Seagrass Meadow Distribution Mapping in the Coastal Lagoon of Buan Island, Anambas

Dominikus Yoeli Wilson Laia[1]*, Ganang Wibisono[1], Eddy Handoko[1], Gita Endang Palufi[1], Fajar Kurniawan[2], Syofyan Roni[2], Muhammad Alrizky Ratno Budiarto[2]

[1]Anambas Islands National Marine Protected Area Office, National Marine Protected Area Office of Pekanbaru, Indonesian Ministry of Marine Affairs and Fisheries, Indonesia
Jl. Tanjung No. 29, Siantan, Anambas Islands, Riau Islands, 29791
[2]National Marine Protected Area Office of Pekanbaru, Indonesian Ministry of Marine Affairs and Fisheries, Indonesia
Jl. Budi Luhur, Mentangor, Pekanbaru, Riau 28286
E-mail: dominikus.laia@kkp.go.id

Abstract

Seagrasses are vital monocotyledonous marine flowering plants that serve as essential food sources for megaherbivores, contribute significantly to organic carbon production, and offer a multitude of crucial ecosystem services. Preserving seagrass habitats is of utmost importance, but the lack of comprehensive spatial data poses challenges to conservation efforts. The Anambas Islands, consisting of 255 small islands in the Natuna Sea, the southern part of the South China Sea, exemplify the scarcity of seagrass data, with the current distribution map only covering the Central and East Siantan region. In this study, our aim was to map the Buan coastal lagoon, where previous visual interpretation of Google Earth imagery suggested the presence of seagrasses. To achieve this, we carried out a drone survey and collected field data to classify and map the substrate types in the study area. The field survey documented four species in the location: T. hemprichii, E. acoroides, H. ovalis and S. isoetifolium, thereby expanding the known seagrass species in Anambas to nine. By employing a pixel-based classification of orthophotos, we achieved a promising overall accuracy of 69.5%. Our findings demonstrated that imageries from the Google Earth platform are viable alternatives for identifying seagrass meadows and can be utilized to support seagrass mapping efforts. This discovery offers valuable support for future seagrass mapping initiatives, especially at a local scale. Ultimately, our study contributes to the broader understanding of seagrass distribution in the Anambas Islands, and emphasizes the importance of further exploration to support conservation efforts in the seagrass ecosystem.

Keywords: *Natuna Sea, Google Earth, Drone Mapping, Marine Environment*

INTRODUCTION

Seagrasses are monocotyledonous marine flowering plants that live in near-shore environments and very shallow waters, down to a 60 m depth across the world's oceans except the Antarctic (Coles *et al*., 2011; Unsworth *et al*., 2019). They provide essential food sources for most megaherbivores, such as green sea turtles and dugongs, and serve as nurseries for many animals, including economically important fishery species (Beck *et al*., 2001). In the Indo-Pacific region, seagrass meadows are highly utilized as fishing areas (Unsworth and Cullen, 2010). Moreover, seagrasses stabilize sediments and produce an enormous amount of organic carbon, particularly in the tropics where the $CaCO_3$ saturation state is high (Orth *et al*., 2006; Unsworth and Cullen, 2010; Mazarrasa *et al*., 2015).

Seagrasses are distributed across the globe, but they exhibit low taxonomic diversity with approximately 60 species worldwide (Orth *et al*., 2006). Globally, six bioregions encompass all the oceans across the world where seagrasses are found: the Temperate North Atlantic (Bioregion 1), Tropical Atlantic (Bioregion 2), Mediterranean (Bioregion 3), Temperate North Pacific (Bioregion 4), Tropical Indo-Pacific (Bioregion 5), and Temperate Southern Oceans (Bioregion 6) (Short *et al*., 2007). Among these bioregions, the Indo-Pacific stands out as the center of seagrass biodiversity, boasting extensive seagrass meadows (Green and Short, 2003; Coles *et al*., 2011).

The Anambas Islands is an archipelago consisting of 255 small islands believed to have unique and complex ocean characteristics (Purba *et al*., 2014). This archipelago is located in the

Diterima/Received : 03-10-2023, Disetujui/Accepted : 27-10-2023
DOI: https://doi.org/10.14710/jkt.v26i3.20450

Natuna Sea, the southern part of the South China Sea, and has been designated as a national marine protected area (NMPA) (KKP, 2022). According to the bioregion classification of seagrass distribution, the Anambas is part of the Indo-Pacific bioregion, specifically in the seas of Southeast Asia. These seas, based on their benthic and pelagic biota characteristics, have been further classified into seven provinces and 22 ecoregions (Fortes *et al*., 2018). In this more detailed division, Anambas belongs to the Sunda Shelf province and Sunda Shelf/Java Sea ecoregion, which is claimed to have the highest species richness of seagrasses in the Southeast Asia seas (Fortes *et al*., 2018).

Seagrasses, as important marine ecosystems, encounter threats to their existence. Their common presence in shallow waters at the coastal-land interface makes them very vulnerable to disturbance and anthropogenic impacts (Unsworth *et al*., 2019). The decline of seagrass meadows areas globally was first observed in 1879 and is expected to continue (Waycott *et al*., 2009; Tan *et al*., 2020). According to Grech *et al*. (2012), the major threats to seagrasses in the Indo-Pacific bioregion are urban/port infrastructure development, urban/industrial runoff, trawling, and dreddging. These threats, coupled with rapid population growth and expansion of urban areas, are evidently occurring in Southeast Asia's coastal ecosystems, including the Anambas Islands (Stankovic *et al*., 2021).

Unfortunately, peoples' recognition of what seagrass is and its importance is poor, mainly because its values are mostly indirect (Unsworth *et al*., 2019). In reality, seagrasses produce a wide variety of ecosystem services, such as compost fertilizers, fish habitats, nurseries for marine life, pharmaceuticals, coastal protection, water purification, education, spiritual value, and tourism (Costanza *et al*., 1997; Mtwana Nordlund *et al*., 2016). The unquestionable importance of seagrasses makes it crucial to carry out initiatives to protect and preserve their existence.

Mapping the distribution of the current seagrass meadows is a mandatory measure to protect their existence (Coles *et al*., 2011; Fortes *et al*., 2018; Thalib *et al*., 2018; Tan *et al*., 2020). However, in many locations, seagrass habitats are largely uncharted, even at a low spatial resolution and scale; thus, most marine conservation initiatives are difficult to accomplish (Unsworth and Cullen, 2010). Moreover, efforts to map the global distribution of seagrass are stagnant, and some regions that are predicted to have seagrass meadow potential are still largely unmapped (Unsworth *et al*., 2019). Anambas Islands is one such case where spatial seagrass data are limited. Estimation of the seagrass area in Anambas has been conducted since 2012, but the mapping was concentrated in the region of Central and East Siantan only (KKP, 2014). This is assumed to be due to the large number of small islands in Anambas and the inadequate preliminary data on seagrass distribution. This research explores the potential of integrating remote sensing images derived from Google Earth computer program as preliminary data, with drone mapping and field survey to discover existing seagrass meadows in the Anambas Islands. This study marks the first instance of mapping the seagrass beds in Anambas outside the Central and East Siantan region.

MATERIALS AND METHODS

Image interpretation of areas speculated to be seagrass meadows in Anambas (outside of Central and East Siantan Region) was carried out to fill the gap in sources of information about seagrass existence across the entire region. The observation used Google Earth technology, which provides high accessibility to the most recent high-resolution imagery. Buan Island coastal lagoon and Ujung Island were found and chosen as the study site due to having similar visual characteristics, in terms of substrate, to seagrass meadows in the previously known and validated area (Figure 1). The existing seagrass meadow distributions that are well known in Anambas and have previously been studied are the Teluk Sunting area (an inlet to the south of Matak Island) and the Air Asuk Strait area (Air Asuk, Lidi, and Liuk Island) as also mentioned in Damar *et al*. (2013), KKP (2014) and Budiarto *et al*. (2020, 2021).

A Drone survey was conducted using the DJI Phantom 4 RTK camera. A prior flight mission was designed using DJI GS Pro software on iPad. The front-lap and side-lap were set at 85% and 65% respectively, with a flight height of 80 meters. These settings resulted in a ground image resolution of 2.2 centimeters per pixel. Further analysis utilizes the Agisoft Photoscan Professional software and workflow to process the aerial photos, generating the RGB orthomosaics TIFF file.

The observation points along line transects were designed prior to the field survey which situated based on their visual characteristics in Google Earth images. Observation points were placed every two meters along the line transect using the "Generate Points Along Lines" tool in ArcGIS Pro 3.1.2 software. A total of 151 observation points were generated in the Buan coastal lagoon, with 92 points serving as model samples and 59 points serving as reference samples for accuracy assessment. We observed and recorded the dominant substrate type (coral reef, seagrass, macro algae, or bare substrate) at each point.

Supervised classification and accuracy assessment

Pixel-based classification on an RGB orthomosaic drone photo was conducted using the "Maximum Likelihood Classification" tool in ArcGIS Pro 3.1.2 software. The supervised classification test was performed in the shallow water of the Buan coastal lagoon which terrestrial objects has been masked out prior the analysis. The default settings of 0,0 were used for the "Reject Fraction", and the Sample option was selected for "A Priori Probability Weighting". A priori probability weighting determines the probabilities based on the number of cells in each class relative to the total number of cells sampled across all classes.

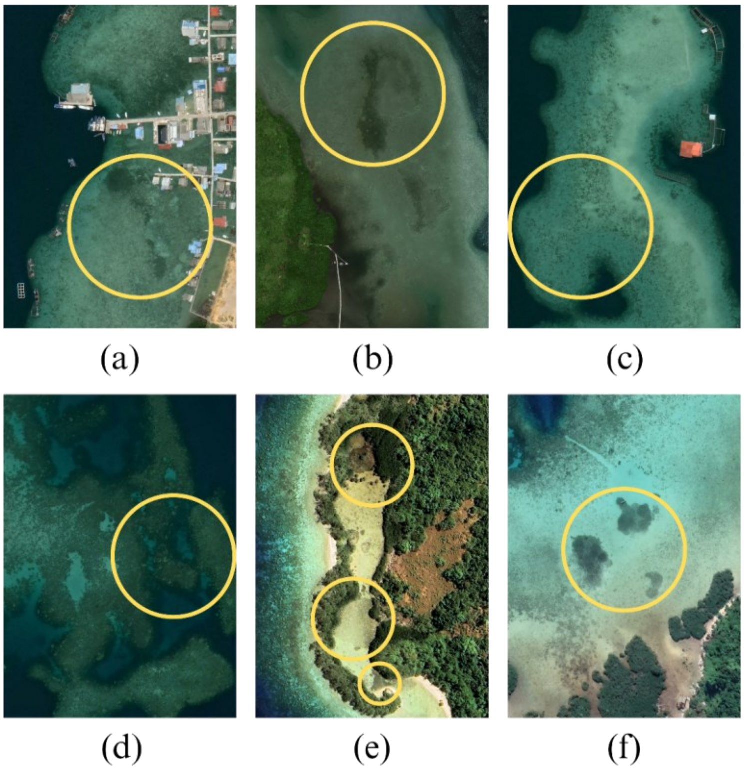


Figure 1. Visual appearance of substrate types in Anambas from digital images from Google Earth: (a) seagrass meadow in Air Asuk; (b) seagrass meadow in Teluk Siantan; (c) macro algae in Air Asuk strait; (d) coral reef in Lidi Island; and the visual appearance of expected seagrass meadows: (e) Buan Island; (f) Ujung Island

A site-specific assessment was conducted for accuracy assessment for substrate types. In this study, the site-specific assessment utilized the error matrix (Congalton and Green, 2019) to determine the spatial comparison between the classification results and the reference data. The error matrix is a square array that displays the number of sample units assigned to a specific class in the classified data compared to the referenced data. This matrix computes the overall accuracy (OA), producer's accuracy (PA), and user's accuracy (UA).

RESULTS AND DISCUSSION

The research anticipates the presence of newly discovered seagrasses. As demonstrated in Figure 1 we suggested that the Buan coastal lagoon and Ujung Island are likely to contain seagrass meadows based on their visual characteristics. Through field surveys, we confirmed that all the areas speculated to be seagrass in these two locations are indeed seagrass meadows (Figure 2). This experiment validated the approach whereby Google Earth imagery served as preliminary data to identify the locations of seagrass meadows in Anambas.

Buan Island is a very small island, covering an area of 0.94 square kilometers. The island boasts two lagoons on its western coast. The north lagoon contains inlets facing towards the north, while the south lagoon has inlets that open towards the south. For the purpose of this study, we refer to the south lagoon as the "Buan coastal lagoon". Encircled by a thriving mangrove ecosystem, this lagoon supports a diverse array of marine juveniles and biota. During our field investigations, we identified four seagrass species thriving in the lagoon: *T. hemprichii*, *E. acoroides*, *H. ovalis*, and *S. isoetifolium*. Remarkably, the presence of *S. isoetifolium* in Anambas has been documented for the first time in this particular location. Furthermore, the seagrass community structure in this area is visually dominated by *T. hemprichii* species. This differs from the findings in the study by Budiarto *et al*. (2020) in Central Siantan, where *E. acoroides* dominated in all parameters, including density, coverage, and Importance Value Index (IVI) of seagrass meadows.

Ujung Island is located seven kilometers southwest of Buan Island. This is one of the closest islands to Buan, second only to Taloyan Island in the northwest. Its proximity to Buan was one of the reasons for considering Ujung Island as a validation site. However, this site has visually distinct dominant species compared to Buan, with *E. acoroides* being the most commonly found species in the communities. In addition to *E. acoroides*, we identified *T. hemprichii* and *H. ovalis* in the study location. The validation area focused on the northern bay, where a small mangrove ecosystem and insignificant human infrastructure can be found along its coast.

The existence of seagrass in Buan coastal lagoon and Ujung Island demonstrates the ability of Google Earth technology to provide preliminary information on seagrass distribution in Anambas. Based on the results of this study, we attempted to identify the locations of other potential seagrass meadows through image interpretation on Google Earth. One such location is the bay to the south of Temiang Island. This location exhibits textures and patterns similar to those of Ujung Island.

(a)

(b)

Figure 2. Existing seagrass meadows in (a) Buan coastal lagoon with T. hemprichii and S. isoetifolium species; and (b) Ujung Island with E. acoroides species

The use of Google Earth technology and other remote sensing data for discovering seagrass meadows does, however, have limitations. Suggesting the location of seagrass meadows only from remote sensing data is difficult to accomplish if the meadows consist of patchy monospecies of "small leaf" seagrasses. The key elements for visual interpretation for this type of bed might be different and even challenging to identify. The Mapping Team for the 2023 Anambas Islands NMPA Ocean Account Survey and Validation (MTOA) from the Indonesian Geospatial Information Agency (BIG) and the Indonesian Ministry of Marine Affairs and Fisheries (KKP) recently reported seven locations of seagrass meadows that have never been documented. Most of the meadows are formed with monospecies of small-leafed seagrasses such as *H. ovalis*, and *H. pinifolia*. Each reported location usually exhibits the visual characteristics of bare substrate domination, and determining these meadows from Google Earth is nearly impossible. The mapping and validation of seagrass meadow areas in these locations need to be carried out by further studies.

Along with the MTOA reports, the previous documentation of seagrass species by Liao *et al*. (2004), Damar *et al*. (2013), LKKPN Pekanbaru (2015), and Wibisono (2023), as well as the findings in this study, a total of nine species were found across fifteen locations of seagrass meadows across the Anambas Islands. Among these, five species belong to the Cymodoceaceae family, while the rest belong to the Hydrocharitaceae family (see Table 1). Twelve of the 15 seagrass meadow locations are situated outside the Central and East Siantan region (Figure 3). These 12 locations consist of two validated areas and one potential area from this study, seven potential areas from MTOA reports, and one potential area each from the reports by Liao *et al*. (2004) and LKKPN Pekanbaru (2015).

The seagrass meadows in the Anambas Islands are unique. The area is composed of 255 small islands, with only three of them having an area above 1,000 square kilometers. These very small islands are located in the open sea, which forces the seagrasses to spread widely in small areas throughout the region. They are mostly found in bays or in intertidal areas with minimal impact from the south and north winds. Coles *et al*. (2011) explained that the environmental parameters affecting the existence of seagrass include biophysical variables such as temperature, waves, currents, salinity, wave action, water currents, substrate, depth, light, day length, epiphytes, and diseases, as well as the availability of seeds and anthropogenic inputs. Even though this region does not have an extensive seagrass area, it is considered significant in conservation initiatives. In terms of management, the loss of a meadow in a small area may be a greater concern than a loss occurring as a fraction of a larger area (Coles *et al*., 2011). Furthermore, the Anambas Islands NMPA is mainly designed to protect coral reefs, seagrasses, and coral fishes as its conservation targets (KKP, 2022). Therefore, mapping seagrasses at a local scale across the Anambas Islands region is highly recommended.

Table 1. The list of species found in the Anambas Islands region

Species	Family	Abbreviations
Enhalus acoroides (L.f.) Royle	Hydrocharitaceae	Ea
Thalassia hemprichii (Ehrenb. ex Solms) Asch.	Hydrocharitaceae	Th
Cymodocea rotundata Asch. and Schweinf	Cymodoceaceae	Cr
Halophila ovalis (R.Br.) Hook.f.	Hydrocharitaceae	Ho
Oceana serrulata (R.Br.) Byng and Christenh.	Cymodoceaceae	Os
Halodule uninervis (Forssk.) Boiss.	Cymodoceaceae	Hu
Syringodium isoetifolium (Asch.) Dandy	Cymodoceaceae	Si
Halodule pinifolia (Miki) Hartog	Cymodoceaceae	Hp
Halophila spinulosa (R.Br.) Asch.	Hydrocharitaceae	Hs

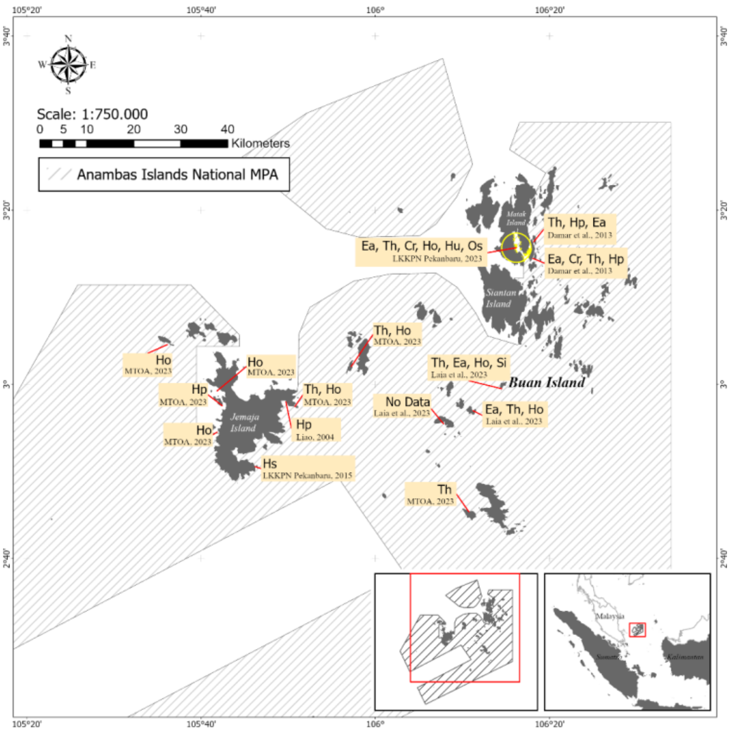


Figure 3. Distribution of potential and existing seagrass meadows across the Anambas Islands region. The area within the yellow circle indicates the existing seagrass meadows map of the Anambas Islands

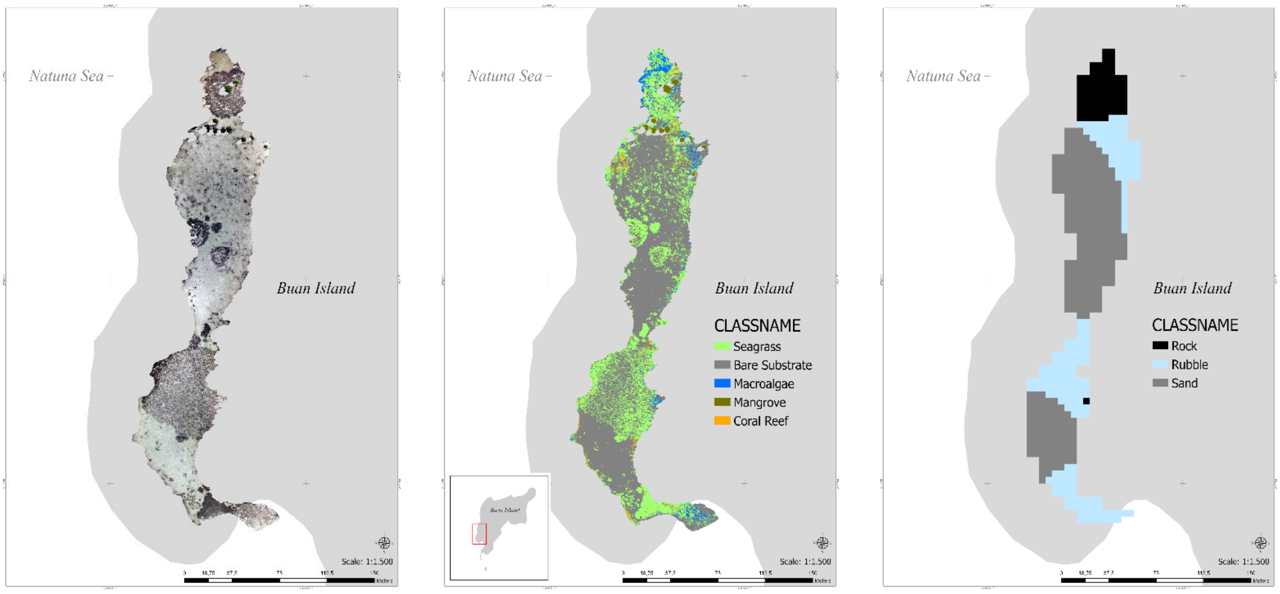
Common substrates that can be observed in most of the optically shallow waters of Anambas include bare substrates, coral reefs, seagrass meadows, and macroalgae. Distinguishing between these substrate types based solely on their tone or color in satellite imagery is quite challenging, except for bare substrates. Therefore, we also utilized secondary, tertiary, and higher elements of image interpretation to identify the substrate types (Jensen, 2007). We discovered that the key elements for differentiating between coral reef ecosystems, seagrass meadows, and macroalgae communities in the shallow waters of Anambas are the texture and pattern. As shown in Figure 1 (a–d), coral reef communities have a rougher texture compared to seagrass meadows and macroalgae communities. Additionally, based on their pattern, seagrass meadows exhibit an agglomerated pattern, while macroalgae communities display a more dispersed pattern. We acknowledge that these key elements may not be applicable to other locations outside Anambas, but this approach offers a higher likelihood of determining substrate types in the shallow waters of Anambas.

Drone mapping and field data collection were conducted during the low tide. This strategy aimed to identify seagrass species when the seagrasses were partially exposed. Moreover, drone mapping during low tide reduced glint effect and turbidity on the water, which can be challenging during image processing (Koedsin *et al*., 2016). Doukari *et al*. (2021) discovered that the environmental conditions (presence of sunglint, illumination, wind speeds, solar elevation angles) and acquisition time in drone mapping affect the accuracy of coastal habitat classification. Therefore, we undertook to conduct the survey at the preferred time, in the morning when the tide was low. However, there are mangroves inside and surrounding our location site, thus illumination on the substrates was unavoidable. Shadows are indeed often acknowledged as the most important challenge in any UAV/drone mapping (Agarwal *et al*., 2021). Hence, in addition to terrestrial masking, we performed shadow masking to exclude them from the classification processing.

The Maximum Likelihood classification resulted in an overall accuracy of 69.5% for mapping the substrate types in Buan coastal lagoon (Figure 4). This accuracy is higher than that achieved for seagrass species distribution mapping using the same classification based on Sentinel-2 images by Fauzan *et al*. (2017), and lower than the accuracy achieved with unsupervised pixel-based classification based on drone orthophotos by Duffy *et al*. (2018). The accuracy improvement in this study may be attributed to the higher spatial resolution and the generalization of the seagrass class, while the decreased accuracy might be due to the different method used in classification. Lower accuracy is also demonstrated in Wicaksono and Lazuardi (2018) research, where they used high-resolution satellite PlanetScope images in a more complex benthic habitat and classification scheme. However, it should be noted that these accuracies may be considered questionable because the algorithm attempts to extrapolate the area outside of the fieldwork statistically (Hossain *et al*., 2015). Therefore, the number of samples and class determination are crucial in order to reduce the subjectivity arising from statistical extrapolations. Despite these challenges, remote sensing-based seagrass mapping is claimed to be an effective alternative tool to obtain seagrass spatial data. It provides very rich information datasets that cannot be accomplished with commonly used in situ methods alone (Kuriandewa and Supriyasdi, 2006; Hamad *et al*., 2022; Wijantara *et al*., 2022).

Classes with the lowest user and producer accuracy are macroalgae and coral reef, both of which have zero percent (0%) accuracy. This indicates that there is no chance that the classified results for macroalgae and coral reef are true representations in the field. Furthermore, the zero percent producer accuracy for both macroalgae and coral reef implies that neither of these classes in the field was correctly classified. Instead, they are often misclassified as seagrass and bare substratum (Table 2). In contrast, mangrove is the only class that was perfectly classified, mainly due to its distinct spectral characteristics compared to the other classes.

The error in this classification may have resulted from various factors. The first factor could be the variation in coverage and distribution of each class in the study site. Coral reef and macroalgae were found very sparsely and with low coverage. Macroalgae and coral reef were



(a) (b) (c)

Figure 4. (a) Drone orthomosaic photo of Buan coastal lagoon; (b) the result of Maximum Likelihood classification with 69.5% overall accuracy; (c) the benthic habitat classification of Buan coastal lagoon from Allen Coral Atlas (2022)

Table 2. Error matrix for classification of substrate types in Buan coastal lagoon

Classified Pixels	Reference Data						
	Seagrass	Macroalgae	Bare substrate	Coral reef	Mangrove	Total	UA (%)
Seagrass	17	2	4	1	0	24	70.8
Macroalgae	2	0	0	0	0	2	0
Bare substrate	5	3	19	1	0	28	67.9
Coral reef	0	0	0	0	0	0	0
Mangrove	0	0	0	0	5	5	100
Total	24	5	23	2	5	OA 69.5%	
PA (%)	70.8	0	82.6	0	100		

misclassified as seagrass and bare substrate due to having a similar tone and color to seagrass, and their locations were mixed with bare substrate. Higher spatial resolution produced more detailed information and heterogeneous spectral information, which may have contributed to the decrease in accuracy (Ruwaimana *et al*., 2018). The second factor is the accuracy of mobile phone positioning systems during field data collection. The horizontal accuracy of mobile devices ranges from 1.72 to 13 meters and varies between mobile types, seasons, and area conditions (Zandbergen and Barbeau, 2011; Merry and Bettinger, 2019; Tomaštík *et al*., 2021). The higher level of error while receiving global navigation satellite system (GNSS) data on mobile phones is certainly a serious concern in field surveying and mapping. The last factor is the error possibility from the interpreter inconsistencies in the in situ sample assessment during field data collection (Fauzan *et al*., 2017).

Compared to a satellite-based method, airborne remote sensing data has proven to be more effective in generating local-scale products. The benthic habitat of the Anambas Islands, which comprises a high number of very small islands, may be less effectively mapped using satellite-based remote sensing data. As an example, the Allen Coral Atlas (2022) employed the Sentinel 2, Landsat 8, and Planet Dove data along with object-based analysis to map benthic habitats around the world. However, due to its large-scale nature, this mapping produced coarser information. Examining the habitat map of the Buan coastal lagoon obtained from the Allen Coral Atlas, we can observe that the lagoon was classified as sand, rock, and rubble (Figure 4). This illustrates that satellite imagery is effective for regional to global scale mapping, while small areas require very high spatial resolution to obtain more reliable information.

CONCLUSION

In conclusion, our study highlights the power of combining Google Earth imagery and drones for seagrass meadow identification in the Anambas Islands. This helps advance conservation efforts, improve seagrass distribution understanding, and emphasizes the importance of local-scale mapping and collaboration for effective preservation.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the NMPA Office (LKKPN) of Pekanbaru for funding this research and to the Mapping Team for the 2023 Anambas Islands NMPA Ocean Account Survey and Validation from BIG and KKP for reporting the locations of seagrass meadows discovered during the survey.

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