DETECTION OF SUBMERGED AQUACULTURE RAFT USING A DRONE-BASED MULTISPECTRAL CAMERA

Hiroki Murata[1,2], Chinatsu Yonezawa[1]

[1]Graduate School of Agriculture Science, Tohoku University
468-1 Aramaki Aza Aoba, Aoba-ku, Sendai 980-0845, Japan
Email: murata.ykhm@gmail.com
[2]Research Center for Advanced Science and Technology, The University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan

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ABSTRACT: Coastal aquaculture is widely practiced along Japan's coast using small-scale aquaculture facilities. As numerous aquaculture facilities are placed in coastal waters, efficient management is needed for the proper use of aquaculture areas. Remote sensing can be an efficient management method. Notably, high-resolution satellite images can be used to detect aquaculture rafts and track changes in the number of aquaculture rafts over time. Nevertheless, drones have become more widely available in recent years and are effective for the aforementioned purposes because they can acquire higher resolution images than satellite images, thereby offering more detailed information about aquaculture facility management. In this study, we attempted to detect submerged aquaculture rafts using a drone-based multispectral camera RedEdge-MX Dual Camera Imaging System in Hirota Bay, Iwate Prefecture, Japan. Consequently, a submerged aquaculture raft was detected. We identified the difference in reflectance between 10 wavelength bands of submerged aquaculture rafts and revealed that the reflectance of the blue-475 nm and nir-840 nm bands could be used to detect submerged aquaculture rafts. We defined normalized differences for aquaculture raft detection to detect submerged aquaculture rafts using these two bands. Drone-based multispectral images could identify each piece of the wood poles that constitute the aquaculture raft. This detailed information can also be obtained from Google Earth images but not from high-resolution satellite images. High-resolution satellite images can be used to manage the number of aquaculture rafts over large areas, whereas drones are better suited for localized and daily management of aquaculture areas.

1. INTRODUCTION

Coastal aquaculture is widely practiced along Japan's coast using small-scale aquaculture facilities. Natural disasters, vessel accidents, and age-related deterioration can all cause damage to aquaculture facilities. In such cases, these facilities should be recovered or repaired immediately. However, as numerous aquaculture facilities are placed, daily management of fishing boats is challenging. Therefore, efficient methods are required to manage these aquaculture facilities. Remote sensing can be an efficient management method. In previous studies in Japan, satellite and airplane-borne synthetic aperture radar were applied to detect and discriminate the types of aquaculture facilities or areas (Murata et al. 2019a, Murata et al. 2019b). High-resolution optical satellite images were also applied to detect aquaculture facilities and monitor the spatial distribution and changes in the number of aquaculture facilities over time (Komatsu et al. 2020; Murata et al., 2021). Recently, drones have become more widely available. Drones have the advantage of acquiring higher-resolution images than satellite images and are then considered able to manage more detailed information regarding aquaculture facilities efficiently. Román et al. (2021) used a 10-band multispectral camera equipped with drones to monitor marine macrophytes on the sea floor. They concluded that multispectral imagery has proven to be more accurate than RGB imagery from RGB digital sensors onboard drones. Tait et al. (2019) promoted the use of RGB cameras aboard drones of intertidal macroalgal coverage but cautioned about the number of habitat classes that can be readily separated and suggested that immersed habitats may have insufficient spectral information to be classified accurately. Therefore, multispectral cameras can be considered more effective for investigating underwater objects than RGB cameras. In this study, we aimed to determine whether drone-based 10-band multispectral cameras are useful for efficient aquaculture facility management through the detection and analysis of submerged aquaculture facilities.

2. STUDY AREA AND DATA

2.1. Study area

The study site was selected in the inner part of Hirota Bay, Iwate Prefecture, Japan (Figure 1). Oysters and scallops were cultured using aquaculture rafts (Figure 2). The size of all aquaculture rafts is standardized to 10 × 4 m. This area was damaged by the tsunami caused by the 2011 Great East Japan Earthquake, which destroyed almost all the aquaculture facilities, and had been rapidly recovered since then. The aquaculture rafts are replaced in stages each year, depending on the needs that arise following recovery.

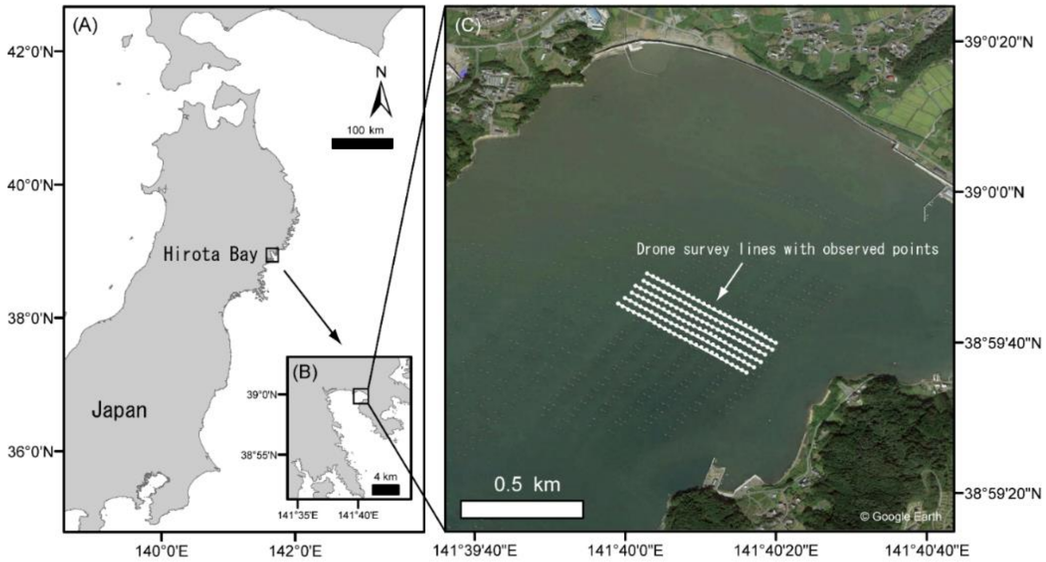

Figure 1. Map showing the location of the study site in the inner part of Hirota Bay, Iwate Prefecture, Japan (A–B). Drone survey lines with observed points are also shown on the Google Earth image (C).

Figure 2. Photograph of aquaculture rafts in Hirota Bay, Iwate Prefecture, Japan, taken on September 29, 2015.

2.2. Field survey and data

We used a multispectral camera RedEdge-MX Dual Camera Imaging System (Micasense, USA) attached to drone Inspire2 (DJI, China). This camera imaging system comprises two cameras and 10 bands of wavelengths—444 nm (coastal aerosol); 475 nm (blue); 531 and 560 nm (green); 650 and 668 nm (red); 705, 717, and 740 nm (red edge); and 840 nm (nir)—were observable at the same time. The field survey was conducted on July 26, 2022. At the time of observation, the weather was cloudy and sometimes sunny. Images were taken from an altitude of 140 m with a 75% overlap rate both in front and on the far side and between survey lines without hovering (Figure 1C). The time from takeoff to landing in this study was 10 min, and 156 images were observed in each of the 10 bands. Drone takeoff and landing were performed from the ground, and batteries did not change during the survey. The acquired 10-band images were each combined into a single orthomosaic image using Pix4Dmapper software (Pix4D, Switzerland). Images observed outside the survey lines and between the survey lines while moving to the next survey line were excluded before being applied to Pix4Dmapper. The 10 bands of orthomosaic images were converted to reflectance using a calibration plate that was observed just before the takeoff. A submerged raft included in 10 bands of orthomosaic images was analyzed. The reflectance of the sea surface, submerged aquaculture raft part, and normal aquaculture raft part in one survey line was analyzed to identify the differences between the 10 bands. Afterward, we proposed equitation to detect submerged aquaculture rafts.

To identify the advantage of drone-based multispectral images, we compared the images with the high-resolution satellite WorldView-3 1.6 m resolution multispectral band and 0.4 m resolution panchromatic band images (Maxar Technologies, USA) on April 12, 2021, and the Google Earth image (Google, USA) on October 20, 2020. We researched how detailed information about the aquaculture raft could be extracted in each image from visual interpretation.

3. RESULTS AND DISCUSSION

3.1. Differences in reflectance of submerged aquaculture rafts of 10 bands

We created 10 bands of orthomosaic images and zoomed them into a submerged aquaculture raft (Figure 3). We set a survey line of measurement of 1–45 pixels for the sea surface, 46–68 pixels for the submerged aquaculture raft part, and 69–130 pixels for the normal aquaculture raft part (Figure 4). In all 10 bands, the mean reflectance at the sea surface ranged from 0.059 to 0.094, submerged aquaculture raft part from 0.069 to 0.175, and normal aquaculture raft part from 0.214 to 0.372, respectively (Table 1). The reflectance range increased as one moved from the sea surface to the normal aquaculture raft part.

Although the mean reflectance ranges at the sea surface and submerged aquaculture raft part in visible bands (coastal aerosol-444 nm band to red-668 nm band) were 0.071–0.094 and 0.069–0.097, respectively, showing a slight difference, those of the invisible bands (red edge-705 nm band to nir-840 nm band) were 0.059–0.070 and 0.153–0.175, respectively (Table 1, Figure 5). The reflectance range was more than twice as high in the submerged aquaculture raft part than at the sea surface. Hence, to detect submerged aquaculture rafts, the reflectance of invisible bands seems to be an indicator. Particularly, it is preferable to use the nir-840 nm band, which has the highest mean reflectance. The blue-475 nm band showed the lowest mean reflectance 0.069 at the submerged aquaculture raft part and almost the same reflectance 0.071 at the sea surface. According to the characteristics of the submerged aquaculture raft area, the reflectance of the nir-840 nm band exceeds that of the sea surface, whereas the reflectance of the blue-475 nm band is nearly equal to that of the sea surface.

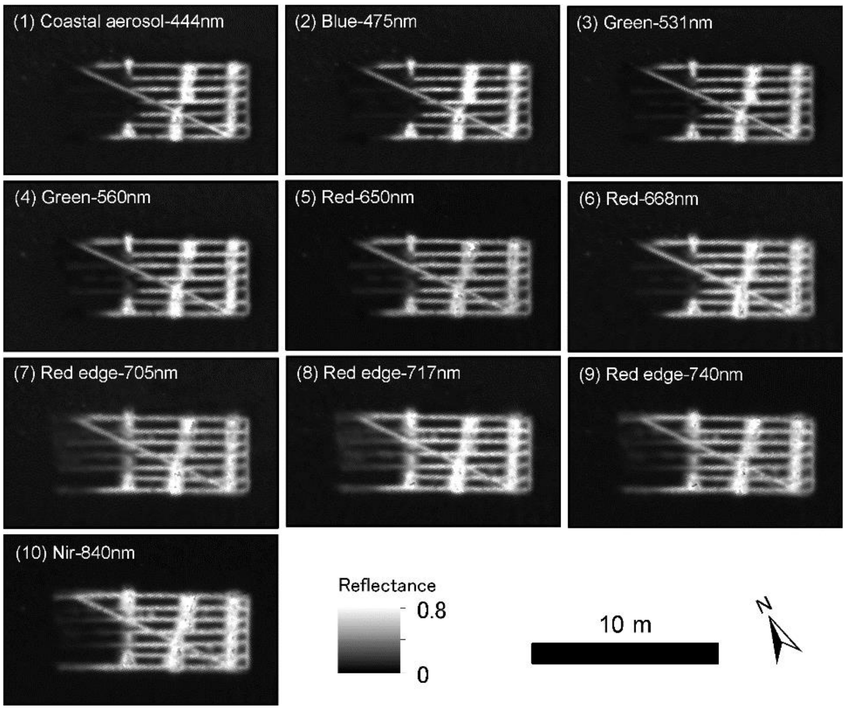

Figure 3. Orthomosaic images of 10-band reflectance of submerged aquaculture raft observed by a drone-based multispectral camera on July 26, 2022.

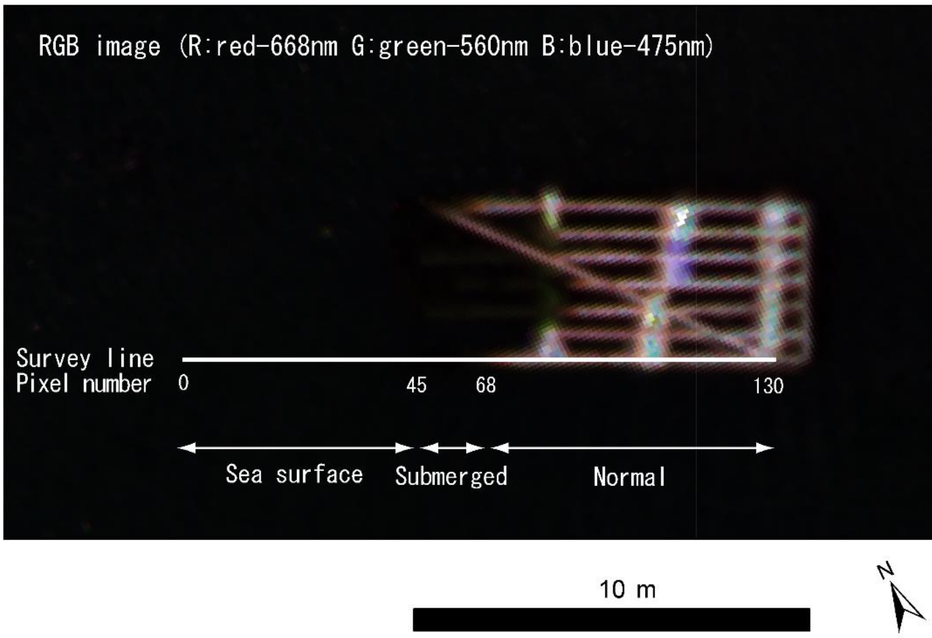

Figure 4. Survey line with pixel number on RGB (R: red-668 nm, G: green-560 nm, and B: blue-475 nm) image observed by a drone-based multispectral camera on July 26, 2022.

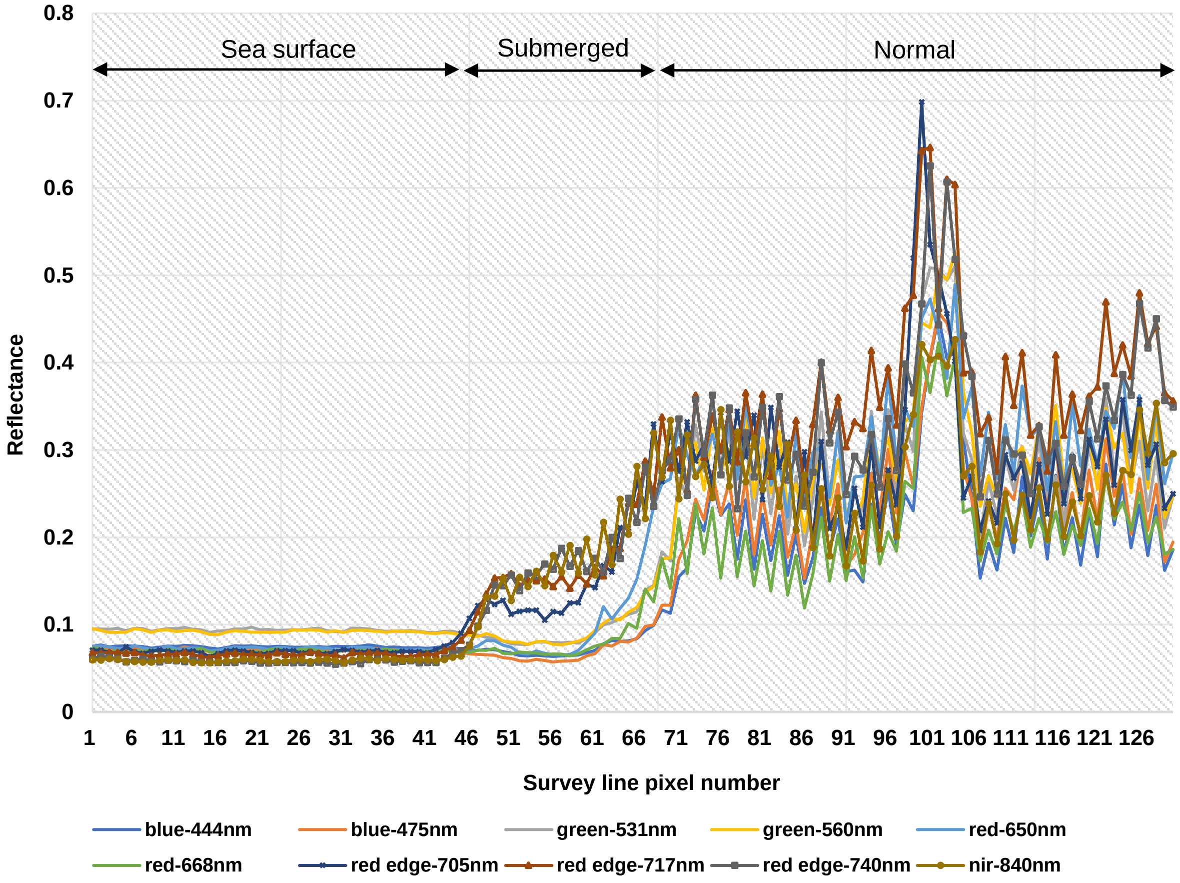

Figure 5. Graph showing the reflectance of sea surface (1–45), submerged aquaculture raft part (46–68), and normal aquaculture raft part (69–130). Figure 4 shows the survey line and pixel numbers.

Table 1. Results of the reflectance in 10 bands on the sea surface (1–45), submerged aquaculture raft part (46–68), and normal aquaculture raft part (69–130). Figure 4 presents the survey line and pixel numbers.

	Sea surface (1–45)			Submerged (46–68)			Normal (69–130)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Coastal aerosol-444 nm	0.072	0.077	0.075	0.064	0.099	0.073	0.113	0.452	0.220
Blue-475 nm	0.068	0.074	0.071	0.057	0.100	0.069	0.122	0.458	0.245
Green-531 nm	0.090	0.097	0.094	0.077	0.145	0.093	0.173	0.510	0.289
Green-560 nm	0.089	0.095	0.092	0.077	0.144	0.094	0.175	0.526	0.297
Red-650 nm	0.070	0.076	0.073	0.065	0.235	0.097	0.217	0.490	0.315
Red-668 nm	0.068	0.074	0.070	0.064	0.141	0.079	0.119	0.423	0.214
Red edge-705 nm	0.064	0.090	0.070	0.105	0.330	0.153	0.187	0.698	0.299
Red edge-717 nm	0.062	0.082	0.067	0.094	0.287	0.168	0.255	0.646	0.372
Red edge-740 nm	0.055	0.070	0.059	0.077	0.281	0.170	0.233	0.626	0.336
Nir-840 nm	0.057	0.064	0.059	0.076	0.320	0.175	0.168	0.427	0.268

3.2. Detection of submerged aquaculture rafts using normalized difference for aquaculture raft detection

As a result of the previous section’s findings, we investigated whether the blue-475 nm and nir-840 nm bands could be used as indicators to detect submerged aquaculture rafts. We defined the normalized difference for aquaculture raft detection (NDARD) using blue-475 nm and nir-840 nm bands and calculated equitation as follows:

$$\mathbf{NDARD} = \frac{\mathbf{NIR-BLUE}}{\mathbf{NIR+BLUE}}\ (\mathbf{-1 \leq NDARD \leq 1})$$

After applying NDARD, the submerged aquaculture raft parts became easier to visualize (Figure 6), which were difficult to visualize in the 10-band images (Figure 3). The value range of NDARD was −0.05 to −0.143, 0.037 to 0.598, and −0.016 to 0.536 on the sea surface (1–45), submerged aquaculture raft part (46–68), and normal aquaculture raft part (69–130), respectively. There was some overlap between submerged and normal aquaculture raft parts, but they were clearly distinguished from the sea surface. By setting a threshold value higher than the sea surface, the aquaculture raft, including the submerged aquaculture raft part, could be clearly detected.

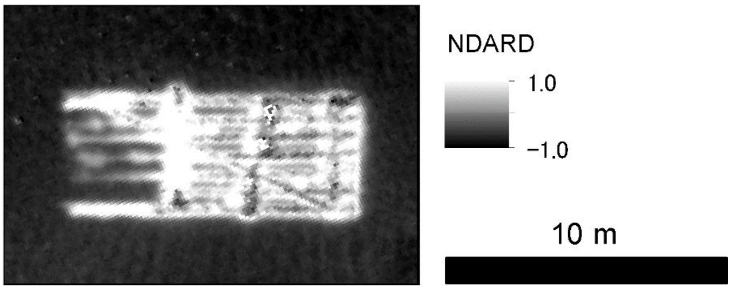

Figure 6. Results of normalized difference for aquaculture raft detection, showing the same aquaculture raft in Figures 3 and 4.

3.3. Comparison of the images of multispectral cameras, Google Earth, and high-resolution satellites

Figure 7 shows four images of the same aquaculture raft observed on different dates. It was possible to identify each piece of the wood poles that constitute an aquaculture raft from drone-based multispectral camera RGB images (Figure 7A) and Google Earth images (Figure 7B). From these images, seven wood poles of approximately 10 m were clearly detected. High-resolution satellite WorldView-3 RGB and panchromatic images could not detect each piece of the wood poles (Figure 7C–D).

Google Earth imagery provides a more detailed spatial resolution than high-resolution satellite imagery. Nevertheless, the latest images are not always updated, so drones have an advantage in terms of daily monitoring. High-resolution satellite imagery can observe a wider area than drones and can detect aquaculture rafts as one object. It has the advantage of managing the spatial distribution and number of aquaculture rafts in aquaculture areas.

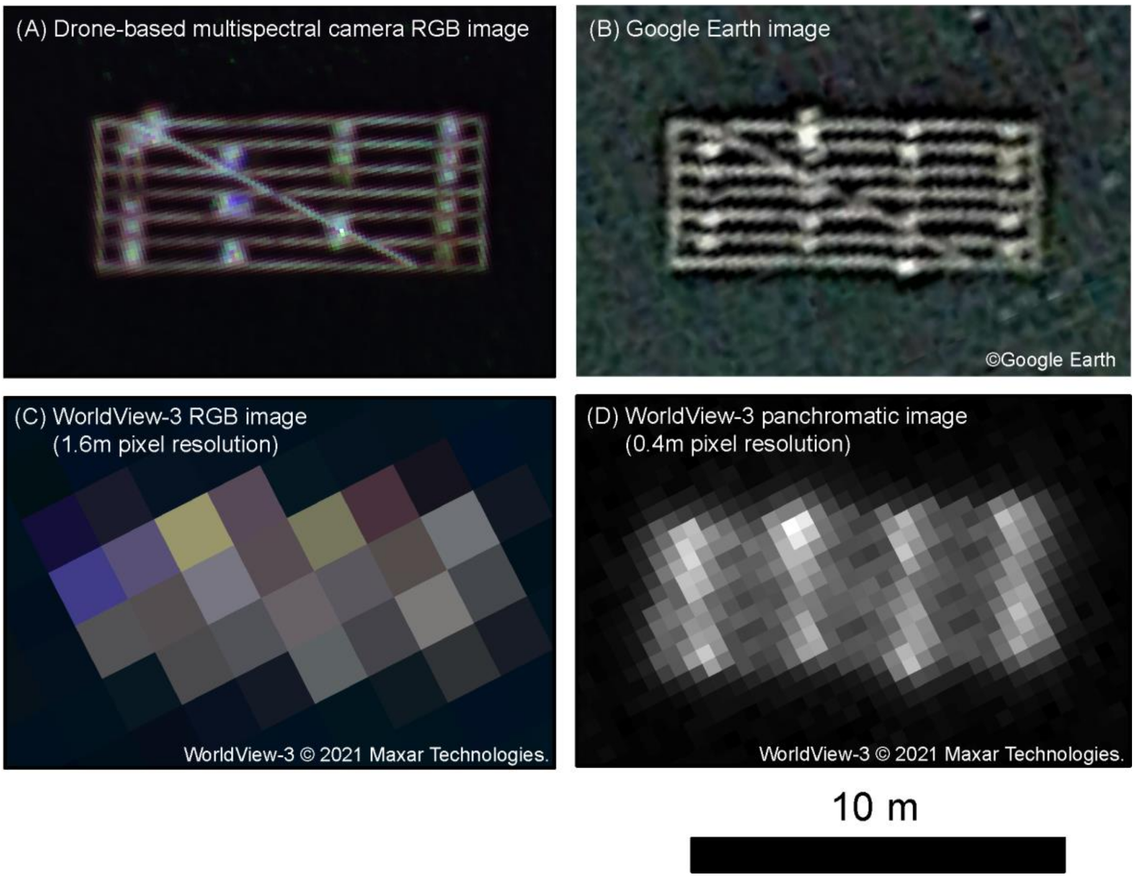

Figure 7. Comparison of a drone-based multispectral camera RGB image (A), Google Earth image (B), WorldView-3 RGB image (C), and WorldView-3 panchromatic image (D). Images showing the same aquaculture raft placed on different dates. The drone-based multispectral camera was observed on July 26, 2022, a Google Earth image was observed on October 20, 2020, and a WorldView-3 image was observed on April 12, 2021.

4. CONCLUSIONS

We investigated submerged aquaculture raft parts showing different reflectance bordering wavelengths of the visible band (red-668 nm) and invisible band (red edge-705 nm). We defined NDARD based on blue-475 nm and nir-840 nm bands to detect submerged aquaculture rafts and investigated how it became clear to visualize. Our results suggest that multispectral imagery is more accurate than RGB imagery in detecting submerged aquaculture rafts, which follows the results of Román et al. (2021). Although submerged aquaculture rafts can be detected from RGB imagery due to their shape (Figure 3), if the aquaculture rafts are completely submerged, they will be difficult to detect. In such cases, a multispectral camera is considered effective, although it depends on the submerged depth of the water.

Drones have an advantage in spatial resolution over high-resolution satellite images. In this study, we detected wood poles that make up aquaculture rafts from drone-based multispectral images observed at an altitude of 140 m. High-resolution satellite imagery is suitable for wide-area coverage of aquaculture areas, such as the number and spatial distribution, whereas drones are suitable for localized and daily management, such as detecting submerged aquaculture rafts. Therefore, we believe that both are useful for efficient aquaculture area management.

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