

Ulva spp. Distribution Observed by Using High-Spatial Resolution Satellites —Case study: Yatsu tidal flat, Chiba Prefecture—

SHIRAKI Yohei* OISHI Yuhei** LEE Seongwon* KITAZAWA Toshiyuki*

Key words : *Ulva* spp., High-Spatial Resolution Satellite, NDVI, Water Column Correction Method, Yatsu tidal flat

1. Introduction

A tidal flat is land formed of clay or mud that is smooth with a gentle gradient and that, as the sea surface rises and falls with the tides, is below the water surface at flood tides and exposed above the water surface at ebb tides. Tidal flats are generally supplied with organic matter, nutrients and the like by rivers. The organic matter and nutrients are consumed by bacteria, shellfish, macroalgae and phytoplankton living in and on the mud. The phytoplankton are consumed by benthic organisms living in the mud of the tidal flats, such as protists, polychaetes, crustaceans such as crabs, and shellfish such as *Venerupis philippinarum* Manila clams. Ultimately, the benthic organisms are eaten by fish, birds and so forth. This characteristic food web of tidal flats strongly influences ecological functions. Tidal flats provide water-cleaning effects, with nitrogen removal by bacteria and nitrogen and phosphorus removal by algae preventing eutrophication, and organic matter being removed by filter-feeding organisms; they also provide biological production facilities and other ecosystem services, supplying shelter for a wide range of species, nurseries for their young, and furnishing feeding and rest sites for birds. Being a place of easy access to the water, a tidal flat also has many benefits for humans, as can be seen in the popularity of clam-gathering, birdwatching, other nature watching, environmental studies and so forth (Japan Fisheries Agency). However, there have

been reports of decreases in tidal flats in many regions in recent years due to the effects of urbanization, coastal development and so forth (N. J. Murray *et al.* 2014; Z.Y. Wu *et al.* 2016; Y. Chen *et al.* 2016); Japan is no exception to this trend. A decrease of about 40% of the area of tidal flats in Japan has been reported due to land reclamation in the development of coastal regions during the period of high economic growth from 1954 to 1973 (Nature Conservation Bureau of the Environment Agency, 1994). The destruction of tidal flats from 1945 to 1977 has been reported at 89.2% in Tokyo Bay, 54.48% in Ise Bay/Mikawa Bay, and 35.5% in the Seto Inland Sea (T. Kikuchi 2000). In this context, it is important to restore what is left of our tidal flats to healthy states and to preserve and manage them. This requires that we conduct periodic monitoring in order to ascertain their conditions. However, monitoring the conditions of large areas of tidal flats on foot requires large amounts of time and money and is generally not practical.

Against this background, remote sensing technologies, being capable of acquiring information over large areas and of conducting periodic observations of subject areas, have often been employed to monitor the conditions of tidal flats in recent years (L. Sochea and Y. Sakuno 2008; T. Takemura *et al.* 2017; Y. Shiraki *et al.* 2018). However, previous studies using remote sensing to monitor the conditions of tidal flats have mostly used satellite images with relatively low spatial resolutions, such as images from the environmental

* Faculty of Geo-Environmental Science, Rissho University

** National Land Information Department, PASCO CORPORATION

monitoring satellite Landsat (the resolution of Landsat-8's multi-spectrum Operational Land Imager is 30m). The conditions of tidal flats cannot be considered to have been ascertained in detail. Accordingly, in this study we made use of high-spatial resolution satellites capable of monitoring conditions in a tidal flat in more detail, with the study subject area being Yatsu tidal flat in Narashino, Chiba Prefecture (Fig.1). We intended to assess how effective a role the use of high-spatial resolution satellites might play in monitoring conditions in a tidal flat.

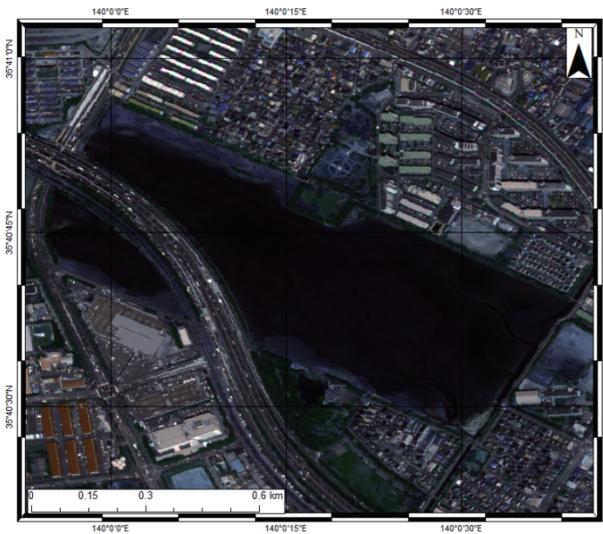


Fig.1. Overview of the study subject area (Yatsu tidal flat) captured by the high-spatial resolution satellite WorldView-3

2. Outline of the study subject area

Yatsu tidal flat is located in Narashino City, Chiba Prefecture, at the head of Tokyo Bay. Although it escaped direct land reclamation during the period of high economic growth, it is encircled by dikes and has very particular characteristics: it has an area of approximately 40 ha, is connected with Tokyo Bay by the Yatsu River and the Takase River, and exchanges seawater with Tokyo Bay through these rivers. Yatsu tidal flat is well known as a rest area for birds migrating from cold winter regions to warm regions. In 1993, it was the first tidal flat in Japan to be listed under the Ramsar Convention (the Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat), an international treaty for the

conservation of wetlands. However, excessive growth of *Ulva* spp. (green tides) was first confirmed in 1995 and has continued at extreme levels to the present day (Fig.2). The effects of this excessive growth on the environment—such as hypoxia in bottom mud resulting from the death and decay of benthic organisms and a decrease in waterfowl—are recognized as a problem (T. Yabe *et al.* 2009). Moreover, in recent years *Ulva* spp. have not been dying out but surviving the winters, leading to various kinds of second-order damage such as unattractive scenery and strong odors from decaying *Ulva* spp. (T. Yabe *et al.* 2009).



Fig.2. *Ulva* spp. distributed in Yatsu tidal flat

3. Analysis methods

As described above, to restore the environment of Yatsu tidal flat to healthy conditions and to preserve and manage it, we must first identify causes of the excessive growth of *Ulva* spp. Therefore, it is important to monitor the distribution of *Ulva* spp. In this study, we conducted analyses in accordance with the following methods with a view to ascertaining conditions in Yatsu tidal flat and monitoring the distribution of *Ulva* spp.

3.1. Source data

We decided to use the Earth observation satellites GeoEye-1 and WorldView-3 to attempt to ascertain the distribution of *Ulva* spp. GeoEye-1 has four bands in the visible and near-infrared regions: 450-510nm (blue), 510-580nm (green), 655-690nm (red) and 780-920nm

(near-IR). WorldView-3 has eight bands in the visible and near-infrared regions: 400-450nm (coastal), 450-510nm (blue), 510-580nm (green), 585-625nm (yellow), 630-690nm (red), 705-745nm (red edge), 770-895nm (near-IR1) and 860-1040nm (near-IR2). Both satellites have very high-spatial resolutions: 1.64m for GeoEye-1 looking straight down (2.00m at 30° off-nadir) and 1.24m for WorldView-3 (1.38m at 20° off-nadir). Therefore, it seemed likely that we could properly ascertain the distribution of *Ulva* spp. in the tidal flat by using data from these satellites.

3.2. Selection of study subject dates

Previous studies have reported that *Ulva* spp. is most pervasive in Yatsu tidal flat in the spring (E. Yauchi *et al.* 2006). Accordingly, for this study we chose a sampling date in the spring (using GeoEye-1 data from 10:20 on April 16, 2015) and analyzed this data together with data from the fall six months later (WorldView-3 data from 10:50 on October 26, 2015) in order to study changes. The tide level at Yatsu tidal flat is known to lag 1.5 to 2h behind the tide level at Tokyo (Harumi). For the tidal ranges at Yatsu tidal flat at the times of the images, we recorded 60-70cm in both spring and fall.

3.3. Deducing *Ulva* spp. distributions using NDVI

The spectral reflectance of *Ulva* spp. is low in the visible light range and high in the near-infrared range, similar to the characteristics of land vegetation (Y. Shiraki *et al.* 2018). The normalized difference vegetation index (NDVI) is a typical index for using such characteristics to estimate vegetation activity levels. NDVI can be calculated from expression (1):

$$NDVI = \frac{NIR-R}{NIR+R} \quad (1)$$

In this expression, *NIR* represents a reflectance in the near-infrared region and *R* represents a reflectance of red light in the visible light region. The index values vary between -1 and +1. The higher the value, the higher the level of activity. *Ulva* spp., having similar spectral reflectance to terrestrial plants, can be expected to produce different values from non-

vegetation surfaces such as mud or shellfish. We can make use of NDVI to ascertain the distribution of *Ulva* spp. For the calculations of NDVI in this study, from the GeoEye-1 data we used the 780-920nm band for *NIR* and the 655-690nm band for *R*, and from the WorldView-3 data we used the 770-895nm band for *NIR* and the 630-690nm band for *R*.

3.4. Deducing *Ulva* spp. distributions from a bottom index

The water depth in Yatsu tidal flat differs between locations. In particular, mud deposited during land reclamation in the western half is known to be gradually washed away, as a result of which the mud thickness is decreasing and the ground level is falling (Yatsu national wildfowl conservation area preservation project). In this context, although it is simple to obtain distribution information of *Ulva* spp. that is completely exposed at the water surface, it is hard to obtain distribution information for *Ulva* spp. submerged in the water by using NDVI (L. Sochea. and Y. Sakuno 2008, Y. Shiraki *et al.* 2018). Accordingly, we calculated a bottom index (BI) using a water column correction method that has been used many times in previous studies (D. R. Lyzenga 1981) and used the bottom index to assess the distribution of *Ulva* spp. This bottom index is an algorithm that cancels the effects of water depth and identifies covering materials structuring the bottom (algae, sand, shellfish and the like) calculated with as follows:

$$BI_{ij} = Ln(DN_i - DN_{deepi}) - K_{ij} \left(Ln(DN_i - DN_{deepj}) \right) \quad (2)$$

In this expression, BI_{ij} represents a bottom index calculated for bands *i* and *j*, DN_i represents a digital number (DN value) in band *i*, DN_{deepi} represents the deep sea DN value for band *i*, DN_j represents a DN value in band *j*, DN_{deepj} represents the deep sea DN value for band *j*, and k_{ij} represents the ratio of the scattering coefficients in water for bands *i* and *j*. In this study, we used the blue visible light and green visible light bands from both GeoEye-1 and WorldView-3 as bands *i* and *j*. To find k_{ij} , we plotted a scatter graph of natural logarithms of the DN values of blue light and

green light in the satellite images and used the slope of a regression line of the graph as k_{ji} .

4. Results and Observations

Fig.3 shows the NDVI distribution in Yatsu tidal flat on April 16, 2015, and Fig.4 shows the NDVI distribution on October 26, 2015. Although there are differences in the NDVI values due to seasonal effects, the most prominent feature is that the values are higher in the eastern half and lower in the western half. As mentioned above, the ground level in the western half of the Yatsu tidal flat is falling and, relatively, the ground level in the eastern half is rising. Therefore, in periods during which the water level is low, such as at ebb tides, *Ulva* spp. is more likely to be exposed above the water surface in the eastern half. Based on a number of site surveys, among materials constituting the bottom of the tidal flat, there is nothing other than *Ulva* spp. that has similar spectral reflectance to vegetation. Therefore, areas with higher NDVI values can be understood to be areas where *Ulva* spp. is exposed. Fig.5 shows the bottom index distribution on April 16, 2015, and Fig.6 shows the bottom index distribution on October 26, 2015. In these images, it can be seen that areas with bottom index values close to +1 (brown) on April 16, 2015 match the areas with high NDVI values in the eastern half; that is, the pattern matches areas at which *Ulva* spp. is exposed above the water surface. A pattern of similar values (close to +1) can also be seen in the western half where the ground level is falling and the water level is deeper. For October 26, 2015 too, a pattern that matches the areas with high NDVI values can be seen in the eastern half, and a pattern of similar values can also be seen in the western half where the water level is deeper. If, as described above, we can assume that areas with high NDVI values show the distribution of *Ulva* spp., it seems likely that *Ulva* spp. is also present in the areas in the western half with bottom index values close to +1 (brown).

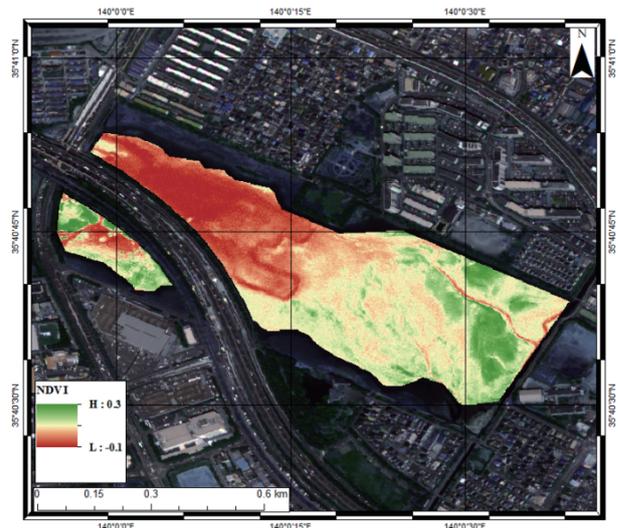


Fig.3. NDVI distribution in Yatsu tidal flat (April 16)

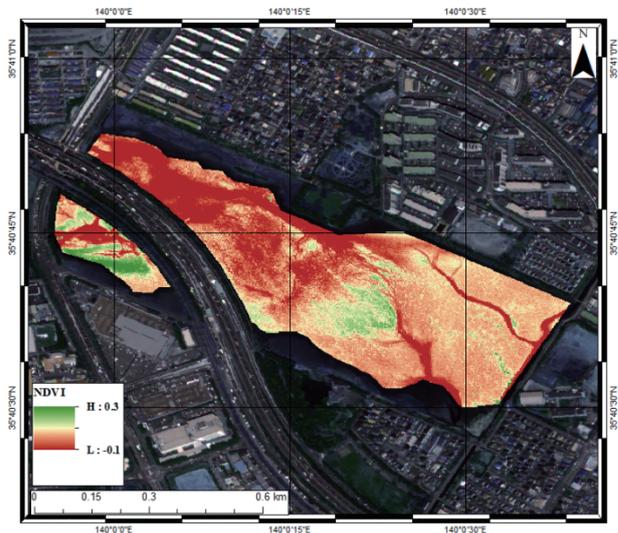


Fig.4. NDVI distribution in Yatsu tidal flat (October 26)

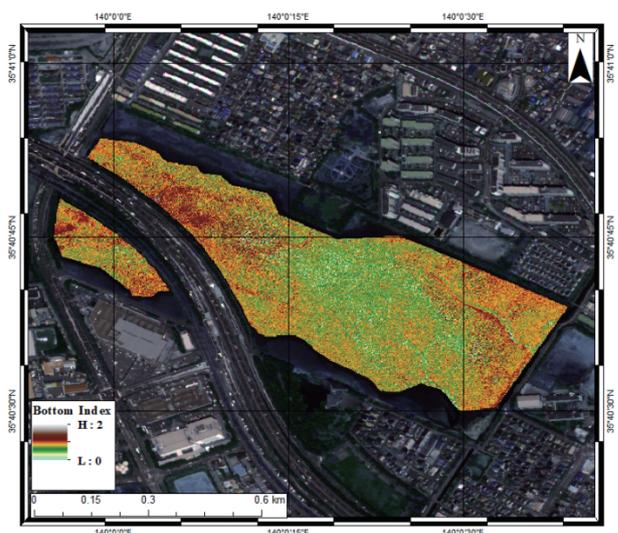


Fig.5. Bottom index distribution in Yatsu tidal flat (April 16)

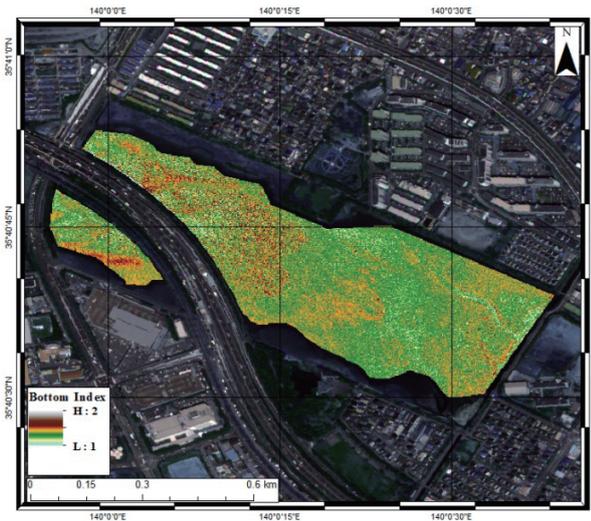


Fig.6. Bottom index distribution in Yatsu tidal flat (October 26)

5. Conclusions and Future Challenges

In this study, we selected Yatsu tidal flat located in Narashino, Chiba Prefecture, as the study subject area and, using high-spatial resolution data from the satellites GeoEye-1 and WorldView-3, we sought to monitor the detailed distribution of *Ulva* spp. caused by the deterioration of the tidal flat environment. We found that although we could identify signals of *Ulva* spp. exposed at the water surface with NDVI, we could not identify signals of *Ulva* spp. submerged below the water surface. However, employing the bottom index calculated using the water attenuation correction method allowed us to surmise that it may be possible to obtain detailed information on the distribution of *Ulva* spp. throughout Yatsu tidal flat. By making use of these findings, we think it should be possible to monitor total amounts of *Ulva* spp. and learn about seasonal changes and so forth. However, this study assumed that areas with high NDVI values are *Ulva* spp. and we can only discuss a comparison with the bottom index. In the future, it will be necessary to obtain detailed ground truth data synchronously with the imaging times of satellites and to assess whether the information provided by the bottom index matches the ground truth. Furthermore, additional analysis will be carried out about the results acquired in this study.

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高空間分解能衛星を用いたアオサ類の分布把握手法に関する一考察 —千葉県谷津干潟を例として—

白木洋平* 大石悠平** 李盛源* 北沢俊幸*

*立正大学地球環境科学部

**株式会社パスコ 国土情報部

Abstract:

千葉県習志野市に位置する谷津干潟では、アオサ類の異常繁殖（グリーンタイド）によって底生生物の斃死や腐敗による底泥の嫌気化、水鳥の減少など環境への影響が問題視されている。本研究では高空間分解能衛星のGeoEye-1とWorldView-3を利用して干潟内におけるアオサ類の分布の把握を試みた。その結果、NDVIでは水面上に露出しているアオサ類についてはシグナルを得ることが出来るものの、水面下に沈降しているアオサ類についてはシグナルを得ることが出来なかった。しかしながら、水柱放射量補正手法を用いて算出した底質指標を用いることで、谷津干潟全体のアオサ類の分布情報を得られる可能性について示唆することが出来た。

キーワード：アオサ類，高空間分解能衛星，NDVI，水柱放射量補正，谷津干潟