ohba T, Miyata M (2007) Seagrasses of Japan. Hokkaido University Press, pp. 114

Park SR, Kim J-H, Kang C-K, An S, Chung IK., Kim JH, Lee K-S (2009) Current status and ecological roles of *Zostera marina* after recovery from large-scale reclamation in the Nakdong River estuary, Korea. Estuarine, Coastal and Shelf Science, 81: 38-48

Paymeeva LG (1973) Distribution of *Zostera* communities in Peter the Great Bay. Izvestia TINRO 87: 145-148

Paymeeva LG (1974) Epiphytes of *Zostera* (The Sea of Japan). Izvestia TINRO 98: 193-201.

Petrov KM (2004) Underwater vegetation at the coast zone of Sakhalin Island – landscape approach to investigation of coastal zone vegetation. Bulletin of St Petersburg State University 7(2): 58-69

Ralph PJ, Durako MJ, Enríquez S, Collier CJ, Doblin MA (2007) Impact of light limitation on seagrasses. Journal of Experimental Marine Biology and Ecology 350: 176-193

Sagawa T, Mikami A, Komatsu T, Kosaka N, Kosako A, Miyazaki S, Takahashi M (2007) 'Technical Note. Mapping seagrass beds using IKONOS satellite image and sidescan sonar measurements: a Japanese case study’. International Journal of Remote Sensing 29(1): 281-291

Sagawa T, Boisnier E, Komatsu T, Mustapha KB, Hattour A, Kosaka N, Miyazaki S (2010) Using bottom surface reflectance to map coastal marine areas: a new application method for Lyzenga's model, International Journal of Remote Sensing 31(12): 3051-3604

Sagawa T, Mikami A, Aoki MN, Komatsu T (2012) Mapping seaweed forests with IKONOS image based on bottom surface reflectance. Proceedings of the SPIE Asia-Pacific Remote Sensing, 8525, 85250Q1-85250Q7 (29 Oct. – 1 Nov. 2012. Kyoto, Japan).

Short FT, Coles RG, Pergent-Maritint C(2001) Global Seagrass Research Methods. EKSEVIER pp.5-30

Short FT, Polidoro B, Livingstone SR, Carpenter KE, Banderia S, Bujang JS, Calumpong HP, Carruthers TJB, Coles RG, Dennison WC, Erftemeijer PLA, Fores MD, Freeman AS, Jagtap TG, Kamal AHM, Kendrick GA, Kenworthy WJ, Nafie YAL, Nasution IM, Orth RJ, Prthep A, Sanciangco JC, Tussenbroek BV, Vergara SG, Waycott M, Zieman JC (2011) Extinction risk assessment of the world’s seagrass species. Biological Conservation, 144: 1961-1971

Sugimoto K, Hiraoka K, Tanida K, Terawaki T, Okada M (2008) Restoration of eelgrass (*Zostera marina* L.) beds by filling up borrow pits with natural sediment. Journal of Japan Society on Water Environment, 31(4): 217-221

Terauchi G, Tsujimoto R, Ishizaka J, Nakata, H (2014) Preliminary assessment of eutrophication by remotely sensed chlorophyll-a in Toyama Bay, the Sea of Japan. Journal of Oceanography 70: 175-184

Topouzelis K, Spondylidis S, Papakonstantinou A, Soulakellis N (2016) The use of Sentinel-2 imagery for seagrass mapping: Kalloni Gulf (Lesvos Island, Greece) case study. Proc. SPIE 9688, Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016), 96881F SPIE. doi: 10.1117/12.2242887

Vyshkvartsev DI, Peshehodko VM (1982) Mapping of the dominant species of aquatic vegetation and analysis of their role in the ecosystem of the shallow inlets of Posiet Bay of the Sea of Japan. Underwater Hydrobiological Studies, pp.120-130.

Waycott M, Duarte CM, Carruthers TJ.B, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean, JW, Heck KL, Hughes, AR, Kendrick GA, Kenworthy WJ, Short FT, Williams SL （2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences 106: 12377-12381

Yang D (2017) Seagrass distribution, ecological structure and carbon sink in China. Chinese Sciences Press

Yang Z (1979) The geographical distribution of seagrass. *Transactions of Oceanology and* Limnology 2: 41-46

Yu H, Ma Y, Zhang Y (2007) Ecological characteristics of eelgrass (*Zostera marina L.*) and its response to environmental changes. Transactions of Oceanology and Limnology Suppl. pp. 112-120

Zhang X, Zhou Y, Wang F, Liu P, Liu B, Liu X, Yang H (2013) Ecological characteristics of *Zostera japonica* population in Swan Lake of Rongcheng, Shandong Province of China. Chinese Journal of Applied Ecology 24(7): 2033-2039

Zharikov VV, Preobrazhensky BV (2010) Ecosystem transformation and its eventual landscape manifestation in the aquaculture-affected Alekseeva cove (Peter the Great Bay, The Sea of Japan). Underwater Research and Robotics 2(10): 72-84

Zharikov VV, Bazarov KY, Egidarev EG, Lebedev AM, Lysenko VN (2015) Mapping of higher aquatic vegetation in the eastern section of the Far Eastern Marine Reserve using data of LANDSAT-8, Geosystems and their components in Northeastern Asia: Evolution and dynamics of natural, natural and resource, and social and economic ties, pp.183-188

Zharikov VV, Smirnova EV, Lebedev AM (2016) Ecological-landscape assessment of the current state of biota in Severnaya inlet (Amursky Bay, The Sea of Japan). The Scientific Works of Far Eastern State Technical Fisheries University 2: 11-16

Zheng F, Qiu G, Fan H, Zhang W (2013) Diversity, distribution and conservation of Chinese seagrass species. Biodiversity Science 21(5): 517-526 (in Chinese)

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