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Status and temporal change in the distribution of seagrass beds and coral reefs in the waters of Phu Quoc islands, Kien Giang province

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ABSTRACT

To assess the status and changes in the distribution of seagrass beds and coral reefs in Phu Quoc from 2005 to 2018, we utilized high-resolution multi-spectrum satellite images, aerial photographs, and Google maps. We collected data from three time periods: 2005 (using ASTER with 15 m resolution), 2010 (using SPOT5 with 10 m resolution), and 2018 (using SENTINEL-2 with 10 m resolution). We also conducted an accuracy assessment of 78 key sites in March-April 2019, representing corals (25 sites), seagrasses (28 sites), rocks (8 sites), and sand (12 sites) through SCUBA diving. The results showed that in 2018, the waters of Phu Quoc contained 513 ha of coral reefs and 10,035 ha of seagrass beds, with 290 ha of coral reefs and 9,185 ha of seagrass beds located within the Phu Quoc marine protected area. While the area of coral reefs remained stable between 2005 and 2018, the seagrass beds experienced a significant decline of 652 ha (6.1%), with most losses occurring at Bai Vong (501 ha; 4.69%), Ong Doi cape - Dam Ngoai island (55 ha; 0.52%), Mot Island and Vinh Dam (42 ha; 0.4% each), and Da Chong cape (12 ha; 0.12%). This decline is largely due to recent infrastructure development for community and tourism purposes, which has caused the degradation of seagrass beds.

Key words: Distribution, temporal change, coral reefs, seagrass beds, Phu Quoc MPA.

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INTRODUCTION

The use of GIS technology and satellite imagery in mapping the status and changes in the distribution and changes of marine habitats, including mangroves, seagrass beds, and coral reefs, has become widely popular worldwide [1–7]. In Vietnam, numerous studies have used similar methods to map the marine habitats in several areas, including in Phu Quoc islands in 2005 using SPOT images combined with aerial photographs [8], Bach Long Vi and Con Dao in 2006 by IKONOS images [9], Nha Trang bay from 2002 to 2015 using Orbview-3 combined with aerial photographs, SPOT5 and ALOS-AVNIR2 [10], Cam Ranh Bay and Thuy Trieu lagoon from 1996 to 2015 by Landsat TM/ETM+/OLI images [11], Cu Lao Cham - Hai An from 2015 to 2018 using Landsat 5-TM, SPOT4, and AVNIR2 SENTINEL 2-MS [12].

Phu Quoc islands, located in Kien Giang province, are home to diverse marine habitats, including rocky shores, seagrass beds, coral reefs, and muddy bottoms [13]. These habitats support high levels of marine resource production, making the area an important fishing ground for the local communities and the southwestern region of Vietnam. To enhance the management of marine resources, Phu Quoc islands established a marine protected area (MPA) in 2007. Recent results reported the distribution of coral reefs, with 474 ha identified in the waters surrounding Phu Quoc islands, mainly distributed around the island group in the southern part of An Thoi islands (362 ha, occupied with 76% of the total area) [8]. Seagrass beds were reported to cover 2006 reported more than 10.063 ha, mainly distributed in the northern and eastern parts of Phu Quoc big island with 9 species [14]. The study on ichthyoplankton on seagrass beds conducted in July 2013 reported high densities of fish eggs and larvae, giving mean values of 436.97 eggs/100 m³ and 50.36 larvae/100 m³, with the highest being recorded around Mot Island to Bai Bon (95–162.96 larvae/100 m³) [15]. For target resources related to marine habitats, analysis of data and information from local consultations in 2010 reported more than

142 tonnes of commercial resources (mainly by groupers and fusiliers) and 80,000 seeds of groupers exploited on coral reefs, and more than 900 tonnes of commercial resources from seagrass beds [16]. The results indicate that seagrass beds and coral reefs play essential roles in resources and seeds for fisheries in this area.

Recently, the use of marine biodiversity and resources in the coastal waters of Phu Quoc islands for socio-economic, fisheries, and tourism development has contributed to improving income for local communities. However, the area is facing negative impacts and threats to the maintenance and sustainable use of marine biodiversity and resources due to factors such as the fast socio-economic growth of infrastructure development for the local population, and marine transportation, climate changes, and conflicts in the resource utilization among stakeholders. Nevertheless, studies on the impacts of these activities on the marine environment and resources have been lacking. Therefore, this study aims to provide an updated status and temporal changes in the distribution of vital marine habitats for assessments and orientation of planning and sustainable use of marine biodiversity in Phu Quoc islands.

MATERIALS AND METHODS

Assessments of status of distribution

Sources of satellite images for analysis

The combination of classification of satellite images and aerial photographs with ground truthing for mapping the distribution of seagrass beds and coral reefs in Phu Quoc islands was carried out in 2018. Sets of satellite images and aerial photographs used for classification in this study include:

2 satellite image scenes of multi-spectrum SENTINEL-2 with radiation resolution of 12 bit and spatial resolution 10 m: S2B_MSIL1C_20180213T032829_N0206_R018 taken on 13 February 2018 and S2A_MSIL1C_20181102T031901_N0206_R118 taken on 02 November 2018 (Fig. 1a & b).



Figure 1a. SENTINEL-2 satellite image with a resolution of 10 m was taken on 13 Feb. 2018



Figure 1b. SENTINEL-2 satellite image with a resolution of 10 m was taken on 2 Nov. 2018

Google Maps with a scene taken on 10 April 2018 applied for classification.

Materials for the establishment of critical sites for analysis of satellite images

The field ROI (regions of interest) data were based on a review of available data and information from previous studies for the classification of the distribution of coral reefs and seagrass beds to interpret the distribution of coral reefs and other substrates by the DII method. Sites were separated into two groups:

Group 1: selected 150 homogenous sand sites at each location in the study area that are taken at different depths to calculate DII in band pairs for image classification of underground habitats.

Group 2: selected 132 sites in different substrates (corals, mangroves, seagrasses, rock, and sand at each location in the study area) for image classification and habitat mapping.

Classification techniques

Classification of the distribution of coral reefs and seagrass beds by GIS technology: Based on principles of classification of coral reefs by calculating Depth Invariance Index [11, 17, 18], the following steps: geometry correction, radiometric correction, atmospheric correction, the masked land, and outside images (eliminating non-processing parts), supervised classification and converting raster to vector GIS layers.

Using image sources from Google Map to assess the status and temporal changes of seagrass beds: Visual interpretation and screen digitizer of the distribution of seagrass beds in 2005, 2010, and 2018 were conducted on the background of Google Earth images with steps as follows: a) Positioning concerned objects on Google Earth; b) Using images with very high resolution and aerial photographs, editing them by using Add/Image overlay to mask the existing images into Google Earth; c) Screen Digitizer by Add Path/Add Polygon from Google Earth; d) Converting file (*.kml) in Google Earth to GIS (*.shp, *.tab, *.csv,...) by using tools kml2shp or kml2x; and e) Mapping,

calculating status and temporal changes in the area of seagrass beds and coral reefs.

Ground truthing and mapping the distribution of marine habitats

Based on the results of the classification of satellite images in 2018, we selected 75 sites of key substrates (corals: 25, seagrasses: 28, rock: 10, and sand: 12) for ground truthing to evaluate the accuracy of the classification of images. The sites selected for coral reefs were mainly located in the locations of Ganh Dau (north to the north-west of Phu Quoc big island), especially submerged reefs, due to a lack of data from the previous studies and the island group in the south of Phu Quoc big island. The sites selected for ground truthing of seagrass beds were mainly located at Rach Vem (north of Phu Quoc), Bai Bon to Bai Vong (east of Phu Quoc), and Ong Doi Cape (south of Phu Quoc). The ground truthing was carried out in March-April 2019.

Results from the ground truthing show that the accuracy of the classification of images was high, in which rock and sand were 100%, while seagrasses and corals were 92.8% (26/28 sites corrected) and 88% (22/25 sites corrected), respectively.

Assessments of temporal changes to marine habitats

Sources of satellite images and aerial photographs

Assessments of temporal changes of coral reefs and seagrass beds were identified in 2006, 2010, and 2018, coinciding with the times of marine biodiversity surveys. The classification was mainly based on satellite images taken in 2005 and 2010:

4 satellite image scenes of multi-spectrum ASTER with radiation resolution of 11 bit and spatial resolution of 15 m covering Phu Quoc islands: AST_L1T_00311242004033624, AST_L1T_00301112005033708, AST_L1T_00301032011034337, AST_L1T_003102420100, 33724 and AST_L1T_00301032011034337 (Fig. 2a–d).

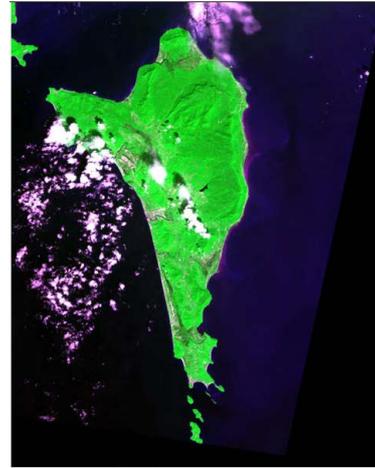


Figure 2a. ASTER image (15 m) taken on 24 November 2004



Figure 2b. ASTER image (15 m) taken on 11 January 2005

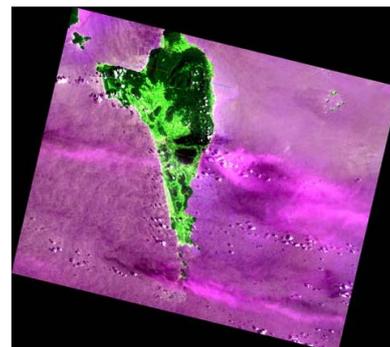


Figure 2c. SPOT5 image (10 m) taken on 18 March 2005

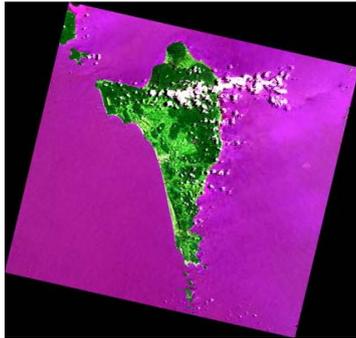


Figure 2d. SPOT5 image (10 m) taken on 23 May 2010



Figure 2e. ASTER image (15 m) taken on 24 October 2010



Figure 2f. ASTER image (15 m) taken on 3 January 2011

2 satellite image scenes of multi-spectrum SPOT5 with radiation resolution of 8 bit and spatial resolution of 10m: 5 271-329/7 05/03/18 03:54:34 2J and 5 271-329/6 10/05/23 03:42:05 1J (Fig. 2e–f).

Aerial photographs with high resolution (1 m) covering the area of the islands group of An Thoi islands were taken by the Aerial Photography Company - Ministry of National Defense in February 2005 (Fig. 3).



Figure 3. The complex color images of the island group in the South of Phu Quoc islands were taken by airplane in February 2005

Additionally, we combined Google Earth images, including those taken on 1 January 2004, 16 December 2011, 19 December 2011, and 10 April 2018, for analysis.

Calculation of Depth Invariance Index (DII)

The Depth Invariance Index of each band pair DII_{12} , DII_{13} , and DII_{23} for each satellite image, area, and time is taken as follows:

ASTER was taken on 24 November 2004 for seagrass beds covering Bai Bon and adjacent locations with a Depth Invariance Index of 1.8148, 1.2990, and 0.6944 (Figure 4).

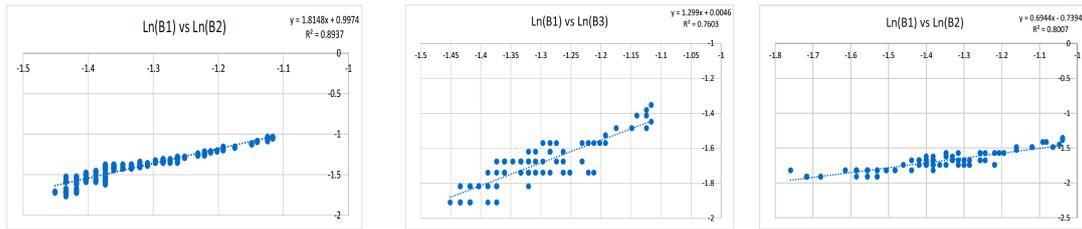


Figure 4. The Depth Invariance Index (DII) was calculated from the ASTER image dated 24 November 2004 for seagrass beds at Bai Bon and adjacent waters

ASTER was taken on 11 January 2005 for locations with a Depth Invariance Index of seagrass beds covering Vung Bau and adjacent 1.3728, 0.8320, and 0.6165 (Fig. 5).

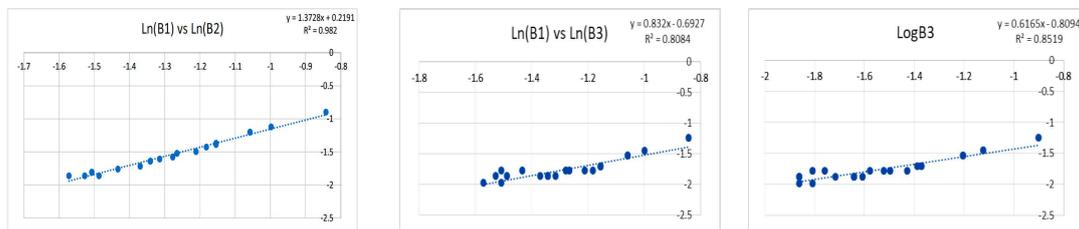


Figure 5. The Depth Invariance Index (DII) was calculated from the ASTER image dated 11 January 2005 for seagrass beds at Vung Bau and adjacent waters

ASTER was taken on 11 January 2005 for locations with a Depth Invariance Index of coral reefs covering Ganh Dau and adjacent 2.0248, 0.7055, and 0.3375 (Fig. 6).

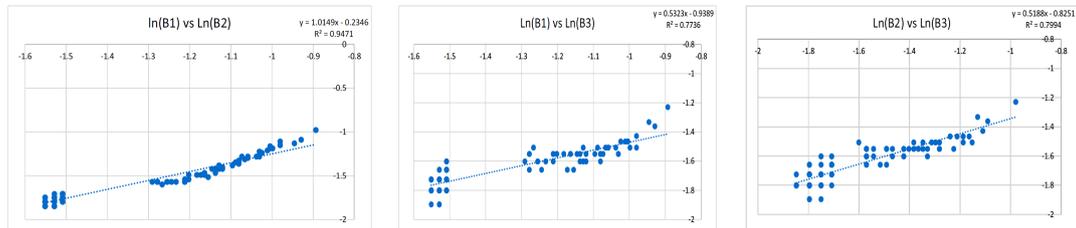


Figure 6. The Depth Invariance Index (DII) was calculated from the ASTER image dated 11 January 2005 for coral reefs at Ganh Dau and adjacent waters

ASTER was taken on 11 January 2005 for locations with a Depth Invariance Index of coral reefs covering An Thoi and adjacent 1.0149, 0.5323, and 0.5188 (Fig. 7) covering.

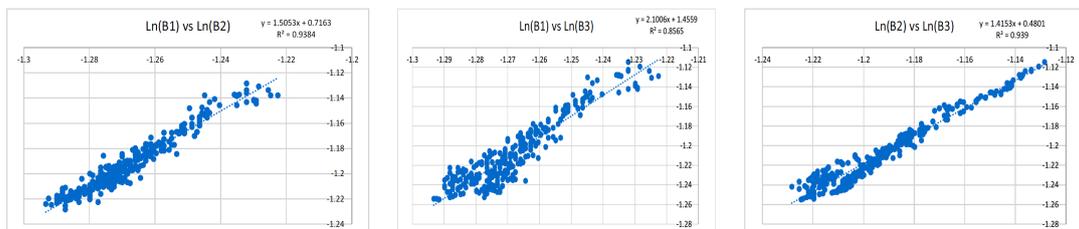


Figure 7. The Depth Invariance Index (DII) was calculated from the ASTER image dated 11 January 2005 for coral reefs at An Thoi and adjacent waters

ASTER was taken on 24 October 2010 for locations with Depth Invariance Index of 1.5035, 2.1006, and 1.4153 (Fig. 8).

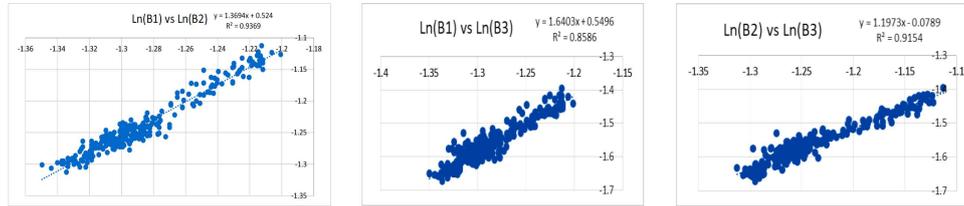


Figure 8. The Depth Invariance Index (DII) was calculated from the ASTER image dated 24 October 2010 for seagrass beds at Bai Bon and adjacent waters

SPOT5 was taken on 23 May 2010 for locations with a Depth Invariance Index of 1.3694, 1.6403, and 1.1973 (Fig. 9).

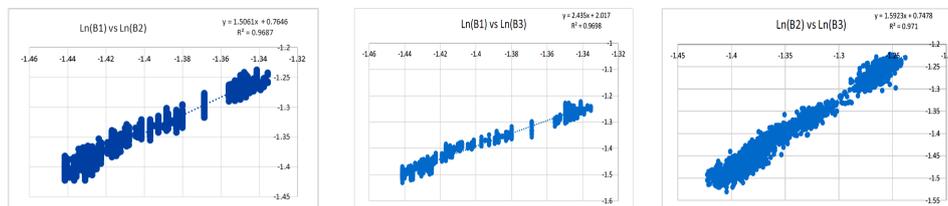


Figure 9. The Depth Invariance Index (DII) was calculated from the SPOT image dated 23 May 2010 for coral reefs at Ganh Dau and adjacent waters

SENTINEL-2 was taken on 2 November 2018 for seagrass beds covering Bai Bon and adjacent locations with a Depth Invariance Index of 1.5061, 2.4350, and 1.5923 (Fig. 10).

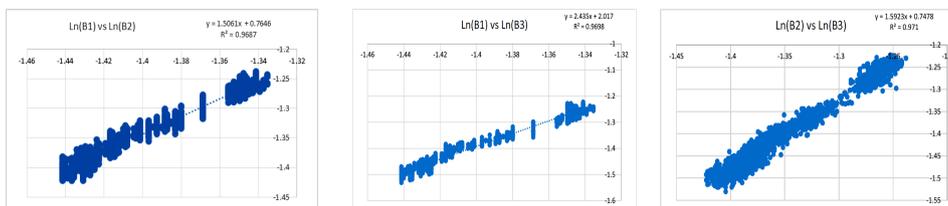


Figure 10. The Depth Invariance Index (DII) was calculated from the SENTINEL-2 image dated 02 November 2018 for seagrass beds at Bai Bon and adjacent waters

SENTINEL-2 was taken on 13 Nov. 2018 for coral reefs covering Ganh Dau, An Thoi, and adjacent locations with a Depth Invariance Index of 1.2672, 1.9045, and 1.4181 (Fig. 11).

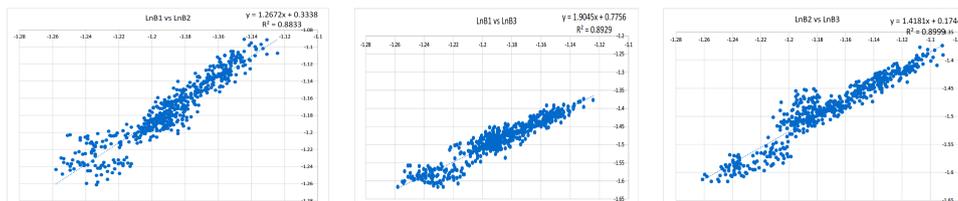


Figure 11. The Depth Invariance Index (DII) was calculated from the SENTINEL-2 image dated 13 February 2018 for coral reefs at Ganh Dau, An Thoi and adjacent waters

Data storage and analysis

Due to a lack of field surveys to check the analysis results from satellite images and aerial photographs in 2005 and 2010, we used data from ground truthing and correction in 2018 for regression analysis of the distribution of key marine habitats in 2005 and 2010. Development of maps of the distribution of marine habitats was converted from the grid system of UTM, WGS84, and 49 zones to the local grid system (VN 2000, 3-degree zone, axis meridian of 108°15'E). On that basis, we calculated the areas of coral reefs and seagrass beds.

RESULTS AND DISCUSSION

Status of marine habitats in 2018

Coral reefs

Based on an analysis of satellite images and aerial photographs, and ground truthing conducted in 2018, it was found that coral reefs are primarily located around the islands in the southern part of An Thoi, on the western side (Cua Can, Ong Quoi Cape) and the north-western side (Doi Moi island, Thay Boi island,

Bang island, and Ganh Dau), and some narrow bands in the eastern side (including Den Phach Cape, Vinh Dam, and Ong Doi Cape) of Phu Quoc island. Besides, there were some submerged reefs on the eastern side of Thay Boi island (Northwest of Phu Quoc island) and the Southwestern side of May Rut Trong island (South of An Thoi) (Fig. 12).

The total area of coral reefs recorded in 2018 was approximately 513 ha, including 442 ha of the coastal reefs surrounding the islands (occupied by 86.13% of the total) and 71 ha of submerged reefs (13.87%). The majority of coral reefs (56.54%) were located in the waters of the Phu Quoc MPA, with the Southern part of An Thoi supporting the highest area of coral reefs with 306 ha (59.75% of the total). The west to northwestern side of Phu Quoc Island had the second-highest area of coral reefs at 190 ha (37.13%), followed by the eastern side with 16 ha (3.11%) (Table 1).

Among the islands, Thom island had the largest area of coral reefs at 44.16 ha, followed by Vang island with 37.58 ha. Doi Moi island, Roi, Xuong, Gam Ghi, Vong, and May Rut Trong islands had similar areas ranging from 21.96–25.46 ha, while Dam Trong island had 13.71 ha. The other islands supported less than 10 ha each (Table 1).

Table 1. Area of coral reefs at the locations surrounding Phu Quoc islands

| No. | Location | Area (ha) | % | No. | Location | Area (ha) | % |
|-----|---|-----------|------|-------|---|-----------|-------|
| 1 | North of Ganh Dau | 44.88 | 8.75 | 15 | Dua island | 7.94 | 1,55 |
| 2 | West of Ganh Dau | 22.78 | 4.44 | 16 | Roi island | 25.46 | 4,96 |
| 3 | Bang island | 8.88 | 1.73 | 17 | Thom island | 44.16 | 8,61 |
| 4 | Thay Boi island | 6.68 | 1.30 | 18 | Vang island | 37.58 | 7,33 |
| 5 | Submered reefs in the Eastern part of Thay Boi island | 9.42 | 1.84 | 19 | Xuong island | 22.2 | 4,33 |
| 6 | Doi Moi island | 22.2 | 4.33 | 20 | Mong Tay island | 3.7 | 0,72 |
| 7 | Ong Quoi Cape | 32.65 | 6.37 | 21 | Gam Ghi island | 22.14 | 4,32 |
| 8 | Cua Can | 42.94 | 8.37 | 22 | Vong island | 21.96 | 4,28 |
| 9 | Den Phach Cape | 14.09 | 2.75 | 23 | May Rut Trong island | 23.79 | 4,64 |
| 10 | Vinh Dam | 1.68 | 0.33 | 24 | Kim Quy island | 6.51 | 1,27 |
| 11 | Ong Doi Cape | 0.22 | 0.04 | 25 | Kho island | 1.57 | 0,31 |
| 12 | Hanh Cape | 3.25 | 0.63 | 26 | Trang island | 3.19 | 0,62 |
| 13 | Dam Trong island | 13.71 | 2.67 | 27 | Submerged reefs in the Western part of May Rut Trong island | 61.72 | 12,03 |
| 14 | Dam Ngoai island | 7.57 | 1.48 | Total | | 512.87 | 100 |

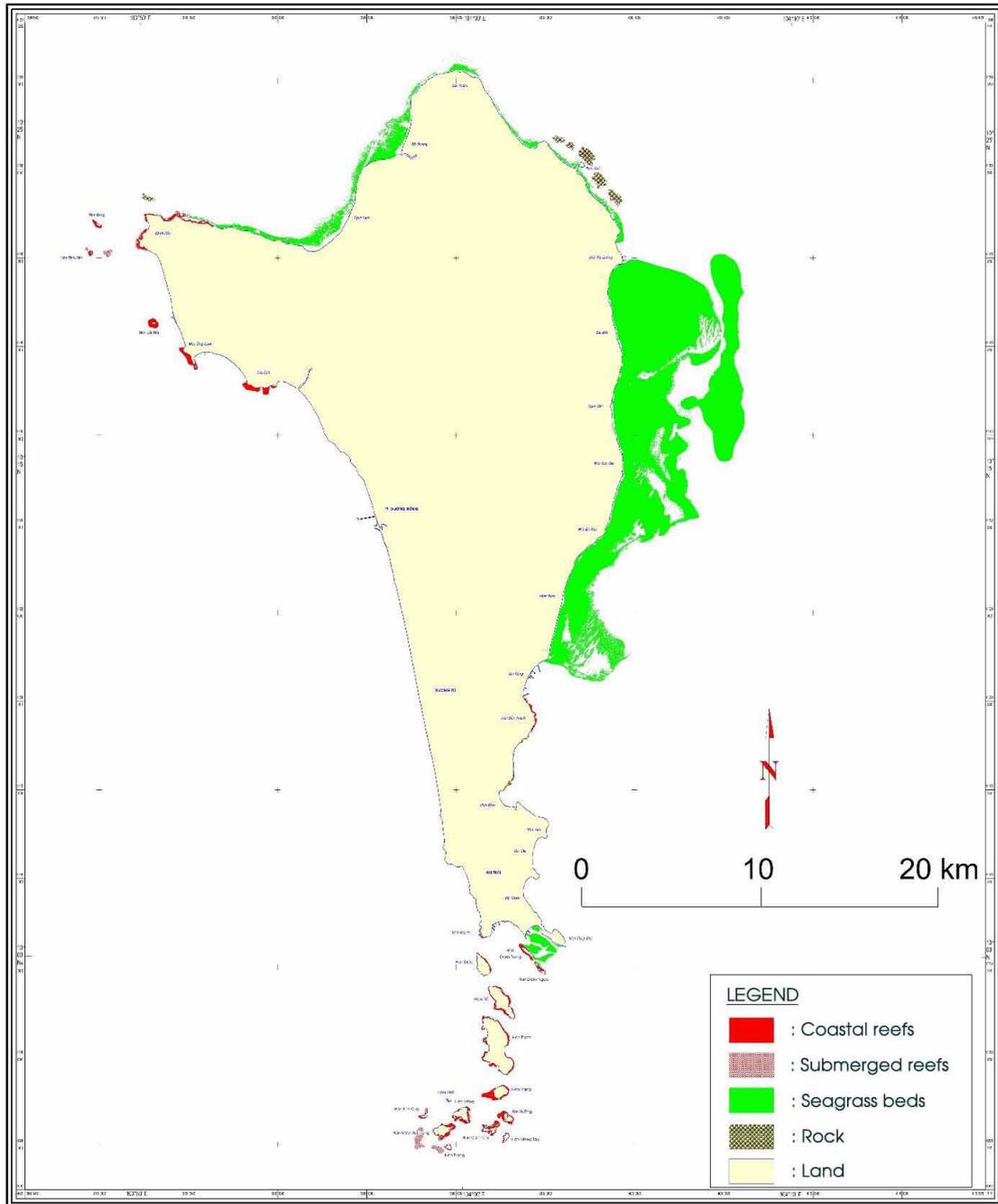


Figure 12. Distribution of key marine habitats surrounding Phu Quoc islands in 2018

Compared to a previous study in 2006 that used the manta tow technique in combination with point checking along the margin of coral reefs using GSP, the results from the present study were higher, totaling 293 ha more than the previous study's reported area of 220 ha;

[9]). The difference in methods between the two studies may account for the discrepancy in results. The previous study's calculation of area was mainly based on the length and width of each tow on each reef, which had low precision and could not detect submerged reefs in deeper

waters with low visibility. In the present study, a combination of high-resolution satellite images, aerial photographs, and ground truthing was used, resulting in higher precision and accuracy. The study was able to identify a larger area of submerged reefs in the eastern part of Thay Boi and the western part of May Rut Trong island, contributing to a more accurate and comprehensive understanding of the distribution of coral reefs in the area.

Seagrass beds

According to the analysis of satellite images and aerial photographs, seagrass beds were widely distributed around Phu Quoc big island and mostly concentrated on the eastern

side of Phu Quoc Island (from Da Chong Cape to Da Bac Cape), in which the most extensive area was found at Bai Bon (from the shore to 6.8 km offshore) (Fig. 12). The total area of seagrass beds surrounding the shallow waters of Phu Quoc islands surveyed in 2018 was more than 10,035 ha, of which some 9,185 ha (occupied with 91.52% of the total) were distributed in the waters of Phu Quoc MPA and the rest mainly found at Rach Vem and Ong Doi Cape - Dam Trong island outside the MPA. At each location, Da Chong Cape - Cay Sao Cape supported the largest area (6,386 ha; 63.64% of the total area in the MPA), the follower at Cay Sao - Bai Vong (2,684 ha; 26.75%), and the other locations being occupied with 9.62% (Table 2).

Table 2. Area of seagrass beds at the locations

| No. | Location | Area (ha) | % |
|-------|------------------------------|-----------|-------|
| 1 | Ganh Dau-Bai Thom | 671 | 6.69 |
| 2 | Bai Thom-Mot island-Da Chong | 145.4 | 1.45 |
| 3 | Da Chong-Cay Sao | 6,386 | 63.64 |
| 4 | Cay Sao-Bai Vong | 2,684 | 26.75 |
| 5 | Den Phach-Ong Doi Cape | 1.5 | 0.01 |
| 6 | South of An Thoi | 147.4 | 1.47 |
| Total | | 10,035.3 | 100 |

Temporal change in the distribution of marine habitats

Coral reefs

The findings of regression conducted on satellite images and aerial photographs between 2005-2018 reveal that there were no significant changes in the distribution and area of coral reefs in the waters of Phu Quoc islands and the MPA during this period. This is evident from Figs. 13 and 14.

Seagrass beds

In contrast, the analysis of satellite images and aerial photographs shows that seagrass beds underwent notable changes between 2005–2018. Specifically, there was a decline of 608 ha (5.7% of the total) between 2005–2010

and 652 ha (6.1%) between 2005–2018 (Figs. 13 and 14). The areas of the highest loss were Cay Sao Cape to Bai Vong, with a decline of 501ha (4.69%) mainly at Bai Vong. Ong Doi - Dam Ngoai Island (South of An Thoi) had a decline of 55 ha (0.52%), while Bai Thom - Mot island and Den Phach Cape - Ong Doi Cape, mainly at Vinh Dam, had a decline 42 ha (0.4%). There was a decline of 12 ha between 2005–2018 Da Chong Cape (Fig. 15). The decline of seagrass beds was primarily attributed to infrastructure development and dredging of creeks for marine transportation at Da Chong, Bai Vong, and Vinh Dam ports, among other factors.

Several coastal areas, including Nha Trang Bay, Cu Lao Cham MPA, and Thu Bon estuary in Hoi An, have also experienced secular declines in the distribution and area of important marine habitats due to socio-

economic development. For instance, in Nha Trang Bay, the area of seagrass beds declined from 28 ha [19] to 64 ha and the coral reef area decreased by 117.4 ha between 2002–2015 [10]. Similarity, Cu Lao Cham MPA witnessed

a decline of 34–43 ha of seagrass beds [11, 12] and approximately 1 hectare of coral reefs [12], while Thu Bon estuary saw a reduction of 35 ha of seagrass beds and 77 ha of nipa palms between 2003–2017 [11].

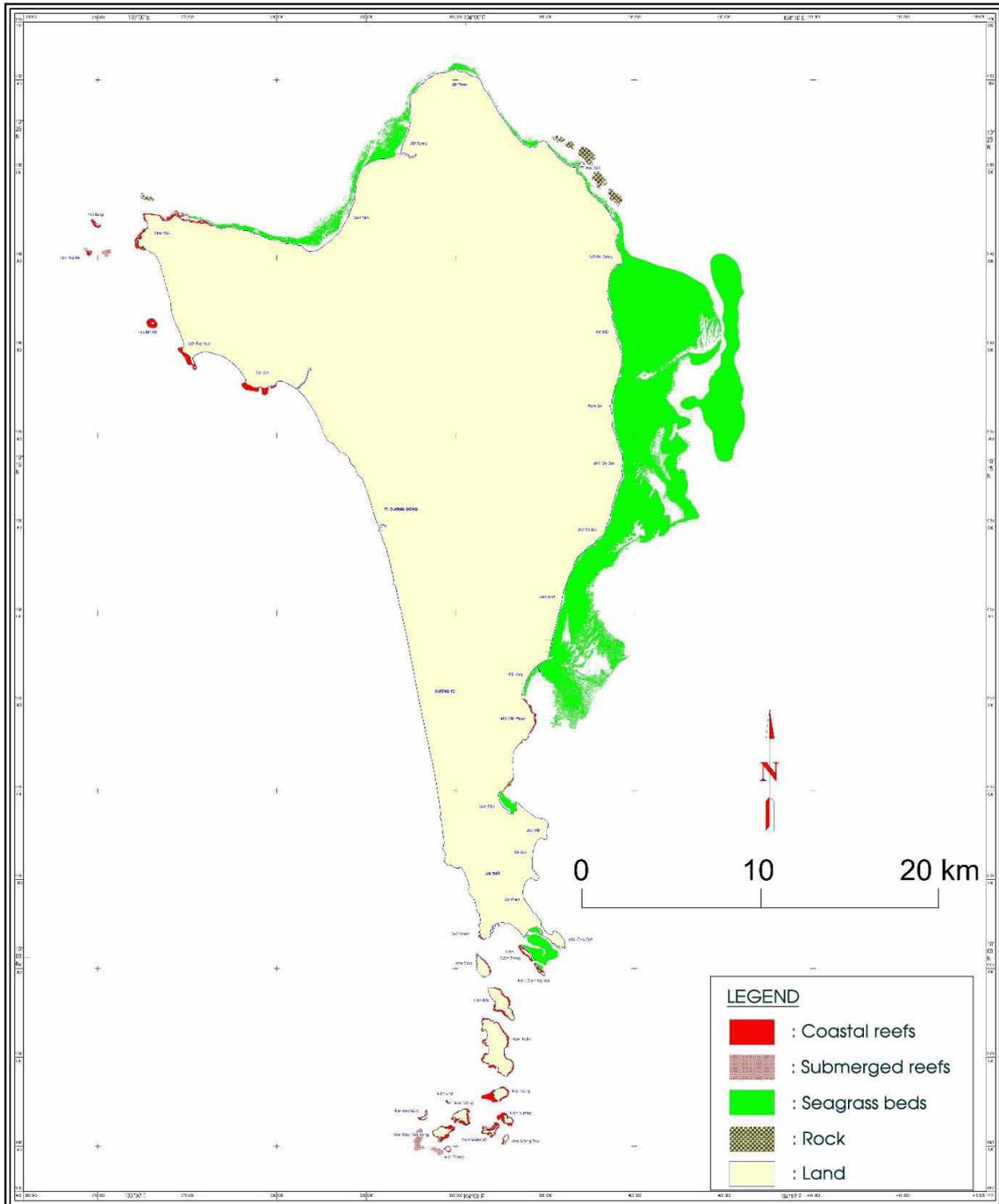


Figure 13. Distribution of key marine habitats surrounding Phu Quoc islands in 2005

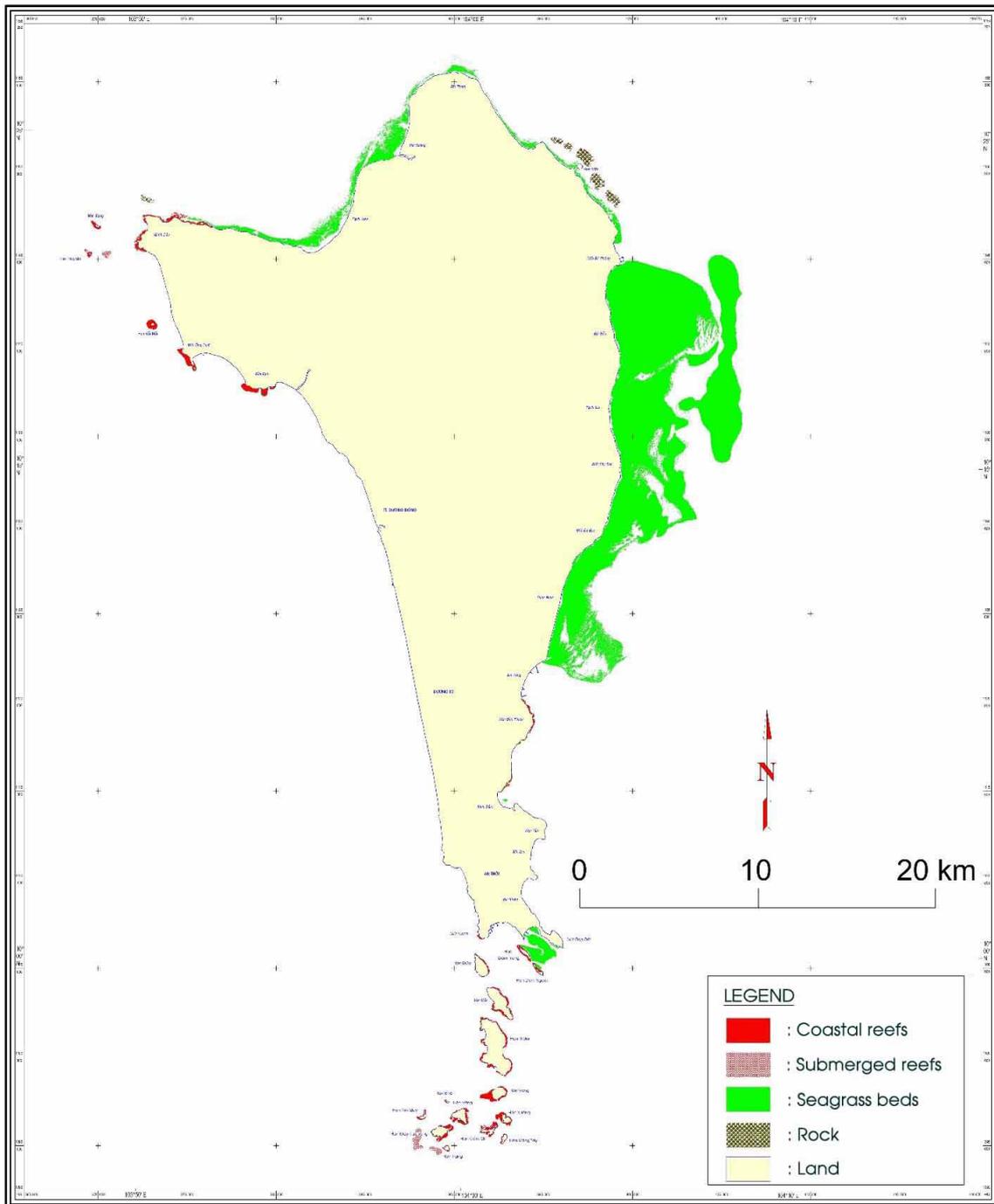


Figure 14. Distribution of key marine habitats surrounding Phu Quoc islands in 2010

In 2018, statistics from the Phu Quoc Management Board of Economic Zone indicated that three marine locations would be delivered to relevant companies and agencies under the agreements on policy by the Kien Giang

Provincial People’s Committee (PPC). These three locations include 7.67 ha at Bai Vong (Ham Ninh Commune) and 6.43 ha at Xa Luc village (Bai Thom) for the Border Guard Military Headquarters of Kien Giang province to

build military ports for ship anchoring and logistics. Additionally, about 25 ha at the south of Bai Vong would be allocated to Trung Son Limited Liability Company for eco-tourism development. According to the study conducted in 2018, the marine areas of 6 ha at Xa Luc village and 25 ha at the south of Bai Vong supported seagrass beds, while the waters

surrounding Bai Vong port had no distribution of seagrass beds. When the location at Xa Luc village becomes operational, it will directly cause a loss of 6 ha of seagrass beds at that area. The potential impacts on the 25 ha of marine area allocated to Trung Son Limited Liability Company could not be predicted due to a lack of clear planning for use and development.

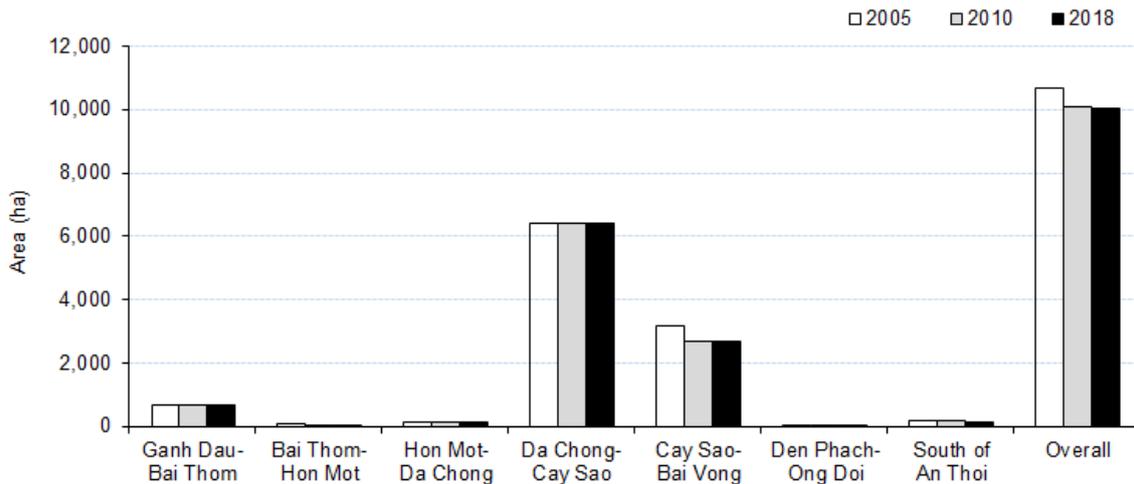


Figure 15. Temporal change in area of seagrass beds in Phu Quoc islands

While some projects in the waters of Phu Quoc MPA have received policy agreements of approval from the Kien Giang PPC, the majority have focused on land development on islands such as Dua Island (the Joint Stock Company for Investment-Infrastructure Development of Dua island-Phu Quoc), Gam Ghi (Limited Liability Company of Gam Ghi Resort La Veranda), Vong island, May Rut Trong island, Kim Quy island and Trang island in the tourist area in the South of An Thoi (the Sun Phu Quoc Limited Liability Company). Despite the eco-tourism development goals of these projects, the investors plan to use marine habitats and resources for marine tourism, which may negatively impact coral reefs and the surrounding environment. Although there has been no significant decline in the area of coral reefs from 2005 to 2018, the socio-economic development goals of the Kien Giang PPC and local authorities pose a threat to the existence of coral reefs in the area. Additionally, coral bleaching caused by temperature increases from climate change,

which has been recorded frequently in recent years [20, 21], combined with anthropogenic impacts, have caused a already led to the decline and degradation of coral reefs on Phu Quoc islands.

CONCLUSIONS

The coastal waters of Phu Quoc islands are home to 513 ha of coral reefs and 10,035 ha of seagrass beds. Of these, 290 ha of coral reefs (56.54% of the total) and 9,185 ha of seagrass beds (91.52% of the total) were located within the boundaries of Phu Quoc MPA. The coral reefs are mostly found around the islands in the southern region of An Thoi, while seagrass beds are mainly concentrated on the eastern side of Phu Quoc Island, stretching from Da Chong to Bai Vong.

However, the period from 2005 to 2018 saw a decline of over 652 ha of seagrass beds (6.1% of the total) in several location including Bai Vong (501 ha; 4.69%), Ong Doi Cape -

Dam Ngoai Island (55 ha; 0.52%), Mot Island and Vinh Dam (42 ha each; 0.4%), Da Chong Cape (12 ha). The decline is attributed to infrastructure development and dredging of creeks for marine transportation in these areas.

Acknowledgments: This study was carried out within the framework of the project titled “Studies on dispersal mechanisms of larvae and population connectivity of target marine resources for the improvement of management effectiveness of marine protected areas in the coastal waters from Quang Tri to Kien Giang” (Code: KC.09.41/16–20), and it analyzed data and information of the provincial project “Assessments of marine biodiversity and recommending solutions for re-zoning of the Phu Quoc Marine Protected Area”. The authors would like to express their gratitude to the Sun Phu Quoc Limited Liability Company and the Management Board of Phu Quoc MPA for their invaluable support and collaboration during this study.

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