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A Method for Determining *Batillaria attramentaria* Distribution Using Aerial Balloon Photography and a Vegetation Index Camera: Demonstration at the Yatsu Tidal Flat, Chiba Prefecture

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Abstract

Located in Chiba Prefecture, the Yatsu Tidal Flat is an important stopover for birds migrating between cold regions such as Siberia and warm regions such as Southeast Asia and Australia. Its importance led to its selection in 1993 as the first tidal flat in Japan to be registered under the Convention on Wetlands of International Importance especially as Waterfowl Habitat (the Ramsar Convention). However, the Yatsu Tidal Flat has in more recent years witnessed blooms of *Ulva* spp. (sea lettuce) and an increase in exotic species such as *Batillaria attramentaria* (Japanese mud snail) and *Mercenaria mercenaria* (hard clam), fueling concerns that the increasing spatial domination of the tidal flat by such species and competition with other species for food may drive a decline in the habitat's self-cleaning capabilities. For this study, we focused on *Batillaria attramentaria*, which is now so widely distributed in the Yatsu Tidal Flat as to preclude reliable monitoring via aerial photographs or satellite imagery. Accordingly, we tested the utility of a simplified method for obtaining data on the distribution of *Batillaria attramentaria* by using aerial balloon photography and a vegetation index camera capable of generating NDVI data. Our results show that under certain conditions, this method can indeed be used to determine *Batillaria attramentaria* distribution.

Keywords

Batillaria attramentaria, *Ulva* spp., NDVI, Yatsu Tidal Flat, Japan, Aerial Balloon Photography

1. Introduction

Japan is an island nation with extremely mountainous terrain and numerous rivers. For this reason, Japan's coastline is highly crenulated and dotted with both large and small bays in most regions. Owing to the characteristics of such terrain, there are also well-developed tidal flats in many of Japan's coastal regions [1]. These tidal flats are important not only as venues for shellfish gathering and other cultural activities, but also as ecosystems boasting rich biodiversity that play a vital role in maintaining water quality through their self-cleaning capabilities. However, widespread coastal development for industrial and other uses during the postwar period of rapid economic growth (late 1950s to early 1970s) resulted in the loss of precious tidal flats throughout Japan [2]. Tokyo Bay underwent particularly extensive urbanization, resulting in the loss of approximately 80% of its tidal flats since 1945 [3]. This is especially true for Chiba Prefecture, which lost more than any other prefecture in Japan, with its tidal flats disappearing at a rate of 129.7×10^4 m^2/year between 1953 and 1991 [4].

Covering an area of about 40 ha in the innermost reaches of Tokyo Bay, the Yatsu Tidal Flat (**Figure 1**) is known as one of the most important of the Bay's few remaining tidal flats. It is characterized by the presence of two rivers, the Yatsu and Takase, as well as by the preponderance of housing in the surrounding area built on land reclaimed during the period of rapid economic growth. Because it is an important stopover for birds migrating between cold regions such as Siberia and warm regions such as Southeast Asia and Australia, it was selected in 1993 as the first tidal flat in Japan to be registered under the Convention on Wetlands of International Importance especially as Waterfowl Habitat (the Ramsar Convention). However, it has in more recent years witnessed explosive increases in *Ulva* spp. (sea lettuce) and exotic species such as *Batillaria attramentaria* (Japanese mud snail) and *Mercenaria mercenaria* (hard clam), fueling concerns of increasing spatial domination of the tidal flat by such species and competition with other species for food [5].

Given these circumstances, measures are needed to restore and maintain the health of the Yatsu Tidal Flat as one of Tokyo Bay's most important tidal flats. Yet before this can be achieved, there is an urgent need to carry out continuous monitoring to develop a sound understanding of the current status of and any ongoing changes in the tidal flat environment. Whereas the large area of the tidal flat makes it unsuited for ground-based monitoring, satellite remote sensing is a relatively inexpensive and non-labor-intensive means of periodically gathering data across a wide area. In fact, the comparatively high spatial resolution available with multispectral satellite imagery has been used in various studies to investigate the distribution of *Ulva* spp. and other seaweeds [6]-[11]. Unfortunately, because the resolution is still insufficient to develop an accurate picture of the distribution of molluscs such as *Batillaria attramentaria*, which is just 2 cm long and scattered over a very wide area, research has up to now depended on the collection of specimens in the field.

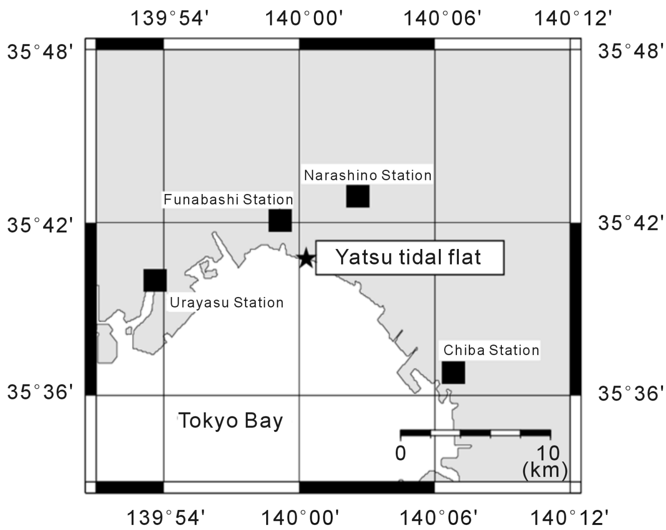

Figure 1. Study area.

Consequently, we sought a simple method of determining the distribution of *Batillaria attramentaria*, for which satellite imagery is not applicable, in the Yatsu Tidal Flat.

2. Method for Investigating *Batillaria attramentaria* Distribution

The density of *Batillaria attramentaria* in the Yatsu Tidal Flat (**Figure 2**) varies according to season, and its habit of attaching itself to *Ulva* spp. (**Figure 3**) also affects its distribution [12]. As with terrestrial plants, the spectral reflectance of *Ulva* spp. and other algae is low in the visible region of the electromagnetic spectrum and high in the near-infrared region.

The normalized difference vegetation index (NDVI), a graphical indicator that makes use of this characteristic of vegetation, can be used to estimate plant activity, and is calculated using the following Equation (1).

$$NDVI = \frac{NIR_{800} - R_{680}}{NIR_{800} + R_{680}} \tag{1}$$

In this equation, NIR stands for reflectance in the near infrared region (800 nm), and R for reflectance in the red, visible light region (680 nm). NDVI values range between 1 and −1. Because the NDVI of *Ulva* spp., which has the same spectral reflectance as terrestrial plants, will differ greatly from that of the non-plant *Batillaria attramentaria*, we inferred that it should be possible to use this difference to accurately determine the distribution of *Batillaria attramentaria*. Therefore, in this study we attached a vegetation index camera capable of photographing NDVI images to an aerial photography balloon, and used this apparatus in August 2015 to quantify the spatial distribution of *Batillaria attramentaria* and *Ulva* spp. in the Yatsu Tidal Flat. We used the YubaFlex camera (Bizworks Corp., Inc.) to obtain a vegetation index. This is a commercially

Figure 2. *Batillaria attramentaria* at the Yatsu Tidal Flat.

Figure 3. *Ulva* spp. covering the Yatsu Tidal Flat (at low tide).

available compact digital camera modified for NDVI by replacing the near-infrared light filter with a blue light filter. The maximum spectral response function values are 600 nm in the red visible light region and 850 nm in the near-infrared region. The aerial photography balloon used in this study was a Hibari-II developed by the National Agriculture and Food Research Organization's Tohoku Agricultural Research Center. The balloon was secured at a height of approx. 5 - 10 m above ground with two ropes that were then pulled by two people to carry out photography (**Figure 4**).

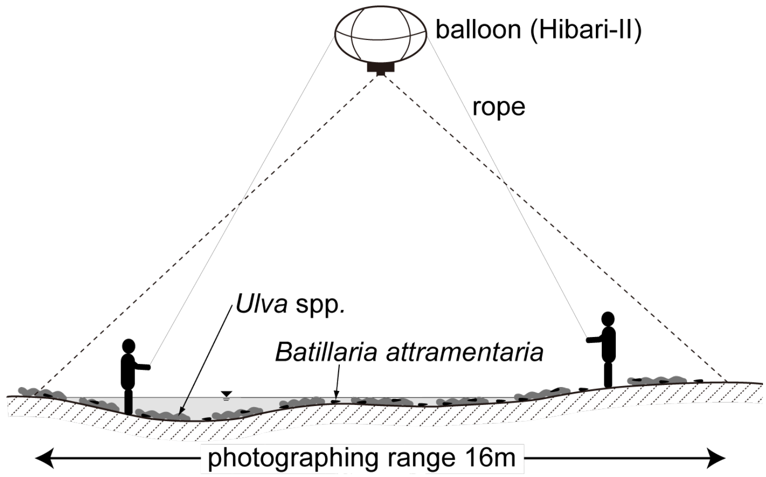

Figure 4. Usage of an aerial photography balloon to carry out NDVI photography in a tidal flat.

To correctly evaluate the NDVI images obtained by the above method, we used a visible/near-infrared portable spectroradiometer (FieldSpec HandHeld2 manufactured by ASD Inc.) to obtain spectral reflectance readings for *Batillaria attramentaria* and *Ulva* spp. in the tidal flat in January 2017, and calculated NDVI values accordingly. On this occasion, we also obtained spectral reflectances for *Batillaria attramentaria* and *Ulva* spp. at different water depths (water surface, 5 cm, 10 cm) to examine the effect of water depth on NDVI. For this analysis, we used the mean of 10 spectral reflectance readings taken under the same conditions. Because light attenuates exponentially with depth [13], spectral reflectance will likely differ according to depth even for the same substrate. However, we decided against correcting for changes in spectral reflectance according to water depth in this study because 1) the study area of Yatsu Tidal Flat is sufficiently exposed at low tide during spring tide, 2) *Batillaria attramentaria* and *Ulva* spp., are found mostly within 10 cm of the surface, and 3) the purpose of this study is to propose a simplified method for ascertaining the distribution of the species concerned.

3. Results and Discussion

3.1. Determining *Batillaria attramentaria* Distribution Using an Aerial Photography Balloon

Figure 5 shows an image of *Batillaria attramentaria* and *Ulva* spp. taken by a vegetation index camera from a height of approx. 150 cm above the water's surface. White indicates an NDVI value close to 1, and black indicates an NDVI value close to −1. In **Figure 5**, the shape of *Batillaria attramentaria* (non-vegetative matter) can be clearly distinguished with the naked eye because its NDVI is higher and accordingly whiter than that of *Ulva* spp. **Figure 6** shows an NDVI image taken from a height of about 10 m. Unlike in **Figure 5**, the shape of individual snails cannot be made out in **Figure 6**, but locations with high NDVI

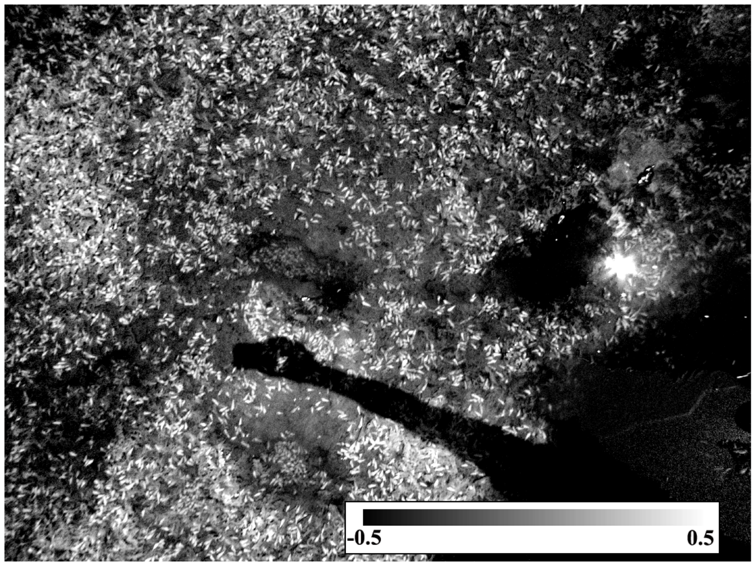

Figure 5. *Batillaria attramentaria* and *Ulva* spp. (at a depth of approx. 5 - 10 cm) photographed from a height of approx. 150 cm above the water surface.

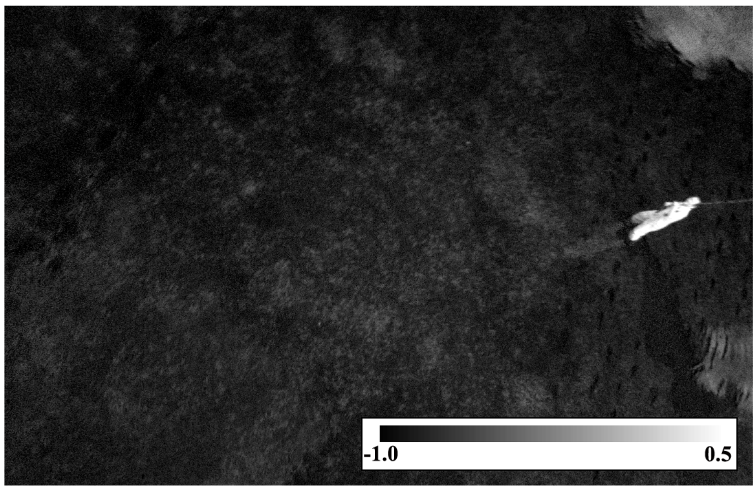

Figure 6. *Batillaria attramentaria* and *Ulva* spp. (at a depth of approx. 5 - 10 cm) photographed from a height of approx. 10 m above the water surface.

values (indicating presence of *Batillaria attramentaria*) are distinguishable. This suggests that combining an aerial photography balloon with a vegetation index camera may enable us to obtain information on the distribution of *Batillaria attramentaria* within a given habitat area.

3.2. The Spectral Reflectance of *Batillaria attramentaria* and *Ulva* spp.

Figure 7 and Figure 8 present the spectral reflectance of *Batillaria attramentaria* and *Ulva* spp., respectively, at various water depths as measured by a visible/near-infrared spectroradiometer. Our measurements show that at the water surface,

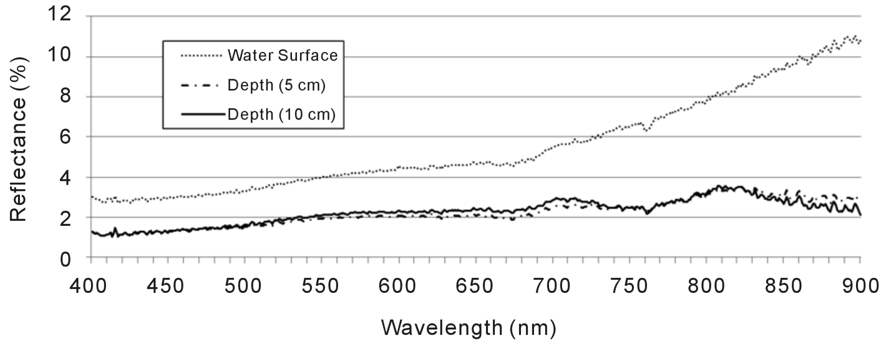

Figure 7. Spectral reflectance of *Batillaria attramentaria* according to water depth (water surface, 5 cm, 10 cm).

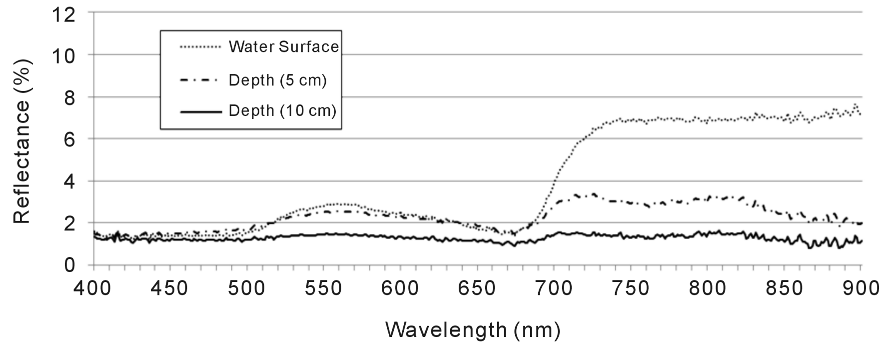

Figure 8. Spectral reflectance of *Ulva* spp. according to water depth (water surface, 5 cm, 10 cm).

the reflectance of *Batillaria attramentaria* increases gradually with wavelength, but that of *Ulva* spp. rises steeply at around the 700 nm mark, following the pattern of most terrestrial vegetation. Furthermore, the reflectance of both *Batillaria attramentaria* and *Ulva* spp. decreased with water depth. At both 5 and 10 cm of depth, the reflectance of *Batillaria attramentaria* showed a slight dip at around 700 nm, but then started rising again at around 750 nm to reach a second peak at around 820 nm.

3.3. Calculation of *Batillaria attramentaria* and *Ulva* spp. NDVI Values Using Actual Measurements

We calculated the NDVI values of *Batillaria attramentaria* and *Ulva* spp. using the spectral reflectances measured with a visible/near-infrared spectroradiometer. Figure 9 shows these calculated NDVI values when the near-infrared region is assumed to occur at 800 nm, and the red, visible light region is assumed to occur at 680 nm. Our results show that while the NDVI values of *Batillaria attramentaria* and *Ulva* spp. differ markedly at the water surface, this difference becomes increasingly unclear in deeper water. We accordingly maximized the Yubaflex spectral response function (850 nm for the near-infrared region, 600 nm for red in the visible light region), and recalculated NDVI values using Equation (2) below:

$$NDVI = \frac{NIR_{850} - R_{600}}{NIR_{850} + R_{600}} \quad (2)$$

Results are shown in **Figure 10**. As when NDVI values are calculated using 800 nm as the near-infrared region and 680 nm as the red, visible light region, the NDVI values for *Ulva* spp. at a depth of 0 cm (water surface) was higher than that of *Batillaria attramentaria*, but was roughly 0 at a depth of 5 cm, and became negative at a depth of 10 cm. The NDVI values for *Batillaria attramentaria*, on the other hand, became positive at a depth of 10 cm, constituting a clear difference compared to when NDVI values are calculated using 800 nm as the wavelength for the near-infrared region and 680 nm as that for the red, visible light region. This serves as further evidence that the NDVI images that we obtained using an aerial photography balloon and vegetation index camera accurately depict the distribution of *Batillaria attramentaria*.

4. Conclusions and Future Work

This study examined the Yatsu Tidal Flat, which has experienced marked environmental deterioration in recent years, to evaluate a simplified method of determining the distribution of *Batillaria attramentaria*, an organism that is too small to be distinguished through conventional aerial photography or satellite imagery, using an aerial photography balloon combined with a vegetation index camera.

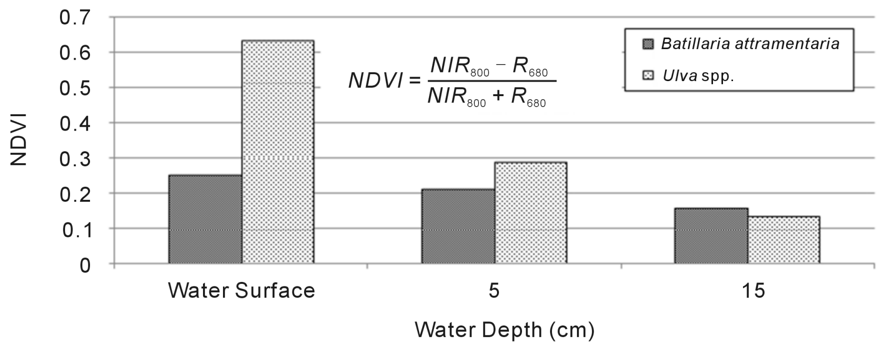

Figure 9. NDVI values of *Batillaria attramentaria* and *Ulva* spp. (NIR: 800 nm R: 680 nm).

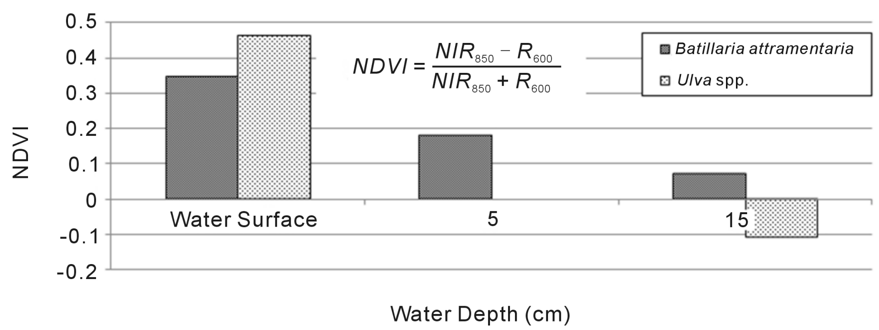

Figure 10. NDVI values of *Batillaria attramentaria* and *Ulva* spp. (NIR: 850 nm R: 600 nm).

Our results show that our method can determine the distribution of *Batillaria attramentaria* in water depths of 5 - 10 cm even from an altitude of approximately 10 m when we set the spectral response function values of the vegetation index camera to 850 nm for the near-infrared region and 600 nm for the red, visible light region. We also obtained the same results using a visible/near-infrared light spectroradiometer when determining NDVI values using reflectances calculated when the near-infrared region is set to 850 nm and the red, visible region is set to 600 nm.

It should be noted that for this study, we did not determine how *Batillaria attramentaria* and *Ulva* spp. NDVI values change at water depths of more than 10 cm. Also, owing to their coastal location, tidal flats are more frequently subject to strong winds than other locations, making it difficult to keep observation balloons stable over prolonged periods of time.

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