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Coral reef classification using drone screening in Teluk Segadas, Pulau Pangkor

Nurul Nadiah Misman[1,*], Muhammad Noor Amin Zakariah[1], Khairul Arifin Mohd Noh[1], Hasrizal Shaari[2], Wan Nurzalia Wan Saelan[2]

[1] Department of Petroleum Geoscience, Universiti Teknologi PETRONAS, 32610, Seri Iskandar, Perak, Malaysia
[2] Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21300, K. Terengganu, Terengganu, Malaysia
* Corresponding author email address: nurul_22002268@utp.edu.my

Abstract: Coral reefs are complex and diverse marine ecosystems that provide numerous benefits to the environment and to humans. However, they face multiple threats that jeopardise their well-being, necessitating effective conservation efforts. Traditional methods for assessing coral reefs are time-consuming and resource-intensive, limiting the scale and frequency of data collection. This study aims to assess the potential of drone technology for studying coral reefs in Teluk Segadas, Pulau Pangkor, where spatial information on benthic habitats is limited. The primary objectives are to determine the presence of coral reefs, and the density of coral cover in the study area. A total of 330 aerial images of Teluk Segadas were taken using a DJI Pro Mavic 2. The aerial photos were combined into a single orthophoto image. Later, segmentation and classification were performed using Structure-from-Motion (SfM) and a supervised classification technique, K-Nearest Neighbour (KNN). The orthomosaic image of Teluk Segadas is presented in this study and five classes were identified, that is live coral, dead coral, sediment, coral rubble and rock. Overall, the shallow water in Teluk Segadas was dominated by live coral (38947.38 m^2) along with sediment (9273.9 m^2). The rest of the area was covered by dead coral (4946.08 m^2), rubble (3709.56 m^2) and rock (1854.78 m^2). Furthermore, coral coverage of Teluk Segadas, Pulau Pangkor was 66% and was dominated by massive coral. The overall accuracy was 73% with producer accuracy (PA) and user accuracy (UA) values ranging from 60-80% and the misclassification rate ranging between 20-30%. This study demonstrates that images captured by drone in any environment setting can be processed, classified, and assessed for accuracy. In addition, this study provides a different perspective in understanding coral reef well-being, and aids in monitoring and management efforts.

Keywords: Drone, mapping, spatial, aerial photography, environment, coral reef, Pulau Pangkor

INTRODUCTION

Coral reefs are complex and diverse marine ecosystems, with benefits extending beyond their visual appeal. These ecosystems support an impressive array of species, ecosystem services and livelihoods (Eddy *et al*., 2018). Coral reefs can be found in tropical regions ranging from latitude 30° North to 30° South of the equator (Jones *et al*., 2022). Generally, they occur in shallow water, but are also found on a smaller scale in deep and cold water (Hebbeln *et al*., 2020). Coral reefs have exceptional productivity and diversity. They serve as biodiversity hotspots and fulfil essential functions such as providing habitat and ecological niches for various marine life, function as coastal protection, sequester carbon and boost fisheries and tourism (Heap *et al*., 2009; Costanza *et al*., 2014; Sale *et al*., 2014; Spalding *et al*., 2017; Harris *et al*., 2018) which is significant essential for both human and the environment. Goods and services rendered by coral reefs have contributed significantly to the global economy (Welle *et al*., 2017). Given their substantial contribution to ecological and economic well-being, reefs are one of the most important ecosystems on Earth. Hence, it necessitates understanding, monitoring, and conserving them.

Regrettably, coral reefs are experiencing a global decline (Bento *et al*., 2016). Natural fluctuations in environmental conditions and anthropogenic stressors such as climate change, overfishing, pollution, and habitat destruction affect the ability of coral reefs to provide these services, with reductions and change over millennial and decadal timescales (Praveena *et al*., 2012; Zaneveld *et al*., 2016; Eddy *et al*., 2021). Projections indicate that by 2030, up to 99% of the ecosystem will be threatened by the synergistic effects of natural pressures (Burke *et al*., 2011). Coral reefs in Malaysia, like those in other parts of the world, are not excluded from experiencing these pressures. According to Praveena *et al*. (2012), sedimentation is mainly responsible for the deterioration of coral health on the West Coast of Peninsular Malaysia, while on the East Coast, reefs are threatened by disease and predation. Destructive fishing practices are having severe impacts on coral reefs in

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East Malaysia (Praveena *et al*., 2012). Prolonged exposure to such pressures jeopardises the well-being and survival of coral reefs, necessitating urgent attention and action to ensure their health and continued existence. The consequences of losing these ecosystems would be severe for the communities that rely on these ecosystems for their livelihood.

Monitoring or assessing coral reefs is important for understanding their condition, their response to environmental changes and identifying the threats, which can facilitate effective coral reef conservation and management. Among the latest methods for assessing the coral reef ecosystems is aerial photography, which captures photographs of the Earth's surface from an elevated position above the ground, typically from aircraft, drone or other airborne vehicles. Unmanned aerial vehicles (UAV), or drones have emerged as a new, relatively low-cost tool that will aid in environmental mapping processes of coral reef ecosystems (Hamylton, 2017). The versatility of UAV has led to their widespread use in many fields, including environment, agriculture, health, and military (Hamylton, 2017; Ayamga *et al.*, 2021). Unmanned aerial vehicles and autonomous underwater vehicles have been extensively used to study coral reefs. Coral surveys have employed photogrammetry analysis to quantify coral coverage (Cornet & Joyce, 2021; Waheed *et al*., 2021). The methods used for this study are well known, and have been the basis of several journal articles, however, they have not been used widely in Malaysia's efforts to map its coastal areas for seamless habitat classification along the coastline, especially in the supratidal-intertidal zone.

The spatial information on benthic habitats around Pulau Pangkor is limited, which has implications for the comprehensive understanding of the coral ecosystem in this region. In the current global focus on achieving sustainable development goals (SDG) with SDG14 (life under water), this limited knowledge and understanding hinders effective conservation efforts (Safuan *et al*., 2016). Traditional in-water surveys of studying coral reefs are time and manpower intensive, resulting in limited coverage in terms of area covered and frequency of data collection (Misman *et al*., 2023). The use of UAVs has the potential to greatly increase the acquisition of data.

This study aims to use aerial images acquired by a UAV of Teluk Segadas (Segadas Bay), near Pulau Pangkor (Pangkor Island) off the West Coast of Peninsular Malaysia, to conduct a study of coral reefs. Currently, spatial data on the benthic environment in the seas around Pangkor Island are limited. The information gathered by this study will help future management and conservation efforts. In addition, the efficacy and accuracy of this method will be evaluated with an eye to expanding its use in the future.

METHODOLOGY

Study area

Pulau Pangkor is the largest island within a small archipelago of four West Coast islands situated in Perak state, Peninsular Malaysia. It is located approximately 3.5 km off the southwestern coast of Perak, off the northwest coast of Peninsular Malaysia. The island lies in the east-central part of the Straits of Malacca. Pulau Pangkor covers an area of 18 km^2 with a length of 9.6 km. The beaches are exposed to pollution risks from potential oil spills originating in the Strait of Malacca. Notably, the water surrounding Pulau Pangkor is very green and murky with the salinity ranging between 29 and 32 parts per thousand (ppt) (Xin *et al*., 2013).

For this study, we focused on one specific site, Teluk Segadas, which has not been previously studied for corals. Previous coral studies have been conducted at other sites around Pulau Pangkor such as Pangkor Laut (Reef Check Malaysia, 2018), Dedan Bay and Raja Bay (Toda *et al*., 2007). This site is not categorized as No-Fly-Zone, which make the process of collecting data using a drone easier, without the need to obtain permission. Teluk Segadas is located on the south side of Pulau Pangkor. The beach lacks direct road access, which keeps it relatively off the beaten path for most visitors. As a result, the beach experiences low human impact, minimising the impact on the surrounding coral reef. This bay is characterised by calm and relatively shallow waters. The map of the study site is illustrated in Figure 1.

General workflow

The general drone mapping workflow involves mission planning, data acquisition, image processing, image analysis and accuracy assessment (Figure 2). During the mission planning phase, we used specialised software for flight planning, where the drone's flight path and the altitude for data acquisition was input, with the area covered and the degree of image overlap were determined. Data acquisition involves the collection of aerial photographs during the flight of the drone. The collected images were then to used to produce maps, 3D models and other desired outputs through the use of photogrammetric processing software. The resulting images were then analysed to extract information

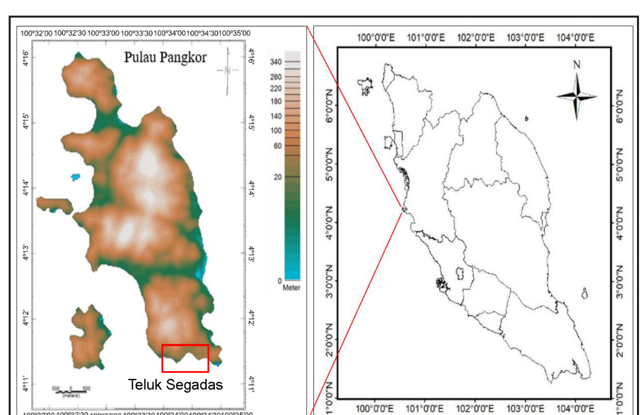

Figure 1: A map of study area - Teluk Segadas, Pulau Pangkor, Perak, Malaysia.

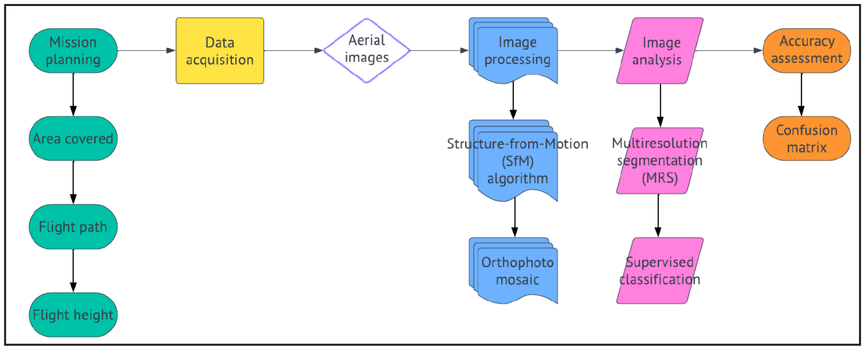

Figure 2: General workflow of drone mapping.

used, for instance, to classify the areas being imaged. The final step of the process involved assessing the collected data for its accuracy and reliability.

Mission planning and data acquisition

The aerial photos were acquired on 11th July 2023 using a DJI Mavic 2 Pro. An application (DroneDeploy, https://www.dronedeploy.com/) running on a device like mobile phone or tablet device with the Android or iOS operating system was used for planning and programming the UAV's flight path. Flights and data acquisition were conducted autonomously.

Aerial photos were acquired during low tide at an altitude of 0.3-0.6m to maximize the visibility of coral formations and other underwater features. Low tide minimizes water depth, allowing for clearer observations of the coral reefs. Take-off and landing were controlled manually from a land-based location to ensure safety. In total, 330 aerial photos were taken of the study area. The parameters set for the flight acquisition were as presented in Table 1.

Image processing

Agisoft Metashape (www.agisoft.com) was used to create the image mosaic, combining all aerial photos captured by the drone into a single photo/image (orthophoto). Agisoft Metashape is software designed for the photogrammetric processing of digital images. It excels in generating high-quality 3D spatial data suitable for a wide array of applications, including GIS. The orthomosaic processes of all aerial photos were carried out by a series of processing steps as shown in Figure 3 were demonstrated by Nababan *et al.* (2021). In this study, water column correction procedures were not undertaken. Aerial images were acquired at low tide, with coral appearing on or close to the surface, thus, the water column's impact on light penetration was minimal.

Images analysis

Further analysis involved object-based image analysis (OBIA) through Trimble eCognition v9.0 (https://geospatial.trimble.com/en/products/software/trimble-ecognition). Segmentation was done using a Multiresolution Segmentation

Table 1: Parameter of flight acquisition.

Parameters	Details
Date	11th July 2023
Tide	1.4
Flight altitude	60 m
Flight duration	16 min 28 sec
Frontal overlap	75%
Lateral overlap	70%
Speed	4.0 m/s
Shutter interval	2.0 s
Covered area	8 Ha
Images numbers	330
Images resolution	1.0 cm/px
Battery used	2

Figure 3: Process flowchart for orthomosaic creation in Agisoft Metshape.

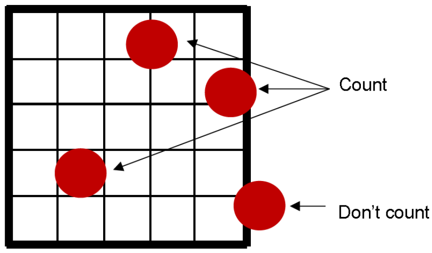

Figure 4: A quadrant (square frames) with a grid pattern.

(MRS) algorithm, as has been demonstrated by Roelfsema *et al*. (2013), applying scale value of 300. A scale value of 300 resulted in the best map, among those tested (100, 150, 200, 350, 400). MRS is an algorithm that can merge single pixels into objects. Three parameters - compactness, shape and scale affect the MRS performance. Then, supervised classification was applied using the K-Nearest Neighbor (KNN) algorithm. Upon selection of a segment, a specific class label was assigned to it in accordance with the type it represents.

Based on image analysis, the study area was subdivided into five classifications: live coral, dead coral, sediment, coral rubble and rock. To determine the area covered by a classification, four quadrants (square frames) with a grid pattern as illustrated in Figure 4 were established and were superimposed on top of the coral by random placement. The percentage of the quadrat area that is covered by corals was estimated visually.

Accuracy assessment

An accuracy assessment of the final classification result was conducted by applying a confusion matrix based on 214 sampling points. This is a common accuracy test performed on remote sensing classification results data. The classified image was compared with the actual classes or objects that were identified during field observations (Wahidin *et al*., 2015), allowing the identification of misclassification, and improving the accuracy. Ground-truthing data was acquired by swimmers using snorkels.

In general, a confusion matrix (Roelfsema & Phinn, 2008) has three important components - overall accuracy (OA), producer (PA), and user accuracy (UA). It was calculated using the following formula:

Overall accuracy (OA) =

$$\frac{\text{(The total number of correctly classified)}}{\text{(The total number of reference sampled)}}$$

Producer accuracy (PA) =

$$\frac{\text{(The total number of correctly classified in a class)}}{\text{(The total number of reference sampled for that class)}}$$

User accuracy (UA) =

$$\frac{\text{(The total number of correctly classified for a class)}}{\text{(The total number of classified as that class)}}$$

RESULT AND DISCUSSION

Digital orthophoto

Overall, 464 aerial photographs taken in Teluk Segadas, Pulau Pangkor were observed and processed. The quality and resolution of the images were adjusted accordingly to produce a good orthophoto image. All these photographs were combined through several steps of the orthomosaic process to produce a single high-resolution drone orthophoto mosaic. The orthophoto was then georeferenced. Orthophoto images generally only generate 2D display images are of two dimensions, with embedded XY coordinate information (Ahmad *et al*., 2013).The orthophoto image of the orthomosaic result in this study is presented in Figure 5. A total of 464 images were used, of which 425 have been successfully aligned. The resulting orthophoto image was processed based on following parameters: (1) tie points were established, resulting in 2,126,550 points; (2) depth maps were created using the high quality setting and aggressive filtering; (3) The creation of a 3D model consisting of 6,65349,086 faces at the high quality setting; (4) A point cloud was generated comprising 111,994,483 points at high quality; (6) a Digital Elevation Model (DEM) possessing 20,264x7, 585, 2.39 cm/pixel and (7) an orthomosaic of 40,528 x 15,170 pixels with a resolution of 1.29 cm/pixel.

The orthophoto image was then used for image classification. The resolution of the orthophoto influences the level of detail captured, which influences the classification process. Accurate georeferencing is essential for spatial analysis, mapping, and integration with other geospatial datasets. While the orthophoto is a powerful tool, it is essential to acknowledge its limitations. A number of factors may influence the quality of the orthophoto, such as cloud cover or the turbidity of the water during the acquisition process (Doukari *et al*., 2021). Future studies may explore methods to mitigate these challenges and enhance the reliability and potential of the digital orthophoto.

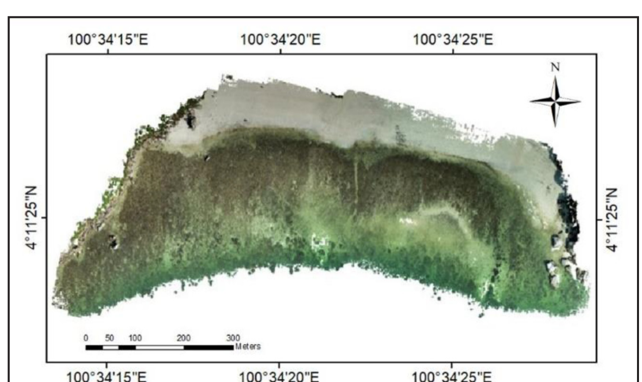

Figure 5: The orthophoto image of the study region that was generated by an orthomosaic process.

Image classification

Using the orthophoto image, this study was able to identify five classes within the studied area, which were coral, dead coral, rubble, rock and sediment. Each of these categories was identified through its distinct characteristics, such as colour and shape. For instance, coral was distinguished by its vibrant brownish-green or yellow hues, whereas dead coral appeared darker in colour and lacked the intricate details of living coral colonies. Similarly, sediment was easily recognizable by its brownish-white hue. Rock was identified by its irregular shape.

A total of 6157 objects were produced through segmentation. Of these, 4457 represent live coral, 200 correspond to dead coral , 1175 correspond to sediment (S), 175 to rubble and 175 to rock. The shallow water of Teluk Segadas was mainly occupied by reef coral that comprised 9273.9 m^2 of the area (Figure 6). Sediment covered 9273.9 m^2. The remaining areas of 44946.08 m^2, 3709.56 m^2 and 1854.78 m^2 were occupied by dead coral, rubble and rock, respectively.

The shallow water of Teluk Segadas is primarily characterized by the presence of live coral with sediments and dead coral, rubble and following in abundance. The large area occupied by live coral colonies in the study area indicate that the habitat is suitable for these species. However, to accurately assess the health of the coral reef ecosystem, it is essential to consider other indicators such as the levels of macroalgae and the diversity of coral reef fish and invertebrates. According to the "Goldilocks Principle," (Hennige *et al*., 2021), the presence of coral in itself indicates favourable environmental conditions for coral survival rather than being a measure of reef health. These favourable environmental conditions include suitable water quality (Browne *et al*., 2015; Wenger *et al*., 2016), adequate light availability (Suggett *et al*., 2013; Ricardo *et al.,* 2021), and minimal anthropogenic disturbances.

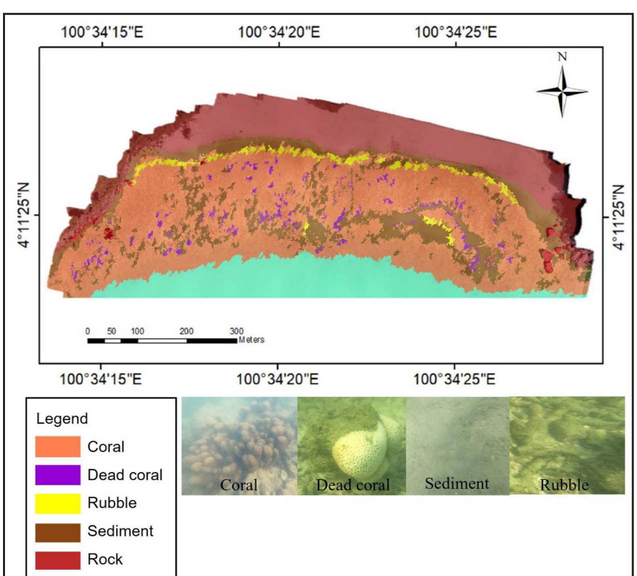

Figure 6: Classification of benthic habitat in shallow water using supervised classification K-Nearest Neighbour (KNN).

Sediment is often found alongside the live coral. There are also areas which are dominated by sediment cover. The distribution of sediment-dominated areas can be attributed to wave movement, which can dislodge and transport corals, leaving the previous area dominated by sediment, or they can be related to the influx of external sediment. Sediment areas play a significant part in shaping the landform and sediment movement. High rates of sediment deposition can result in a negative effect on coral reef ecosystems. Not only can sedimentation smother corals and impede their growth, but it can also affect physical and chemical properties of the coral ecosystem (Goatley & Bellwood, 2013). This effect is significant on reef areas close to the shoreline (Fabricius *et al*., 2005). Influx of external sediment may be caused by natural processes such as erosion, as well as anthropogenic activities such as coastal development and runoff.

The presence of dead coral, rubble and rock may represent areas of past coral mortality, physical damage, or natural substrate variations. In this study, dead coral is sparse, so it is likely that the reef in this area has been exposed to minimal anthropogenic disturbances, since the beach is remote and does not receive many visitors. Most of the dead coral was observed close to the shoreline, where disturbances would be greater compared to deeper water.

Our observations show that the live coral cover in Teluk Sagadas covered 66% of the area, while 16% was covered by sediment, 9% by dead coral, 6% by rubble and 3% by rock, as shown in Figure 7. Findings from this study are consistent with previous work by Riegl & Purkis (2005) who also documented high coral cover (over 50%) using remote sensing techniques. This indicates a healthy coral reef ecosystem within the area of study.

Teluk Segadas appears relatively better off in terms of coral cover than the area studied by Toda *et al*. (2007) at Dedan Bay and Raja Bay. Toda *et al*. (2007) found that the percentage of live coral in Dedan Bay and Raja Bay was only 17.9 % (poor condition) and 35.8%, (fair condition),

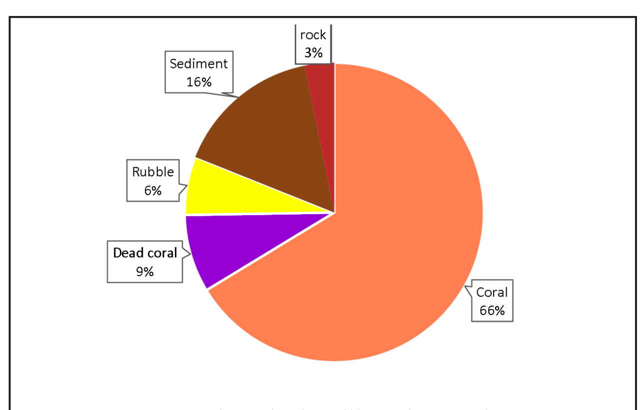

Figure 7: Percentage of coral cover in Teluk Segadas, Pulau Pangkor.

respectively, indicating that anthropogenic pressure is a strong influence on coral ecosystems around Pangkor Island, due to the island's large human population, with tourism as the prime economic activity posing a threat to coral reefs (Praveena *et al*., 2012). It should be noted, however, that the earlier studies might not be comparable with the current one, as observations were taken using a CVT transect, rather than through drone imagery. In addition, coral habitat in the shallow-water benthic habitat of Teluk Segadas is heavily dominated by massive coral. Massive coral species are thought to have a higher tolerance to disturbances which happen nearshore, such as strong wave action (Williams *et al*., 2013).

Coral cover and density are important metrics used to assess the health and condition of coral reefs and the impacts of environmental stressors such as climate change, pollution, overfishing, and habitat destruction. These metrics provide insights into the abundance and distribution of coral species within a given area, helping researchers and conservationists understand the health of coral ecosystems and track changes over time.

As Pulau Pangkor lies in the Malacca Strait, coral reefs in the region are poorly developed due to high levels of turbidity and sedimentation (Praveena *et al*., 2012; Safuan *et al*., 2018). Coral reefs are found exclusively off headlands and islands in the west of Pangkor (Yusuf *et al*., 2009) because they are exposed to the open sea and are less affected by the sedimentation and turbidity.

Accuracy assessment

Accuracy testing reveals that the overall accuracy of supervised classification (KNN) in this study was 73% (Table 2). This indicates fairly well in correctly identifying classes. The producer accuracy (PA) and user accuracy (UA) values range from 60–80%. The misclassification rate ranged between 20-30%, showing that there were instances where incorrectly assigned a class to a certain data point. The obtained accuracy result in this study was higher than 60%, the recommended minimum overall accuracy value for mapping habitat (Mount, 2007), indicating that the classification process employed in this study was reasonably effective in accurately delineating benthic habitats in shallow water.

The use of drones yields a higher accuracy of level classification compared with satellite imagery (Wahidin *et al*., 2015; Anggoro *et al*., 2018). While this is the case, misclassifications can be attributed to the complexity of the benthic habitat and the number of observation points. Further research should be carried out to increase the accuracy of the drone image classification, which may be done by optimizing the drone›s flying time as it captures the image, as well as the angle at which the drone›s camera is positioned in relation to the water surface (Nababan *et al*., 2021). Water depth is one factor that can influence the classification results (Bennett *et al*., 2020). In this study, the flight mission was carried out during low tide, and optimal weather conditions together with a shallow water helped to minimize the effects of ripples and waves.

Drone technology is a low-cost and rapid survey tool for surveying shallow-water coral, producing multispectral and bathymetric data, provided environmental conditions are favourable. Calm water, low winds and minimal sun glint (Casella *et al*., 2017) are examples of conditions favourable to successful data collection. Drone based photography has been found to be more effective in classifying coral habitat types over a finer spatial resolution compared with high-resolution commercial satellite image acquisitions such as WorldView-2, Ikonos, and Quickbird (Zaki *et al*., 2022). To maximize the full potential of drones for future applications, numerous

Table 2: Confusion matrix of classified image.

	Coral	Dead coral	Sediment	Rubble	Rock	Row total	User Accuracy	Commission Error
Coral	56	7	8	5	3	79	0.71	0.29
Dead coral	6	29	4	0	1	40	0.73	0.28
Sediment	5	5	47	4	1	62	0.76	0.24
Rubble	2	2	2	16	0	22	0.73	0.27
Rock	1	0	2	0	8	11	0.73	0.27
Column Total	70	43	63	25	13	214	Overall accuracy	
Producer's Accuracy	0.80	0.67	0.75	0.64	0.62	Overall sum	73%	
Commission Error	0.20	0.33	0.25	0.36	0.38			

studies have been carried out to enhance their utilization (Muslim *et al*., 2019; Chong *et al*., 2022; Mohamad *et al*., 2022).

CONCLUSION

The study concludes by presenting the final digital orthophoto image of the orthomosaic output. The resulting classification revealed that live coral dominates the shallow-water region (38947.38 m^2), followed by sediment (9273.9 m^2), dead coral (4946.08 m^2), rubble (3709.56 m^2) and rock (1854.78 m^2). The coral cover in Teluk Segadas was 66%, indicates coral in 'good condition'. The confusion matrix test revealed the overall accuracy was 73% with producer accuracy (PA) and user accuracy (UA) values ranges from 60–80% and the misclassification rate was 20-30%. This study demonstrates that images captured by drone can successfully be processed, classified, and assessed for their accuracy. These preliminary findings will be interpreted further, together with analyses on sediment to create possible parameters and give a better picture on the coral ecosystem in Teluk Segadas, Pulau Pangkor. This research could provide a difference perspective in understanding coral reef well-being and aid in monitoring and management efforts. While this study represents one specific site, which, although important, might not fully represent the whole of the coral reef environment around Pulau Pangkor, it can be expanded and repeated elsewhere to give a broader picture. Findings from this study may provide valuable insight for the stakeholders to address concerns toward achieving SDG14. The gaps in understanding of the coral reefs in this area underscore the importance of further research and exploration to enhance conservation efforts. Future studies could focus on exploring the opposite (north) side of Pulau Pangkor. That side of Pulau Pangkor is more developed, and the health of the reefs would provide more insight into the effects of anthropogenic inputs.

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AUTHORS CONTRIBUTION

Conceptualization: NNM, MNAZ, KAMN, HS and WNWZ; methodology: NNM, MNAZ, HS and WNWZ; data acquisition: NNM; software: NNM and KAMN; analysis: NNM and MNAZ; writing: NNM; supervision: MNAZ; funding acquisition: KAMN. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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