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OSJO-D-21-00073 - Submission Confirmation - [EMID:1f4e8026429f7ae7]

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To: Nurjannah Nurdin Nurdin

Dear Dr Nurdin,

Your submission entitled "Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia" has been received by Ocean Science Journal

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Kind regards,

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Submissions with an Editorial Office Decision for Author

Page: 1 of 1 (3 total completed submissions)

Results per page 10

Action	Manuscript Number	Title	Initial Date Submitted	Status Date	Current Status	Date Final Disposition Set	Final Disposition
		SPATIAL DYNAMIC OF CORAL REEF ON THE SMALL ISLAND, SPERMONDE ARCHIPELAGO, INDONESIA		30 Aug 2015	Content Files Deleted - Forced to Withdrawn	30 Aug 2015	Forced to Withdrawn
View Submission Author Response View Decision Letter View Attachments	OSJO-D-14-00107	Multisensor and multitemporal of Landsat images for damage detection on coral reef, small island, Spermonde Archipelago, Indonesia	26 Aug 2014	14 Jun 2016	Completed	14 Jun 2016	Accept
View Submission View Decision Letter	OSJO-D-21-00073	Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia	08 Jun 2021	04 Jan 2022	Completed	04 Jan 2022	Accept

Page: 1 of 1 (3 total completed submissions)

Results per page 10

KOREKSI DARI REVIEWER

REVISI 1

em@editorialmanager.com

OSJO: Your manuscript entitled Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small...

Wonho Yih <em@editorialmanager.com>
To: Nurjannah Nurdin Nurdin
Mon, Aug 30, 2021 at 1:01 PM

Ref.: Ms. No. OSJO-D-21-00373
Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia
Ocean Science Journal

Dear Dr Nurdin,

Reviewers have now commented on your paper. You will see that they are advising that you revise your manuscript. If you are prepared to undertake the work required, I would be pleased to reconsider my decision.

The reviewers' comments can be found at the end of this email or can be accessed by following the provided link.

This is your login information:

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When revising your work, please submit a list of changes or a rebuttal against each point which is being raised when you submit the revised manuscript.

Please make sure to submit your editable source files (i. e. Word, TeX).

Your revision is due by 29 Oct 2021.

To submit a revision, go to journal site and log in as an Author. You will see a menu item called 'Submissions Needing Revision'. You will find your submission record there.

Yours sincerely

Wonho Yih
Editor-in-Chief
Ocean Science Journal

Reviewers' comments:

Reviewer #1: This paper tried to estimate seagrass biomass by In Situ measurement and remote sensing technology in Indonesia. However, there are insufficient about description the aims of this study. This paper has serious problems with respect to methods, writing and aims incorrect.

Major comments
1. I would strongly recommend that the authors work with a native English speaker on the manuscript. For example, Page 1 line 37-38: – than surpassing; Page 1 line 45-46: redundant word (affect); Page 1 line 46-47: what does 'Their' mean?
2. I do not know what the aim of this study is. I think the aim of this study should be clearer.
3. Authors mentioned that In situ percent cover was measured inside the 50x50 cm plot by calculating the seagrass density (number of shoots/ m2). Why did you measure In situ percent cover by calculating the seagrass density? Additionally, did you use a small a small 20cm x 20cm plot or a core with 5 cm diameter? Accuracy and sufficient explanation for measurement should be provided in Materials and methods.
4. Why did authors compare Sentinel-2 image with Landsat image? If necessary, they should compare two satellite image data of same time because seagrasses showed seasonal trends.
5. Check references: There were no papers cited in the manuscript in reference list.
6. Page 1 line 28: There is a typo in the 28st line of page 1. Not only that, there are more typos, so I recommend you check again.

Reviewers' comments:

Reviewer #1: This paper tried to estimate seagrass biomass by in Situ measurement and remote sensing technology is Indonesia. However, there are insufficient about description the aims of this study. This paper has serious problems with respect to methods, writing and some incorrect.

Major comments:

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4. Why did authors compare Sentinel-2 image with Landsat image? If necessary, they should compare two satellite image data of same time because seagrasses showed seasonal trends.
5. Check references. There were no papers cited in the manuscript in reference list.
6. Page 1 line 28: There is a typo in the 28st line of page 1. Not only that, there are more typos, so I recommend you check again.
7. Page 1 line 50-51: Are you sure that "It is believed that about a third to half of the world's seagrasses have been lost since 1879 and the continuing rate of disappearance is estimated to be 110 km2 per year with net loss rates of 0.9% per year". In Mcleod et al. 2011, seagrass loss rates have accelerated over the past several decades, from 0.9% per year before 1940 to 7% per year since 1990.
8. There is no explanation for Figure 7 in the manuscript.
9. Page 3 line 55, Is it right Figure 4 & Table 1?
10. Page 8 line 41, This sentence was not for Figure 8.

Reviewer #2: Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia
This paper provides the information on estimation of seagrass biomass using remote sensing technology by comparing data from in situ measurement in Indonesia. I think that the paper has a value to be published in OSJ. There are some things to be revised before publication.

1) NDVI: full names for this abbreviation should be addressed in the Abstract.
2) L28: Dry weight / what?
3) R2 = 0.8255 : 2 should be superscript.
4) Table 2 and Fig. 8. There was a big discrepancy in the total seagrass area between Landsat 8 and Sentinel-2. But only Sentinel 2 image was used in the correlation analysis. Why? I think that there should be correlation analysis for the Landsat 8 too.
5) Conclusions: "Here is a linear correlation between NDVI and and in situ percent cover~" This is not a conclusive remark. Conclusion should be clearly state what you can conclude based on the result.

Reviewer #3: 3p 12-15 : Latitude and longitude digits and spacing between symbols are inconsistent. To unify in the same way.
3p 48 : Study site abbreviations are BL, BC, KL, but they are BL, CD, KL.
5p 0 : superscript number 2 in m2
5p 16 : superscript number 2 in m2
6p 33/52 : The data format is different. want to match.
7p : Table1 is sorted differently from other tables. I think it would be better to match it with other tables.
7p 33 : There are only A, B, and C in Fig6, but SE is written on it. want to check.
8p 17 : I think it should be indented.
8p : When the species name is mentioned for the first time, the genus name should not be abbreviated. but the species shown in Fig. 6 are not in the text./ The genus name of E. acoroides is not listed in the text.

—

REVISI 2

[Ocean Science Journal] Request for the final version of the manuscript

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To: muzi_din@yahoo.com
Cc: supriadi112@yahoo.com, kaimi.ikl@gmail.com, cymodocea@gmail.com

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Sincerely,
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ACCEPTED JOURNAL FOR PUBLICATION

Date: 20 Dec 2021
To: "Nurjannah Nurdin Nurdin" nurj_din@yahoo.com
From: "Wonho Yih" ywonho@kunsan.ac.kr
Subject: OSJO: Your manuscript entitled Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia

Ref.:
Ms. No. OSJO-D-21-00073R1
Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia
Ocean Science Journal

Dear Dr Nurdin,

I am pleased to tell you that your work has now been accepted for publication in Ocean Science Journal.

Thank you for submitting your work to this journal.

With kind regards

Wonho Yih
Editor-in-Chief
Ocean Science Journal

Reviewer #2: I think that all of my questions were addressed in the revised paper. I recommend publication of this paper in OSJ.

Reviewer #3: I think you have reflected your revision requirements well.

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Ocean Science Journal

Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia

--Manuscript Draft--

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Abstract:	As one of the major blue carbon ecosystems, studying, conserving, and monitoring seagrass meadows, especially on small populated islands has become very important. This is due to its vulnerability to anthropogenic and global environmental factors. In this study, we used image analysis and biological data to map the percent cover of seagrass, seagrass above-ground biomass, and seagrass below-ground biomass on the three most populated islands of Spermonde archipelago, Indonesia: Kodingareng Lompo, Barrang Lompo, and Barrang Caddi. Reflectance and NDVI values of Sentinel-2 satellite imageries with the acquisition on July 29, 2019, were used to classify and calculate percent cover and also to estimate above-ground biomass of seagrass (AGBS). Field data were taken during 3-14 June 2020 on the three islands to measure above and below-ground biomass (BGBS). The result shows a total area of seagrass 126.37 Ha, which was divided into three categories: medium (30% - 59.9%) with a total area of 78.38 Ha; rare/low (0% -29.9%) 13.1 Ha, and dense/hight (60% -100%) 34.89 Ha total area. The highest total of seagrass covered area was observed on Kodingareng Lompo Island (61.07Ha) and Barrang Lompo Island (53.18Ha), while on Barrangcaddi Island covered area was 12.12Ha. Meanwhile, the total (AGBS) on Barrang Lompo, Kodingareng Lompo, and Barrangcaddi Islands was 1.83 tons of dry weight/ha, 1.05 tons of dry weight/ha, and 2.38 tons of dry weight/ha, respectively. Total BGBS's were reported highest on Barrangcaddi island (8.61 tons of dry weight/ha), lowest on Kodingareng Lompo island (2.78 tons of dry weight /), and 6.78 tons of dry weight/ha on Barrang Lompo island. There was also a linear correlation between NDVI value and insitu percent cover with r2 = 0.8255. The framework of this study can be applied to monitor temporal changes of seagrass meadows distribution on small islands for a more sustainable ecosystem

Suggested Reviewers:	Sarah Hamylton, PhD Lecturer, School of Earth and Environmental Sciences, UOW, University of Wollongong shamylto@uow.edu.au
	Laurent Barille, Prof Université de Nantes: Universite de Nantes laurent.barille@univ-nantes.fr
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- ☑ Key details of procedures should be given in the legend or footnotes. 100% relative values **MUST** be given as the actual (absolute) values in the legend or footnote. It is recommended that procedures used only once should be detailed in the legends to figures or footnotes to tables rather than being placed in the **Methods** section.
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Corresponding Author: Nurjannah Nurdin

Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia

Nurjannah Nurdin[1,2*], Supriadi Mashoreng[1], Khairul Amri[1], Teruhisa Komatsu[3,4]

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Acknowledgments

The Ministry of Research Technology and Higher Education of the Republic of Indonesia and the Research Center Institution of Hasanuddin University supports in providing research funds.Thank you to the Ocean Remote Sensing Project of Subcommission of Western Pacific Intergovernmental Oceanographic Commission/ UNESCO supported by Japan Fund in Trust provided by Ministry of Education, Culture, Sports, Science and Technology, Japan.

Abstract: As one of the major blue carbon ecosystems, studying, conserving, and monitoring seagrass meadows, especially on small populated islands has become very important. This is due to its vulnerability to anthropogenic and global environmental factors. In this study, we used image analysis and biological data to map the percent cover of seagrass, seagrass above-ground biomass, and seagrass below-ground biomass on the three most populated islands of Spermonde archipelago, Indonesia: Kodingareng Lompo, Barrang Lompo, and Barrang Caddi. Reflectance and NDVI values of Sentinel-2 satellite imageries with the acquisition on July 29, 2019, were used to classify and calculate percent cover and also to estimate above-ground biomass of seagrass (AGBS). Field data were taken during 3-14 June 2020 on the three islands to measure above and below-ground biomass (BGBS). The result shows a total area of seagrass 126.37 Ha, which was divided into three categories: medium (30% - 59.9%) with a total area of 78.38 Ha; rare/low (0% -29.9%) 13.1 Ha, and dense/hight (60% - 100%) 34.89 Ha total area. The highest total of seagrass covered area was observed on Kodingareng Lompo Island (61.07Ha) and Barrang Lompo Island (53.18Ha), while on Barrangcaddi Island covered area was 12.12Ha. Meanwhile, the total (AGBS) on Barrang Lompo, Kodingareng Lompo, and Barrangcaddi Islands was 1.83 tons of dry weight/ha, 1.05 tons of dry weight/ha, and 2.38 tons of dry weight/ha, respectively. Total BGBS's were reported highest on Barrangcaddi island (8.61 tons of dry weight/ha), lowest on Kodingareng Lompo island (2.78 tons of dry weight /), and 6.78 tons of dry weight/ha on Barrang Lompo island. There was also a linear correlation between NDVI value and insitu percent cover with r2 = 0.8255. The framework of this study can be applied to monitor temporal changes of seagrass meadows distribution on small islands for a more sustainable ecosystem.

Keywords: seagrass, biomass, small islands, NDVI, sentinel-2.

1. Introduction

Seagrass meadows have a high carbon sink capacity that surpassing even the highest productive terrestrial ecosystems (Krause-jensen et al. 2019). They have a carbon fixation ability that exceeds their metabolic needs, hence a large proportion of excess organic carbon is transported to the roots and rhizomes where it is stored, and eventually exuded in the sediment to form anaerobic organic-rich soil (autochthonous) (Lyimo. 2016). A study of carbon sequestered capacity of Australian seagrasses estimates annual Corg accumulation of 0.093 to 6.15 Mt, with a most probable estimate of 0.93 Mt y^{-1} (10.1 t. km^{-2} y^{-1}) (Lavery et.al. 2013). This type of blue carbon ecosystem also has a high global NCP (net carbon production) of 20.73–50.69 Tg C yr^{-1} which comprises 10–18% of the total carbon storage in the ocean (Duarte et al. 2010; Kennedy et al. 2010).

However, human disturbances can negatively affect seagrasses' carbon fixation ability and affect amounts of carbohydrate and starch being sunk in their rhizomes. Their coastal environment habitat is usually subjected to many anthropogenic activities such as sewage disposal, mariculture, propeller boating activities, destructive fishing, construction works and dredging, and increased eutrophication, which are threatening seagrasses into extinction (Roca et al. 2016). It is believed that about a third to half of the world's seagrasses have been lost since 1879 and the continuing rate of disappearance is estimated to be 110 km2 per year with net loss rates of 0.9% per year (Mcleod et al. 2011). Therefore, the remaining seagrass ecosystems need to be conserved and protected.

To efficiently manage and monitor the seagrass ecosystem for conservation, information on seagrass status in terms of percent cover and biomass needs to be acquired as baseline data. For this purpose, remote sensing has been proven to be an efficient and effective tool. Since the launch of the Sentinel-2 (S2) satellite by the European Space Agency (ESA) in 2015, higher spatial resolution imageries, which are suitable for seagrass mapping, can be acquired. at no cost. The use of this S2 imagery for seagrass meadows ecosystem study recently demonstrated on seagrass beds on French and Spain Atlantic coast (Zoffoli et. al. 2020).

Spermonde archipelago is a set of tropical small islands between Kalimantan and Sulawesi island of Indonesia. Three of its most populated islands are Barrang Lompo Island, Barrang Caddi Island, and Kodingareng Lompo Island. On all of these three islands, there is a significant amount of seagrass bed area, despite the most likely highly anthropogenic disturbance factor occurrence. However, a study to analyze the percent cover and biomass of these seagrasses has not been done yet.

2. Materials and Methods

Study sites

The survey for the research was conducted on three islands, Barrang Lompo (BL), Barrang Caddi (BC), and Kodingareng Lompo (KL). These three islands are part of Spermonde Archipelago, which is located west off the coast of Makassar City, capital of South Sulawesi Province, Indonesia. BL Island is located at 5 ° 2'43,577 "- 5 ° 3'6,491" South Latitude (LS) and 119 ° 19 '38,716 "- 119 ° 19' 49.21" East Longitude (BT), which is 12.48 Km from Makassar City. Meanwhile, BC Island is located at 5 ° 4'46,558 "- 5 ° 5'0,778" South Latitude and 119 ° 19 '10,557 "- 119 ° 19' 16,21 "East Longitude with a distance of 10.98 Km, while Kodingareng Lompo Island is located at 5 ° 8'42,536" - 5 ° 9'9,434 "South Latitude and 119 ° 15 '45,006" - 119 ° 15' 58,540 "East Longitude with a distance of 15.24 Km. Based on the distance from the mainland, the three islands were included in the middle zone, with the distance from the mainland's coastline between 10 - 20 km (Fig.1). Field data were taken at BL, BC, and KL Islands on June 3-14, 2020. Satellite image data used were Sentinel-2 acquisition 29 July 2019 and Landsat 8 acquisition 6 January 2019.

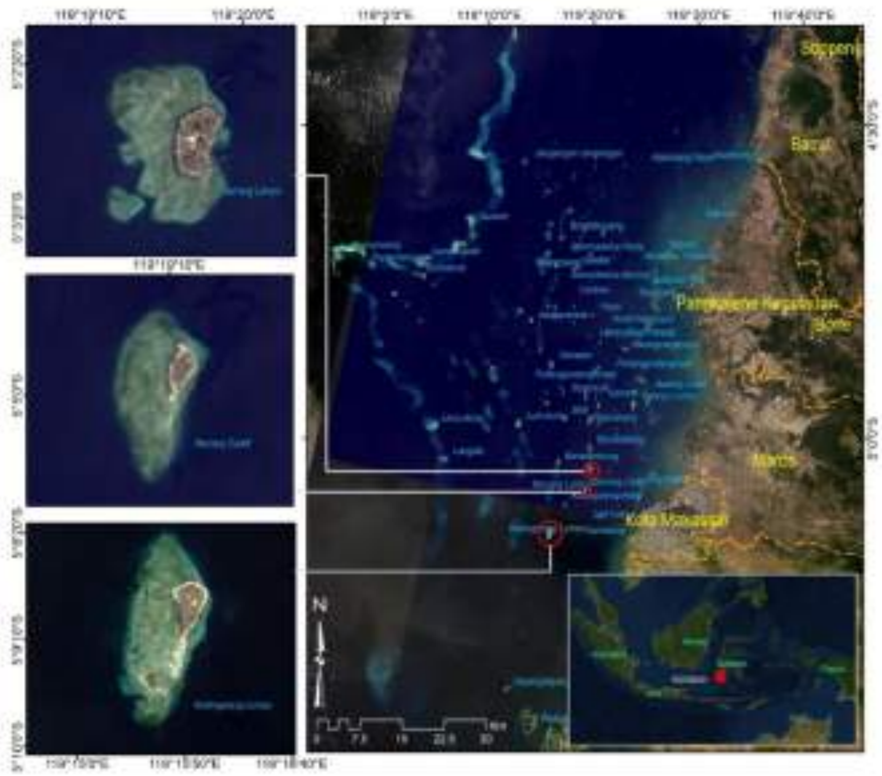

Fig 1. Study site on BL, CD, and KL islands Spermonde Archipelago, South Sulawesi, Indonesia

Satellite Data

Landsat and sentinel-2 image pra-processing

Satellite image data used are Sentinel-2 with acquisition imagery on 29 July 2019 and Landsat 8 on 6 January 2019. Geometrically corrected Sentinel-2 imageries of waters west of South Sulawesi were downloaded from the European Space Agency (ESA) data portal, while Landsat 8 was downloaded from USGS Glovis. Atmospheric correction was conducted using radiometric calibration (DN to reflectance) and Dark Object Subtraction (DOS) to remove the atmospheric effect on the image assuming the darkest pixel value was zero

(Chavez. 1988). Sun glint correction was also applied on Sentinel-2 imagery to correct its sunlight reflection. This correction was not done on Landsat 8 imagery because the image was clearer. The sharpening from Landsat 8 image process was done to facilitate interpretation for image classification. Sun glint correction was carried out using an algorithm developed by Hochberg et al. (2003) refined by Hedley et al. (2005) as in the following equation:

$$R'i = Ri – bi\ (RNIR – MinNIR)\text{.....................................}(1)$$

R'i = The i channel value after being reduced; Ri = Initial i channel value; bi= The amount of slope of the regression; RNIR= NIR channel value; MinNIR= Minimum NIR channel value.

Water column correction (Depth Invariant Index) Corrected images were used to classify shallow-water habitats and percent cover of seagrass using supervised classification. The flowchart for spatial data processing and its integration with non-spatial data.

The Depth water column correction method applied was the Invariant Index (DII) by Lyzenga (1981). The DII method reduces the influence of the water column so that a clearer image of the shallow water habitat could be obtained. Points on the sand area were used to build a model to obtain the attenuation coefficient of the water column. This is because sand objects are easier to recognize, which appears bright white and darker blue as the water depth increases. The algorithm used in this process was:

$$DII(ij) = In\ (Li) - [(Ki/Kj)\ ln\ (Lj)]\text{................................}(2)$$

$$ki/kj = a - [(Ki/Kj)\ ln\ (Lj)]\text{..}(3)$$

$$\alpha = \frac{\sigma i+\sigma j}{2\sigma ij}\text{...}(4)$$

DII = Depth Invariant Index; Li= i-band reflectance value; Lj= j-band reflectance value; ki/kj= i and j band attenuation coefficient ratio; αi= i-band variant; αj= j-band varian; αij= i and j band covariant.

Image classification base on percent cover of seagrass

Images that have been corrected were then classified using the unsupervised classification method (Isoclass). The result was then reclassify based on ground truth data. The final classification of seagrass percent cover was divided into three category sparse (0-29.9%), medium (30%-59.9%), and dense (60%-100%). These categories were then used for determining biomass sampling points.

The classification result mapping accuracy wastested using the error matrix method (confusion matrix) to get the accuracy value of seagrass habitat mapping. It was done by using a matrix table to compare class classification results with the class from the field survey (Congalton and Green. 2008). The following were the formulas used in the error matrix:

$$K = \frac{N\sum_{i=1}^{r} X_{II} - \sum_{i=1}^{r}(X_{i+} * X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} * X_{+i})}\text{.......................}(5)$$

Image classification base on density of seagrass

The NDVI (Normalized Difference Vegetation Index) algorithm is often formulated to describe the density (greenness) conditions of vegetation using the reflectance values of the near-infrared (NIR) and red bands (Pu et al. 2015). Seagrass beds usually grow around shallow waters with the NDVI index value ranges from -1 to 0. The formula used for NDVI was:

$$NDVI = \frac{NIR-Red}{NIR+Red}\text{...}(6)$$

NDVI = Normalized difference Vegetation Index; NIR = Short infrared band spectral reflectance; Red = Red band spectral reflectance.

Field data

Insitu percent cover and biomass sampling

Based on the resulting percent cover categories from image processing, 60 stations were pointed on each of the islands (20 for each of the categories of sparse, medium, and dense). Insitu percent cover was measured inside the 50x50 cm plot by calculating the seagrass density (number of shoots/ m2) (Kenzie et al. 2001). The composition of seagrass species was also determined in every plot. Within the bigger plot, a small 20cm x 20cm plot was made for biomass sampling. This plot was placed based on the types of seagrass that exist so that all types of seagrass in the plot can be extracted. Samples were taken using a core tool with 5 cm diameter and 100 cm length, by the depth of roots penetration (about 30-40 cm). Vined rhizomes were chopped using a machete before picking out any sample. Seagrass samples consisting of roots, rhizomes, leaves, and midribs were collected from each station. Substrate and dirt were cleaned out from the samples and then each of them was put into a labeled plastic bag for further laboratory analysis.

Biomass analysis

In the laboratory, samples were cut into two parts, the biomass above the sediment or above ground biomass (AGB) which consists of leaves and leaf midribs, and the below-ground biomass (BGB) which consists of rhizomes and roots (Rohr et al.2018). The cut seagrasses were then oven-dried (60oC) until a constant weight was achieved (Lyimo. 2016). It was weighted using a 0.01-gram precision level digital scale. Seagrass biomass per shoot was calculated by dividing the total weight of each sample by the total number of its shoots. The mean biomass per area (gram/m2) for each seagrass percent cover category was obtained by multiplying the number of biomass per shoots with each type of seagrass density. The result value was then multiplied by the area of each of the percent cover categories to get the total biomass per category.

Regression analysis

The relation between the biomass (AGB, BGB, and total biomass) and the percent cover results on every island were determined by regression linear analysis. Regression analysis was also done to find the relation between field survey data (*insitu* percent cover and biomass) with spatial data (percent cover and NDVI value).

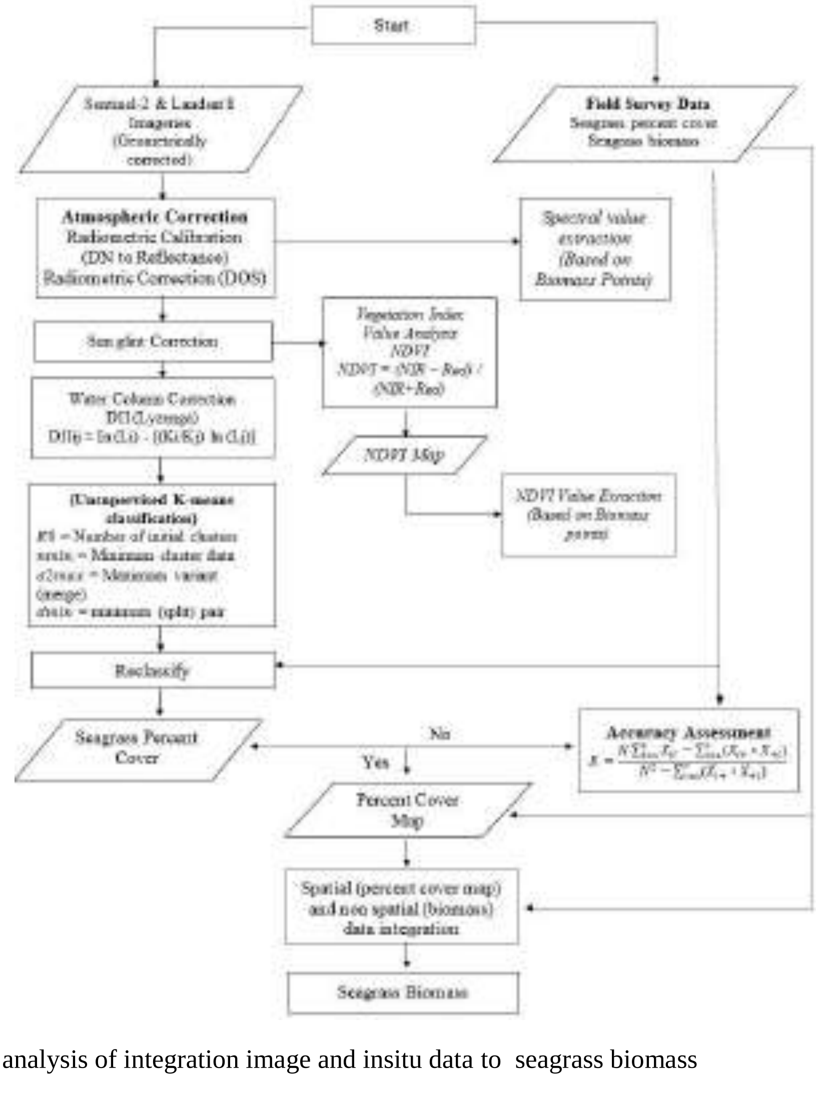

Fig 2. Flowchart analysis of integration image and insitu data to seagrass biomass

3. Result and Discussion

Seagrass condition by percent cover from image processing

The seagrass cover map was generated using a pixel-based classification (unsupervised method). There were 3 highly populated islands analyzed in the Spermonde Islands. Based on the results, it is known that the seagrass cover in KL was mainly in the range of 30 - 59.9% coverage, which was 60.38% from its total seagrass area. The same thing was also found on BC and BL Island which was dominated by 30-59.9% seagrass coverage, which was 62.71% and 63.74% from their total seagrass area respectively. The largest coverage type of 3 (three) islands was the medium coverage which covers 62.02% of all the total seagrass area. The Spermonde Archipelago has 683.70 hectares of seagrass, so it can be said that these three islands contribute around 18.48% of the total seagrass in the Spermonde Archipelago.

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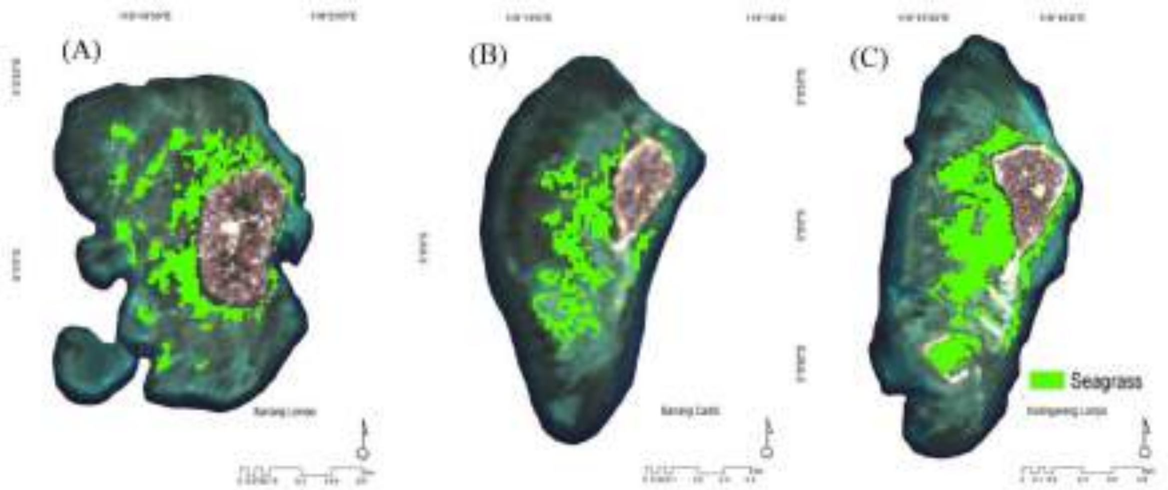

Fig 3. Distribution of seagrass on (A) BL, (B) BC, and (C) KL islands using Landsat 8 OLI Imagery, acquisition 6 January 2019 with 30m^2 spatial resolution

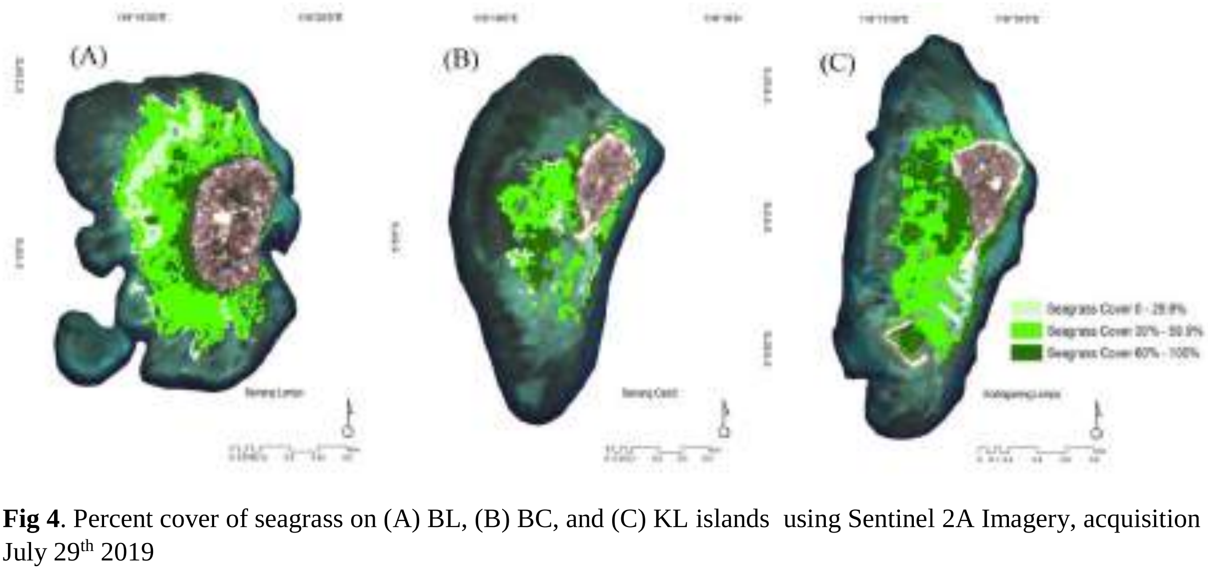

Fig 4. Percent cover of seagrass on (A) BL, (B) BC, and (C) KL islands using Sentinel 2A Imagery, acquisition July 29th 2019

Pixel-based analysis was also applied on Landsat 8 OLI imageries to create a seagrass distribution map. Due to smaller spatial resolution, the analysis of Landsat 8 images was only able to classify up to the aquatic habitat condition or seagrass distribution (Figure 4 & Table 1). Nevertheless, the results also show the same conditions as sentinel image results, where the seagrass was dominantly grown in the western area of the islands, while the eastern part remained barren.

Table 1. Percent cover of seagrass area from Sentinel-2 imagery classification

Seagrass Percent Cover (%)	Area (Ha)
0 - 29.9 (low)	13.1
30 - 59.9 (medium)	78.38
60 – 100 (high)	34.89
Grand Total	**126.37**

There is a difference between the total seagrass area calculated with Landsat and Sentinel-2 image processing. Measurement with Sentinel-2 resulting in a larger seagrass area by 24.2% on KL Island, 20.7% on BC Island, and 60.9% on BL Island. Based on the Sentinel and Landsat imageries analysis, each island has several spots of dominant and sparse seagrass distribution. The seagrass dominant area at KL and BC Island was mostly on the west, southwest, to the south of the island, while on the north to the east side, the seagrass distribution was mostly sparse. Identification from the survey and aerial images indicates that this lack of seagrasses on this side of the island was due to water depth and human activity that mostly centered on the east side of the island (the side that facing the mainland). This side was mostly the main channel for local passenger ships (Figure 5) the port area of each island.

Table 2. Total seagrass area by Landsat 8 and Sentinel-2

Island	Area by Landsat		Area by Sentinel-2	
	Area (Ha)	Years	Area (Ha)	Years
BL	20.75	2016	53.18	2019
BC	9.61	2019	12.12	2019
KL	46.30	2019	61.07	2019

The south side of the islands was mostly covered with exposed white sand that made seagrasses difficult to grow. Meanwhile, the distribution of seagrass on BL Island was a little different, it was almost evenly distributed, except at the port side. Most sides of BL Islands were compacted with house settlements, where people often dump their household organic waste straight into the sea. The same thing also happened on other islands' sides with most settlements. Therefore, seagrasses on this side of the islands were dense (Figure 5A, 5C, and 5E) due to richer organic materials. Nutrient enrichment enhanced seagrass biomass density, particularly in increasing the shoot biomass (Cabaco et.al. 2013).

Fig 5. KL Island condition (A1) East side, sparsed seagrass, (A2) West side, seagrass dominated. BC Island condition (B1) Sparsed seagrass on island's east side, (B2) Seagrass dominated on island's west side. BL Island condition (C1) Sparsed seagrass on island's east side, (C2) Seagrass dominated on island's west side

Accuracy test

The accuracy test of the Sentinel-2A image classification results was using field data. Field data used was a sample of seagrass cover photos that have coordinates. Based on the results of image analysis, the overall accuracy of kappa value of each image was: KL Island 75%, BC Island 82.69%, and BL Island 80.60%.

Seagrass Percent Cover and Density from Insitu measurement

The result shows seagrass' density and seagrass percent cover has a sync pattern, from low to high density, and from rare, medium, and dense categories respectively (Table 3). In some cases, the seagrass density value may be higher in the percent cover high category, than in the medium or low. The consistent pattern of seagrass density in all three islands was due to the relatively similar composition of seagrass species in the three percent cover categorie.

Table 3. Seagrass Density and Percent Cover from in situ Measurement

Plot Category	Density (shoots/m2)			Percent Cover (%)		
	BL	**BC**	**KL**	**BL**	**BC**	**KL**
High	418.2	447	310.733	78.25	76.9	77.867
Medium	367.6	411.8	229.6	45.45	38.95	46.267
Low	239.6	178.2	268.235	23.9	18.6	20

The Composition of seagrass species was dominated by *Thalassia hemprichii* in all categories, except for the rare percent cover category on KL Island which was dominated by *Cymodocea rotundata* (Figure 6).

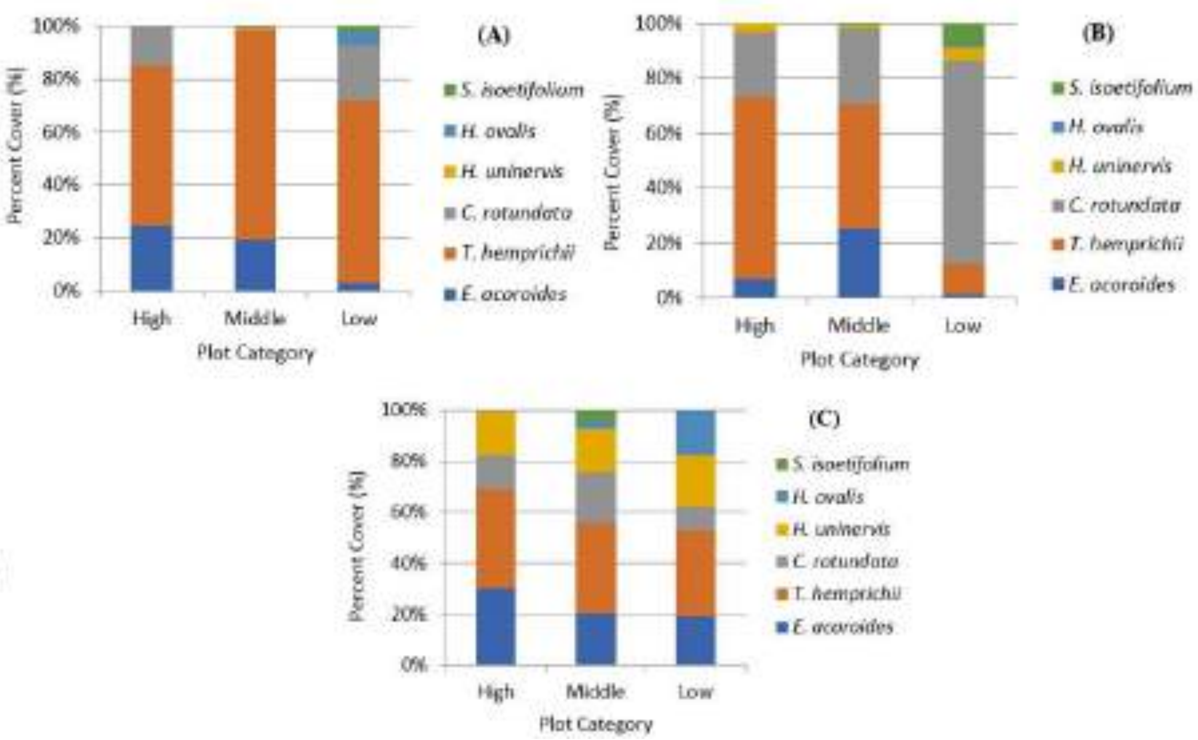

Fig 6. Percent cover of each seagrass species' based on plot categories in (A) BL, (B) KL, and (C) BC.

Correlation between Density of Seagrass using NDVI Algoritma and Percent Cover of Seagrass using Insitu Data

NDVI has been widely used in several studies in Indonesia to estimate vegetation biomass, greenness level, primary production, and dominant species in vegetation. The NDVI index value ranges from $-1.00 \leq NDVI \leq 1.00$. The principle of NDVI is to measure the level of greenness intensity. The intensity of greenness in Landsat images correlates with the level of density of vegetation's canopy.

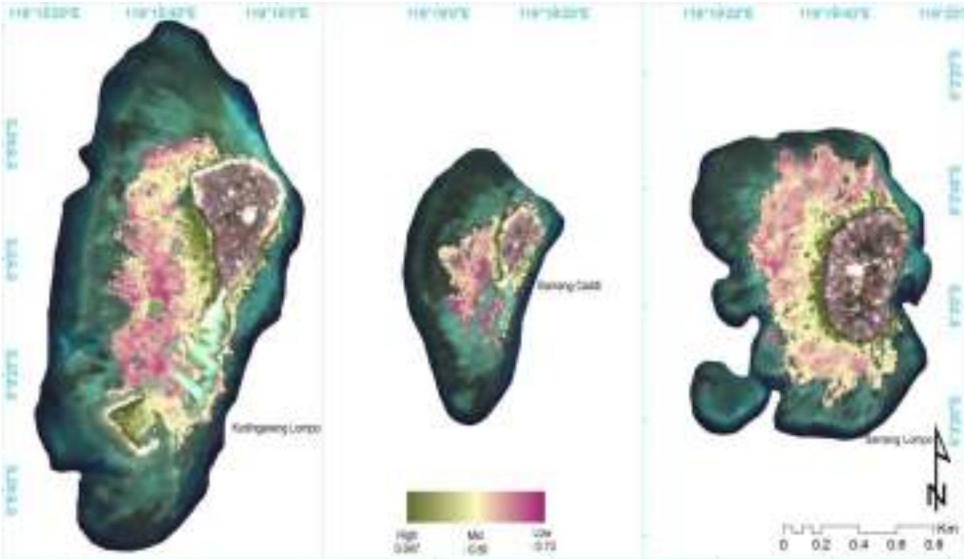

Fig 7. NDVI values on KL, BC and BL islands

The relationship between the percent cover of seagrass from field measurements and NDVI value was analyzed using algorithmic modeling with linear regression. The regression equation was obtained from the relationship between the NDVI value of Sentinel 2 image and the percent value of seagrass cover insitu. The algorithm obtained was y = 0.0053x-0.785. There is a linear correlation between NDVI and insitu percent cover with r^2 value of 0.8255. Based on the r value obtained, it indicates that there is a close relationship between the NDVI value of satellite images and the percent value of actual seagrass cover (Figure 8).

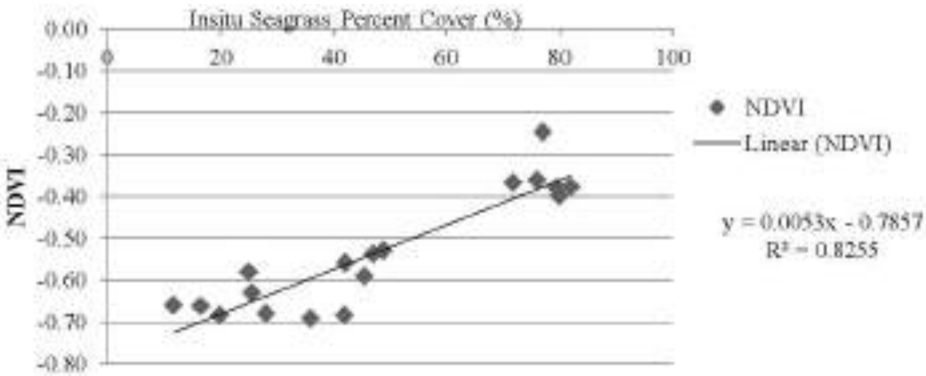

Fig 8. Average in situ Percent cover (PC) vs NDVI value on the three islands

Seagrass Biomass

Total Biomass

In all islands and seagrass cover categories, below-ground biomass (SBG) was higher than above-ground biomass (SAGB). SBG value on BL Island on average was four times higher than SAGB. Meanwhile, on the other two islands, the ratio was smaller, which was about three to three and a half times higher (Table 3). Biomass stored under the substrate is one form of seagrass adaptation. Seagrass grows in shallow waters which made it very vulnerable to the influence of waves. Without special adaptation, it can be easily uprooted by the waves. One form of the adaptations is by storing more photosynthetic products under the ground than above. Therefore, it can stay still under the impact of waves.

Among the three islands, the highest average biomass was found on BC Island, for SGB, SAGB, and total biomass (Table 4). This is due to the large composition of *E. acoroides* especially in the dense percent cover category (Figure 6). The cover percentage of *E. acoroides* reached 23.2% or about 30% of the total seagrass cover in the solid category of the island. *E. acoroides* is a large seagrass (Waycott et al. 2004). This species of seagrass is the largest in Indonesia.

Tabel 4. Dry weight Seagrass biomass base on a high, medium, and low category on BL, BC, and KL islands

Location	Category	Biomass (dry weight ton /ha)		
		Above ground	Below ground	Total
BL Island	High	1.05	3.49	4.55
	Medium	0.58	2.33	2.9
	Low	0.2	0.96	1.17
KL Island	High	0.48	1.28	1.76
	Medium	0.46	1.01	1.47
	Low	0.11	0.49	0.6
BC Island	High	1.33	4.83	6.16
	Medium	0.75	2.75	3.5
	Low	0.3	1.03	1.33

Fig 9. Field photograph of the low, medium, and high seagrass categories on KL and BL islands

On the overall seagrass categories in the three different islands, below-ground biomass (SBG) is generally weighted more than above-ground biomass (SAG). Seagrasses on three different islands were dominated by high or dense categories. There was a total of 8.62 ton dry weight/ha seagrass biomass on BL island, 3.83 ton dry weight/ha on KL island, and 10.99 ton dry weight/ha on BC island.

Correlation between Biomass insitu and NDVI

The c*orreliniarity* test between the total biomass value and the NDVI value on the island of BL obtained R value of 0.919, BL was 0.724 and BC was 0.801. The correliniarity value indicates a significant correlation between the total biomass value and the NDVI value on the BL island. In general, percent cover and carbon biomass of seagrass show a linear relation. However, only on BL Island, the resulting linear regression model shows a strong enough correlation to describe the two ecological parameters of the seagrass (R2 = 0.8443), while the other two islands have a weaker correlation to describe this relationship (R2 = 0.5239 and 0.6421) (Figure 9). Moreover, on BL Island, the biomass value is having more variation in the dense seagrass cover category than in the low and medium (Table 4). This is due to the various species composition. Some plots were *T. hemprichii* dominant, while other plots were more *E acoroides* dominant. Morphologically, the two seagrasses have different sizes, therefore at the same cover percentage, they have very different biomass values. In the rare and medium seagrass cover categories *T. hemprichii* was consistently being the dominant species.

Furthermore, in the dense seagrass cover category, there was quite a lot of overlap between leaves, especially with the *T. hemprichii* species. In some plots (Figure 9), a large addition of seagrass cover value can only cause a small increase in biomass value. Meanwhile, in other plots, the addition of the same amount of seagrass cover value can add a substantial biomass value. However, in the sparse and medium seagrass cover categories, the overlap between leaves was less. According to Mallombassi et al (2020), the high slope value of *T. hemprichii* seagrass regression equation at high percent cover was because of the overlapped leaf canopy, resulting in a high increase of biomass value despite the small addition of the percent cover.

The, *E. acoroides* and *C. rotundata* were significantly contributed in the medium to sparse percent cover category KL and BC Islands. This causes the biomass values of those two categories were largely variates. The contribution of the two seagrasses was about half of the dominant species *T. hemprichii*, while on BL Island it can reach a quarter in the same category.

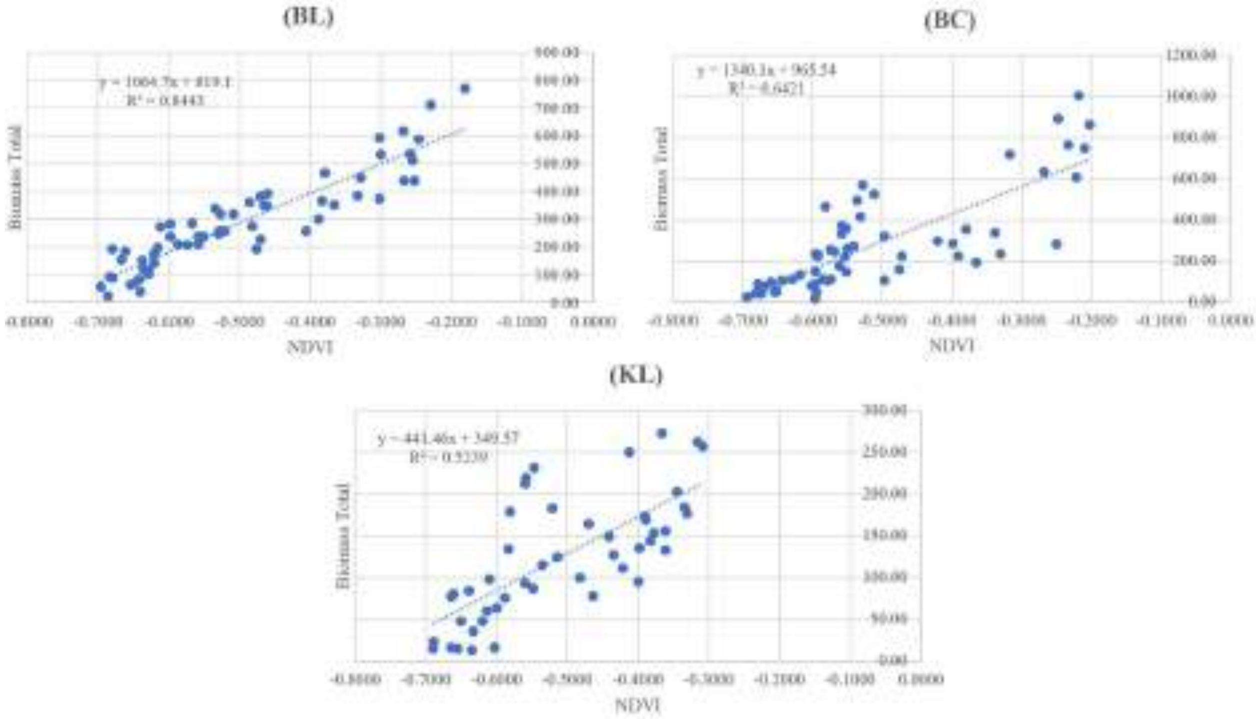

Fig 10. Regression analysis of seagrass biomass and NDVI on BL, BC, and KL islands.

4. Conclusions

Here is a linear correlation between NDVI and insitu percent cover. Insitu measurement shows a significant result with Sentinel image processing for seagrass percent cover at different density levels. However, this method cannot be applied to differentiate seagrass density based on species but is capable to be applied for seagrass condition monitoring.

References

Chavez Jr, P.S. 1988. An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote sensing of environment, 24(3), 459-479. https://doi.org/10.1016/0034-4257(88)90019-3.

Congalton R, & Green K. (2008). Assessing the Accuracy of Remotely Sensed Data, Principles and Practices (secondendn). Taylor & Francis Group. CRC Press.

Duarte C.M, Marbà N, Gacia E, Fourqurean J.W, Beggins J, Barrón C, and Apostolaki E.T. 2010. Seagrass community metabolism: Assessing the carbon sink capacity of seagrass meadows. Global Biogeochemical Cycles, 24(4). https://doi.org/10.1029/2010GB003793.

Hedley J.D, Harborne A.R, & Mumby P.J. 2005. Simple and robust removal of sun glint for mapping shallow-water benthos. Int. J. of Remote Sensing. 26(10): 2107–2112.

Hochberg E.J, Atkinson M.J. 2003. Spectral reflectance of coral reef bottom-types worldwide and implications for coral reef remote sensing. Remote Sensing of Environment 85(2):159-173. DOI: 10.1016/S0034-4257(02)00201-8

Kennedy H, Beggins J, Duarte C.M, Fourqurean J.W, Holmer M, Marbà N, and Middelburg J.J. 2010. Seagrass sediments as a global carbon sink: Isotopic constraints. Global Biogeochemical Cycles, 24(4).https://doi.org/10.1029/2010GB003848.

Lavery P.S, Mateo M.Á, Serrano O, and Rozaimi M. 2013. Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PloS one, 8(9), p.e73748. https://doi.org/10.1371/journal.pone.0073748.

Lyimo L.D. 2016. Carbon sequestration processes in tropical seagrass beds (Doctoral dissertation, Department of Ecology, Environment and Plant Sciences, Stockholm University).

Lyzenga D.R. 1981. Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. International journal of remote sensing, 2(1), 71-82.

https://doi.org/10.1080/01431168108948342.
Mallombassi A, Mashoreng S, and La Nafie YA. 2020. The relationship between seagrass Thalassia hemprichii percentage cover and their biomass. Spermonde 6 (1): 7-10.
McKenzie L.J, Finkbeiner M.A, & Kirkman H. 2001. Methods for mapping seagrass distribution. Global seagrass research methods, 101-121.
Mcleod E, Chmura G.L, Bouillon S, Salm R, Björk M, Duarte C.M, & Silliman B.R. 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Frontiers in Ecology and the Environment, 9(10), 552-560. https://doi.org/10.1890/110004
Pu R, Bell S, & English D. 2015. Developing hyperspectral vegetation indices for identifying seagrass species and cover classes. Journal of Coastal Research, 31(3), 595-615. https://doi.org/10.2112/JCOASTRES-D-12-00272.1
Roca G, Alcoverro T, Krause-Jensen D, Balsby T.J.S, van Katwijk M.M, Marba N, Santos R, Arthur R, Mascaró O, Fernández-Torquemada Y, and Pérez M. 2016. Response of seagrass indicators to shifts in environmental stressors: a global review and management synthesis. Ecological Indicators, 63, pp.310-323.
https://doi.org/10.1016/j.ecolind.2015.12.007
Rohr M.E, Bostrom C, Canal-Vergés P, Holmer M. 2018 Blue carbon stocks in Baltic Sea eelgrass (Zostera marina) meadows. Biogeosciences. https://doi.org/10.1029/2018GB005941
Waycott M, McMahon K, Mellors J, Calladine A, and Kleine D. 2004. A guide to tropical seagrass of the Indo-West Pacific. James Cook University. Townsville.
Zoffoli M.L, Gernez P, Rosa P, Le Bris A, Brando V.E, Barillé A.L, Harin N, Peters S, Poser K, Spaias L, and Peralta G. 2020. Sentinel-2 remote sensing of Zostera noltei-dominated intertidal seagrass meadows. Remote Sensing of Environment, 251, p.112020.
https://doi.org/10.1016/j.rse.2020.112020.

Ocean Science Journal

Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia

--Manuscript Draft--

Manuscript Number:	OSJO-D-21-00073R1
Full Title:	Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia
Article Type:	Article
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Abstract:	As one of the major blue carbon ecosystems, studying, conserving, and monitoring seagrass meadows, especially on small populated islands, has become very important due to its vulnerability to anthropogenic and global environmental factors. In this study, we used satellites' images analysis and biological data to map seagrass percent cover (SPC), above-ground biomass (AGB), and below-ground biomass (BGB) on the three most populated islands of Spermonde archipelago, Indonesia, i.e. , Kodingareng Lompo, Barrang Lompo, and Barrang Caddi. Reflectance and Normalized Difference Vegetation Index (NDVI) values of Sentinel-2 (S2) imagery was used to classify and calculate SPC and AGB. In situ biological data measurements were carried out from 3 to 14 of June, 2020, on the three islands to measureAGB and BGB. The result from image classification shows a total area of 126.37 Ha of seagrass, which was divided into three SPC categories: medium (30% - 59.9%) with a total area of 78.38 Ha; low (0% -29.9%) with a total area of 13.1 Ha, and high (60% -100%) with a total area 34.89 Ha. The highest SPC area was observed on Kodingareng Lompo island with 61.07Ha, followed by Barrang Lompo island with 53.18Ha, and Barrangcaddi island with 12.12Ha. The total AGB on Barrang Lompo, Kodingareng Lompo, and Barrangcaddi in tons of dry weight/ha were 1.83 , 1.05, and 2.38, respectively. The highest BGB was reported on Barrangcaddi island with 8.61 tons of dry weight/ha, followed by Barrang Lompo island with 6.78 tons of dry weight/ha, and Kodingareng Lompo island with 2.78 tons of dry weight/ha. Regression analysis showed a linear correlation between NDVI value and in situ SPC with R^2 = 0.8255. The framework of this study can be applied to monitor temporal changes of seagrass meadows distribution on small islands for a more sustainable ecosystem.

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- ☑ Table number and title should be written in the upper portion of the table. (For example: Table 1. Summary of Resilient Modulus). When placing more than two tables under the same number of title, assign subtitles by dividing each table by (a) or (b). In the text, tables shall be marked as: Table 1, Table 2 a and b, Tables 3 and 4. Tables, each on a separate sheet, are suitable for either single (7.5 cm) or double column (16 cm) printing. Tables, each on a separate sheet, are suitable either for single (7.5 cm) or double column (16 cm) printing. Titles of tables are included with the table and appear above the table itself.
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Supportng information. Results supplied in the form of supplementary tables or figures, or as additional methods, should be listed as a separate section after the Acknowledgements and the list of references. Citation of this information should be given in the text at the appropriate place using "Table A1", "Fig. A1" etc. There is no limit to the amount of information being given in this way though its usefulness for readers must be evident.

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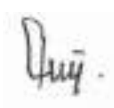


We want to say thank you for your very useful corrections to improve this paper.
We have responded to all of his suggestions, namely:

Reviewer #1: This paper tried to estimate seagrass biomass by In Situ measurement and remote sensing technology in Indonesia. However, there are insufficient about description the aims of this study. This paper has serious problems with respect to methods, writing and some incorrect

Major comments

1. I would strongly recommend that the authors work with a native English speaker on the manuscript. For example, Page 1 line 37-38: ~ than surpassing; Page 1 line 45-46: redundant word (affect); Page 1 line46-47: what does 'Their' mean?

correction result:

- Page 1 line 37-38: ~ than surpassing replaced
  We've revised this part of the sentence (see L22)
- Page 1 line 45-46: redundant word (affect); corrected; replaced with influence
  We've revised this part (see L30)
- Page 1 line 46-47: what does 'Their' mean?:
  We've revised this part of the sentence (see L31 – L34)

2. I do not know what the aim of this study is. I think the aim of this study should be clearer.

correction result:

We've given the explanation about the aim of the study (see L48- L52)

3. Authors mentioned that Insitu percent cover was measured inside the 50x50 cm plot by calculating the seagrass density (number of shoots/ m2). Why did you measure Insitu percent cover by calculating the seagrass density? Additionally, did you use a small a small 20cm x 20cm plot or a core with 5 cm diameter? Accuracy and sufficient explanation for measurement should be provided in Materials and methods.

correction result:

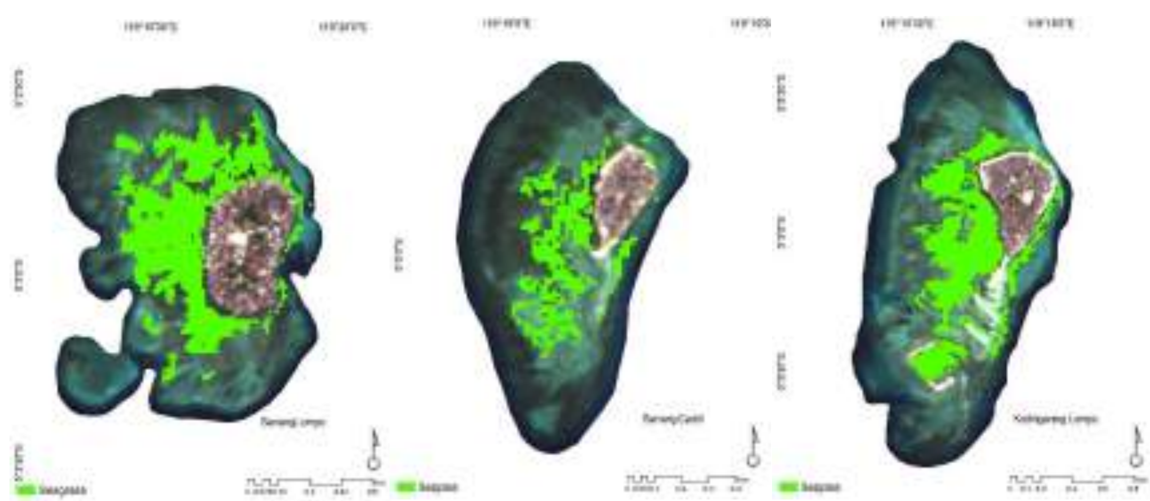
Seagrass percent cover (SPC) and seagrass density are two different parameters, and each has different values with different units (% for SPC and number of shoots/m^2 for density) (see Table 3). So here we didn't measure SPC by calculating the seagrass density, but we calculated those parameters using the same 50 x 50 cm plot. We've made correction on this part. To measure seagrass biomass, we used a 20cm x 20cm plot which we placed within the 50cm x 50cm plot, so here we didn't use 5 cm diameter. We have corrected the sentence in the method. We considered using a smaller plot (20cm x 20cm) to calculate biomass instead of the bigger plot (50cm x 50 cm) to lessen the amount of samples that we had to collect considering this method is a destructive method. (*see L123-L127*)

4. Why did authors compare Sentinel-2 image with Landsat image? If necessary, they should compare two satellite image data of same time because seagrasses showed seasonal trends.

correction result:

We've processed and analyzed new Landsat image with the same year acquisition (2019). Following is the coverage area and map from the new Landsat image (2019): *(also see: Figure 4, L179; Table 2, L191)*

Islands	**Area By Landsat**			**Area By Sentinel**	
BL	37.66	2019		53.18	2019
BC	9.61	2019		12.12	2019
KL	46.3	2019		61.07	2019



5. Check references. There were no papers cited in the manuscript in reference list.

correction result:

There are 2 paper cited that were not written on the manuscript's reference section and this mistake has been corrected. Two references that were added were:

- Cabaço, S., E.T. Apostolaki, P. García-Marín, R. Gruber, I. Hernández, B. Martínez-Crego, O. Mascaró, M. Pérez, A. Prathep, C. Robinson, J. Romero, A. L. Schmidt, F.T. Short, B.I. van Tussenbroek, R. Santos. 2013. Effects of nutrient enrichment on seagrass population dynamics: evidence and synthesis from the biomass-density relationships. Journal of Ecology 101: 1552–1562.

- Krause-Jensen, D., Duarte, C. Substantial role of macroalgae in marine carbon sequestration. *Nature Geosci* **9,** 737–742 (2016). https://doi.org/10.1038/ngeo2790

6. Page 1 line 28; There is a typo in the 28th line of page 1. Not only that, there are more typos, so I recommend you check again.

correction result:
these mistakes have been fixed/corrected

7. Page 1 line 50-51: Are you sure that "It is believed that about a third to half of the world's seagrasses have been lost since 1879 and the continuing rate of disappearance is estimated to be 110 km2 per year with net loss rates of 0.9% per year". In Mcleod et al. 2011, seagrass loss rates have accelerated over the past several decades, from 0.9% per year before 1940 to 7% per year since 1990.

correction result:
We've changed the information regarding seagrass loss rates by citing Waycott et all. (2009), which stated that seagrass loss has increased from 0.9 percent before 1940 to 7 percent in 1990 *(see L33-Ll6)*

8. There is no explanation for Figure 7 in the manuscript.

correction result:
We've corrected this mistake (*see L-232)*

9. Page 5 line 55; Is it right Figure 4 & Table 1?

correction result:
We've corrected this mistakes: *Figure 3 and Table* 1 (*see L-162*)

10. Page 9 line 41; This sentence was not for Figure 9

correction result:
We've revised this part of the sentences (see L275 - L280)

We want to say thank you for your very useful corrections to improve this paper.
We have responded to all of his suggestions, namely:

Reviewer #2: Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia
This paper provides the information on estimation of seagrass biomass using remote sensing technology by comparing data from in situ measurement in Indonesia. I think that the paper has a value to be published in OSJ. There are some things to be revised before publication.

1) NDVI: full names for this abbreviation should be addressed in the Abstract.

correction result:
Added: Normalized Difference Vegetation Index (NDVI) *(see L6*)

2) L28: Dry weight / what?
correction result:
We've corrected this mistake (*see L15*)

3) R2 = 0.8255 : 2 should be superscript.
correction result:
We've corrected this mistake (*see L16*)

4) Table 2 and Fig. 8. There was a big discrepancy in the total seagrass area between Landsat 8 and Sentinel-2. But only Sentinel 2 image was used in the correlation analysis. Why? I think that there should be correlation analysis for the Landsat 8 too.

correction result:
The disparity in total seagrass area between sentinel-2 and landsat images is due to differences in spatial resolution; sentinel-2 images with 10m spatial resolution and landsat with 30m spatial resolution. And we've calculated correlation analysis for landsat image (see Figure 9; L248)

5) Conclusions: "Here is a linear correlation between NDVI and and in situ percent cover~" This is not a collusive remark. Conclusion should be clearly state what you can conclude based on the result.

correction result:
we've revised the conclusion part of this manuscript *(see L304-L312)*

We want to say thank you for your very useful corrections to improve this paper.
We have responded to all of his suggestions, namely:

Reviewer #3:

3p 12-16 : Latitude and longitude digits and spacing between symbols are inconsistent. To unify in the same way
correction result:
We've corrected this part (*see L58-L62*)

3p 49 : Study site abbreviations are BL, BC, KL, but they are BL, CD, KL
correction result: We've corrected this mistake *(see L68)*

5p 0 : superscript number 2 in m2
correction result: We've corrected this mistake

5p 16 : superscript number 2 in m2
correction result: We've corrected this mistake

6p 32/52 : The date format is different. want to match
correction result: all dates have been revised in to the same format (*see L64, L65, L72, L73, L158, L178*)

7p : Table1 is sorted differently from other tables. I think it would be better to match it with other tables.
Answer: all tables are formatted the same

7p 33 : There are only A, B, and C in FIg5, but 5E is written on it. want to check
Answer : we've corrected these mistakes (*see line 197 – L198*)

8p 17 : I think it should be indented
Answer: we've corrected this part (see figure 7, L235; figure 8, L240)

8p : When the species name is mentioned for the first time, the genus name should not be abbreviated, but the species shown in Fig. 6 are not in the text./ The genus name of E. acoroides is not listed in the text.
Answer : We've corrected these mistakes (see L218 – L221)

Enhalus acoroides, *Thalassia hemprichii*, *Cymodocea rotundata*, *Halodule uninervis*, *Halophila ovalis* dan *Syringodium isoetifolium*

Title Page

Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia

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Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia

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Abstract: As one of the major blue carbon ecosystems, studying, conserving, and monitoring seagrass meadows, especially on small populated islands, has become very important due to their vulnerability to anthropogenic and global environmental factors. In this study, we used satellite image analysis and biological data to map seagrass percent cover (SPC), above-ground biomass (AGB), and below-ground biomass (BGB) on the three most populated islands of the Spermonde Archipelago, Indonesia, *i.e.*, Kodingareng Lompo, Barrang Lompo, and Barrang Caddi. Reflectance and Normalized Difference Vegetation Index (NDVI) values of Sentinel-2 (S2) imagery weres used to classify and calculate SPC and AGB. In situ biological data measurements were carried out from 3 to 14 of June, 2020, on the three islands to measure AGB and BGB. The result from image classification shows a total area of 126.37 Ha of seagrass, which was divided into three SPC categories: medium (30–59.9%) with a total area of 78.38 Ha; low (0–29.9%) with a total area of 13.1 Ha; and high (60–100%) with a total area of 34.89 Ha. The highest SPC area was observed on Kodingareng Lompo Island with 61.07Ha, followed by Barrang Lompo Island with 53.18Ha, and Barrangcaddi Island with 12.12Ha. The total AGB on Barrang Lompo, Kodingareng Lompo, and Barrangcaddi in tons of dry weight/ha were 1.83 , 1.05, and 2.38, respectively. The highest BGB was reported on Barrangcaddi Island with 8.61 tons of dry weight/ha, followed by Barrang Lompo Island with 6.78 tons of dry weight/ha, and Kodingareng Lompo Island with 2.78 tons of dry weight/ha. Regression analysis showed a linear correlation between NDVI value and *in situ* SPC with R^2 = 0.8255. The framework of this study can be applied to monitor temporal changes of seagrass meadows distribution on small islands to promote a more sustainable ecosystem.

Keywords: biomass, NDVI, seagrass, sentinel-2, small islands

1. Introduction

Seagrass meadows have a high carbon sink capacity that surpasses even highly productive terrestrial ecosystems (Krause-jensen et al. 2019). Seagrass meadows have a carbon fixation ability that exceeds their metabolic needs; hence a large proportion of excess organic carbon is transported to the roots and rhizomes where it is stored and eventually exuded in the sediment to form anaerobic organic-rich soil (autochthonous) (Lyimo. 2016). A study of the carbon sequestered capacity of Australian seagrasses estimates annual organic carbon (C_{org}) accumulation to be between 0.093 and 6.15 Mt, with a most probable estimation of 0.93 Mt y^{-1} (10.1 t. km^{-2} y^{-1}) (Lavery et al. 2013). This type of blue carbon ecosystem also has a high global net carbon production (NCP) of 20.73–50.69 Tg C yr^{-1}, which comprises 10–18% of the total carbon storage in the ocean (Duarte et al. 2010; Kennedy et al. 2010).

However, disturbances caused by humans can negatively influence the carbon fixation ability of seagrasses and affect the amount of carbohydrate and starch being stored in their rhizomes. Growing in coastal environments, seagrasses are usually subjected to many anthropogenic activities *e.g.,* sewage disposal, mariculture, propeller boating activities, destructive fishing, construction works, dredging, and eutrophication, which threatens their ecosystems and can lead to extinction (Roca et al. 2016). It is believed that about a third to half of the world's seagrasses have been lost since 1879 and the continuing rate of disappearance is estimated to be 110 km^2 per year with net loss rates of 0.9% per year before 1940 to 7% since 1990 (Waycott et al. 2009). Therefore, the remaining seagrass ecosystems need to be conserved and protected.

Information on seagrass status in terms of percent cover and biomass needs to be acquired as baseline data to efficiently manage and monitor the seagrass ecosystems for conservation purposes. Remote sensing techniques have proven to be efficient and effective tools for seagrass monitoring. Since launched by the European Space Agency (ESA) in 2015, Sentinel-2 (S2) images with higher spatial resolution that are suitable for seagrass mapping, have been available and can be acquired at no cost. The use of S2 imagery for seagrass meadows ecosystem study was recently demonstrated with regard to seagrass beds on the Atlantic coasts of France and Spain (Zoffoli et. al. 2020).

Spermonde Archipelago is a set of small tropical islands between Kalimantan and Sulawesi islands in Indonesia. Three of its most populated islands are Barrang Lompo, Barrang Caddi, and Kodingareng Lompo. Despite high anthropogenic disturbance factors most likely occurring on these islands, there are still significant amounts of seagrass ecosystems that can be found on these islands. However, a study to analyze the percent cover and biomass of these seagrasses has not been done yet. The main objective of this study is to map seagrass distribution and the total areas on the three most populated islands in the Spermonde Archipelago using two different spatial resolution imageries, Sentinel-2 and Landsat 8. Several variables, including seagrass density and biomass, were measured directly in the field in order to find a correlation between *in situ* values and NDVI values derived from Landsat 8 and Sentinel-2 image analysis.

2. Materials and Methods

2.1 Study Sites

This study was conducted on three islands: Barrang Lompo (BL), Barrang Caddi (BC), and Kodingareng Lompo (KL). These three islands are part of the Spermonde Archipelago, which is located west off the coast of Makassar City, capital of South Sulawesi Province, Indonesia. BL Island is located at 5°2'43,577"–5°3'6,491" South Latitude (SL) and 119°19'38,716"–119°19'49.21" East Longitude (EL), which is 12.48 Km from Makassar City. Meanwhile, BC Island is located at 5°4'46,558"–5°5'0,778" SL and 119°19'10,557"–119°19'16,21" EL with a distance of 10.98 Km from Makassar City, while Kodingareng Lompo Island is located

Commented [cj1]: At a distance of 10.98 Km from Makassar City?

at 5°8'42,536"–5°9'9,434" SL and 119°15'45,006"–119°15'58,540" EL with a distance of 15.24 Km from Makassar City. Based on the distance from the mainland, the three islands were included in the middle zone, with the distance from the mainland coastline between 10–20 km (Fig.1). Field data were taken at BL, BC, and KL islands from 3 to 14 June 2020. Data derived from satellite images used for this study were acquired from S2 on July 29th 2019 and from Landsat 8 (L8) on January 6th 2019.

Commented [cj2]: See previous memo.

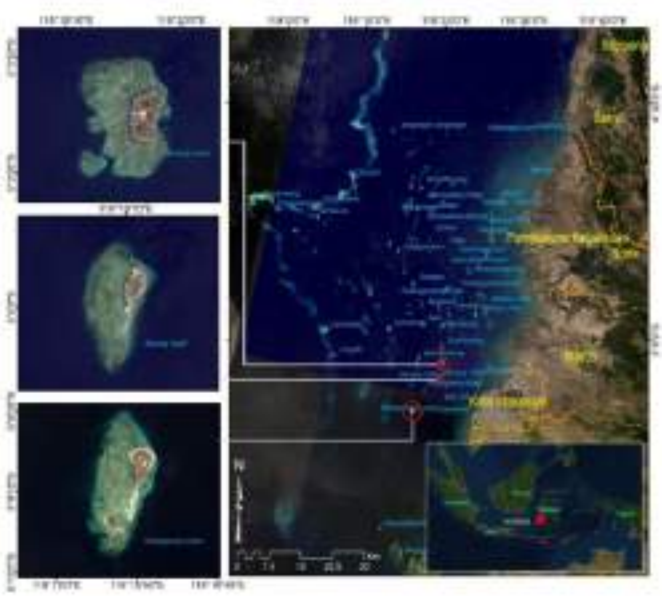

Fig 1. Study site on BL (Barrang Lompo), BC (Barrang Caddi), and KL (Kodingareng Lompo) islands, Spermonde Archipelago, South Sulawesi, Indonesia

2.2 Satellite Data

2.2.1 Landsat 8 and Sentinel-2 Image Pre-processing

Satellite image data used in this study were acquired from S2 on July 29th 2019 and L8 on January 6th 2019. Geometrically corrected S2 images of waters west of South Sulawesi were downloaded from the European Space Agency (ESA) data portal, while images from Landsat 8 were downloaded from USGS Glovis. Atmospheric correction was conducted using radiometric calibration (DN to reflectance) and Dark Object Subtraction (DOS) to remove the atmospheric effect on the images, assuming the darkest pixel value was zero (Chavez. 1988). Sun glint correction was applied on S2 imagery to correct sunlight reflection. This correction was not performed on L8 imagery as the images were clear enough, however a pan-sharpening technique was performed to facilitate interpretation for image classification. Sun glint correction for S2 imagery was carried out using an algorithm developed by Hochberg et al. (2003) and refined by Hedley et al. (2005) as in the following equation:

$$R'i = Ri - bi\ (RNIR - MinNIR) \quad (1)$$

'R'i = The i channel value after being reduced; Ri = Initial i channel value; bi = The amount of slope of the regression; RNIR = NIR channel value; MinNIR = Minimum NIR channel value.

Athmospheric corrections and water column correction were applied to the images to classify shallow-water habitats and seagrass percent cover (SPC) using supervised classification. The flowchart for spatial data processing and its integration with non-spatial data can be seen in Figure 2.Water column correction method was applied to the images using Depth Invariant Index (DII) algorithm by Lyzenga (1981). The DII method reduces the influence of the water column so that clearer images of shallow water habitats could be obtained. Points on the sand area were used to build a model to obtain the attenuation coefficient of the water column. This is because sand objects are easier to recognize in the images, with the bright white appearance becoming a darker blue color as the water depth increases. The algorithm used in this process was:

$$DII(ij) = In\ (Li) - [(Ki/Kj)\ ln\ (Lj)] \quad (2)$$

$$ki/kj = a - [(Ki/Kj)\ ln\ (Lj)] \quad (3)$$

$$\alpha = \frac{\sigma i + \sigma j}{2\sigma ij} \quad (4)$$

DII = Depth Invariant Index; Li = i-band reflectance value; Lj = j-band reflectance value; ki/kj = i and j band attenuation coefficient ratio; αi = i-band variant; αj = j-band varian; αij = i and j band covariant.

2.2.2 Image Classification Based on SPC

Images that have been corrected were then classified using an unsupervised classification method (Isoclass). The results were then reclassified based on ground truth data. The final classification of SPC was divided into three categories i.e., low (0–29.9%), medium (30–59.9%), and high (60–100%). These categories were then used to determine biomass sampling points.

The classification mapping accuracy was tested using a confusion matrix method to calculate the accuracy value of seagrass habitat mapping. It was done by using a matrix table that compares classes from satellite image classification with in situ data (Congalton and Green. 2008). The error matrix method used in this study followed the following formula:

$$K = \frac{N\sum_{i=1}^{r} X_{II} - \sum_{i=1}^{r}(X_{i+} * X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} * X_{+i})} \quad (5)$$

2.2.3 Image Classification Based on Seagrass Density

The NDVI (Normalized Difference Vegetation Index) algorithm has been used to measure vegetation density level (greenness) using the reflectance values of the near-infrared (NIR) and red bands (Pu et al. 2015). Seagrass beds usually grow in shallow waters, with the NDVI index value ranging from -1 to 0. The formula used for NDVI was:

$$\text{NDVI}=\frac{\text{NIR}-\text{Red}}{\text{NIR}+\text{Red}} \quad (6)$$

NDVI = Normalized difference Vegetation Index; NIR = Short infrared band spectral reflectance; Red = Red band spectral reflectance.

2.3 Field data

2.3.1 In Situ SPC and Biomass Sampling

Based on the unsupervised SPC image classification, 60 stations were designated on each island as the sampling points (20 for each SPC categories *i.e.*, low, medium, and high). *In situ* measurements of SPC and seagrass density were carried out by using a 50 cm × 50 cm plot (McKenzie et al. 2001). Seagrass species were also identified in every plot. A smaller plot (20 cm × 20 cm plot) was placed within the bigger plot to measure seagrass biomass. The plot was placed based on the types of seagrasses that exist within the bigger plot so that all types of seagrasses in the plot could be extracted. Seagrass biomass samples were collected with roots up to 40 cm long.-Vined rhizomes were chopped using a machete before picking out any sample. Seagrass samples consisting of roots, rhizomes, leaves, and midribs were collected from each station. Substrate and dirt were cleaned away from the samples and then each of them was put into a labeled plastic bag for further laboratory analysis.

2.3.2 Biomass Analysis

In the laboratory, samples were cut into two parts, the biomass above the sediment or above ground biomass (AGB) which consists of leaves and leaf midribs, and the below-ground biomass (BGB) which consists of rhizomes and roots (Rohr et al.2018). The samples were then oven-dried (60ºC) until a constant weight was achieved (Lyimo. 2016). Samples were then weighted using a 0.01-gram precision level digital scale. Seagrass biomass per shoot was calculated by dividing the total weight of each sample by the total number of its shoots. The mean biomass per area (gram/m^2) for each seagrass percent cover category was obtained by multiplying the number of biomass per shoots with each type of seagrass density. The result value was then multiplied by the area of each of the percent cover categories to get the total biomass per category.

2.3.3 Regression Analysis

The corelation between biomass (AGB, BGB, and total biomass) and the SPC results on every island was determined using regression linear analysis. Regression analysis was also performed to find the corelation between field survey data (*in situ* percent cover and biomass) with spatial data (percent cover and NDVI value).

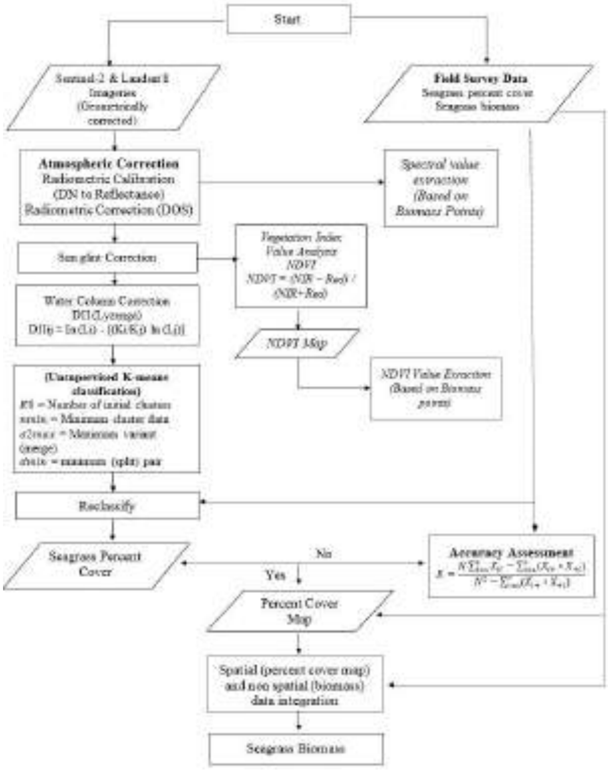

Fig 2. Flowchart analysis of integration image and in situ data to seagrass biomass

3. Result and Discussion

3.1 SPC Based on Image Classification

The seagrass maps were generated using a pixel-based classification method (unsupervised classification). 3 highly populated islands in the Spermonde Archipelago were analyzed in this study. Based on the results, SPC in KL was mainly in the range between 30–59.9% (medium), which accounts for 60.38% of the total seagrass area on this island. Similarly, SPC on BC and BL islands were also mainly characterized by the medium SPC category, which accounts for 62.71% and 63.74%, respectively, of the total seagrass areas that were identified on each island. Overall, medium SPC category accounts for 62.02% of the total seagrass area identified on these three islands. Spermonde Archipelago has 683.70 hectares of seagrass, so it can be said that these three islands contribute around 18.48% of the total seagrass in the Spermonde Archipelago.

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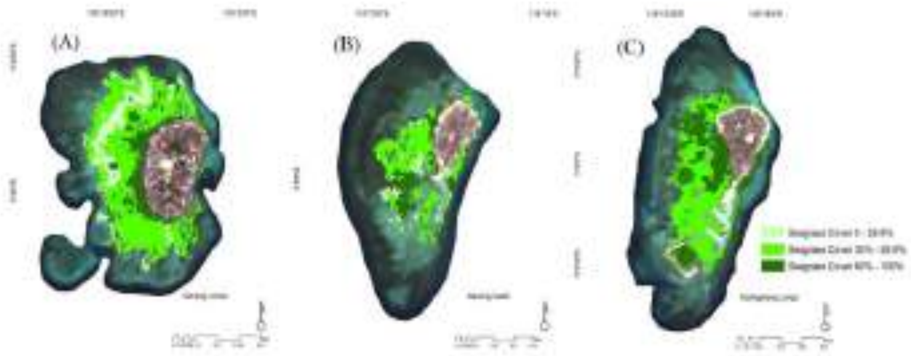

Fig 3. Seagrass distribution maps of (A) Barrang Lompo, (B) Barrang Caddi, and (C) Kodingareng Lompo using 10m spatial resolution Sentinel-2 imagery, with the acquisition date on July 29th 2019. Seagrass were categorized into three classes, i.e., 0–29,9% (low), 30–59.9% (medium) and 60–100% (high)

Pixel-based analysis was also applied on L8 images to create seagrass distribution maps on each island (Fig. 4). Due to its lower spatial resolution (30 m) seagrass mapping using L8 was only up to the aquatic habitat condition or seagrass distribution that was able to be classified using L8 (Fig. 3; Table 1). Nevertheless, the results between L8 and S2 show similar seagrass spatial distribution. As can be seen in Figure 3 and Figure 4, seagrass is dominantly grown in the western area of the islands, while the eastern part remained barren.

Table 1. Percent cover of seagrass area from Sentinel-2 imagery classification

Seagrass Percent Cover (%)	Area (Ha)
0 - 29.9 (low)	13.1
30 - 59.9 (medium)	78.38
60 – 100 (high)	34.89
Grand Total	**126.37**

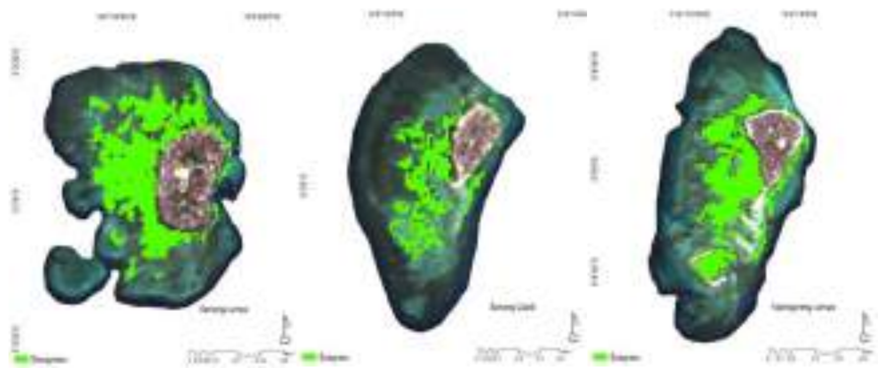

Fig 4. Seagrass distribution maps of (A) Barrang Lompo, (B) Barrang Caddi (C), and (C) Kodingareng Lompo using 30m^2 spatial resolution Landsat 8 OLI Imagery acquired on January 6th 2019

There were differences in total seagrass areas calculated with L8 and S2 image processing. Calculation with S2 resulted in a larger seagrass area by 24.2% on KL Island, 20.7% on BC Island, and 60.9% on BL Island compared with L8. Seagrass maps of KL and BC islands show that each island has several dominant and sparse seagrass distribution spots. The seagrass dominant areas at KL and BC islands were mostly on the west, southwest, to the south of the island, while on the north to the east side of the islands, the seagrass distribution was mostly sparse. Identification from the survey and aerial images indicate that lack of seagrasses on the east sides of the islands was due to water depth and human activities mostly centered on the east side of the island (the side that faces the mainland). This side was the main channel for local passenger ships (Fig. 5: A1, B1, C1) and the port area of each island.

Table 2. Total seagrass area by Landsat 8 and Sentinel-2

Island	Area by Landsat		Area by Sentinel-2	
	Area (Ha)	**Years**	**Area (Ha)**	**Years**
BL	37.66	2019	53.18	2019
BC	9.61	2019	12.12	2019
KL	46.30	2019	61.07	2019

The south side of BC and KL islands were mostly covered with white sands which were exposed during low tide and therefore not suitable for seagrass to grow. Seagrass distribution on BL Island was almost evenly distributed on each side of the island, except at the areas around the main port. BL is a highly populated island and packed with house settlements. People often dispose their household organic waste on the west side of the island, with the waste entering straight into the sea and the same thing occurs on the other islands. Hence, due to this activity, disposed organic materials on this side of the island has resulted in increasing organic nutrients inputs which support seagrass growth. As can be seen in the Figure 5A2, 5B2, and 5C2 there are more seagrass beds that can be observed on the west sides of these islands due to the disposal of richer organic materials compared to the east sides (Fig. 5A1, 5B1, 5C1). Nutrient enrichment enhanced seagrass biomass density, particularly in increasing the shoot biomass (Cabaco et.al. 2013).

Fig 5. Aerial photographs showing the shallow water condition on the east and the west side of Kodingareng Kompo (A1–A2), Barrang Caddi (B1–B2) and Barrang Lompo (C1–C2) islands. The east sides of the islands (A1, B1 and C1) showed less seagrass beds than the west sides of the islands (A2, B2, C2).

3.2 Accuracy Test

The accuracy test of the S2 image classification results was obtained using field data. Field data used was a sample of seagrass cover photos that have coordinates. Based on the image analysis results, the overall accuracy of the kappa value of each image was: KL Island 75%, BC Island 82.69%, and BL Island 80.60%.

3.3 Seagrass Percent Cover (SPC) and Density from In Situ Measurement

The result from in situ measurement shows that seagrass density and SPC have a synched pattern, from low to high density, and low, medium, and high categories, respectively (Table 3). In some cases, the seagrass density value may be higher in the percent cover high category than in the medium or low category. The consistent pattern of seagrass density in all three islands is more likely due to the relatively similar composition of seagrass species in the three percent cover categories.

Table 3. Seagrass Density and Percent Cover from in situ Measurement

Plot Category	Density (shoots/m^2)			Percent Cover (%)		
	BL	**BC**	**KL**	**BL**	**BC**	**KL**
High	418.2	447	310.733	78.25	76.9	77.867
Medium	367.6	411.8	229.6	45.45	38.95	46.267
Low	239.6	178.2	268.235	23.9	18.6	20

Note: BL = Barrrang Lompo, BC = Barrang Caddi, KL = Kodingareng Lompo

Six species of seagrass were found on the three islands, i.e., *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Halodule uninervis*, *Halophila ovalis* dan *Syringodium isoetifolium*. Seagrass composition was dominated by *T. hemprichii* in all categories. An exception was found on KL Island where *C. rotundata* dominated the low category (Fig. 6).

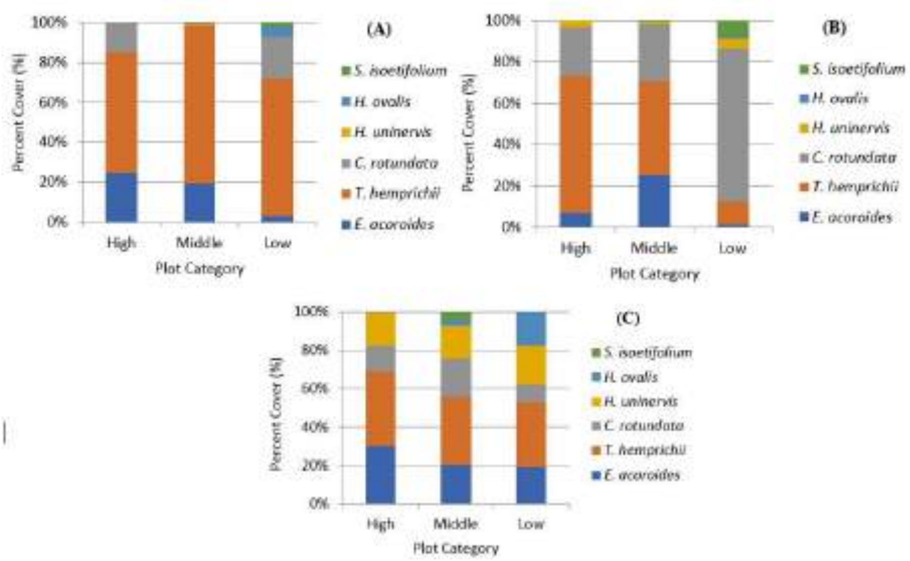

Fig 6. Percent cover of each seagrass 'species' based on plot categories in (A) Barrang Lompo, (B) Kodingareng Lompo, and (C) Barrang Caddi

3.4 Correlation between Density of Seagrass using NDVI Algorithm and Percent Cover of Seagrass using In situ Data

NDVI has been widely used in several studies in Indonesia to estimate vegetation biomass, greenness level, primary production, and dominant species in vegetation. The NDVI index value ranges from -1.00–1.00. The principle of NDVI is to measure the level of greenness intensity. The intensity of greenness in Sentinel-2 (Fig. 7) and Landsat 8 (Fig. 8) images correlates with the level of density of the vegetation canopy.

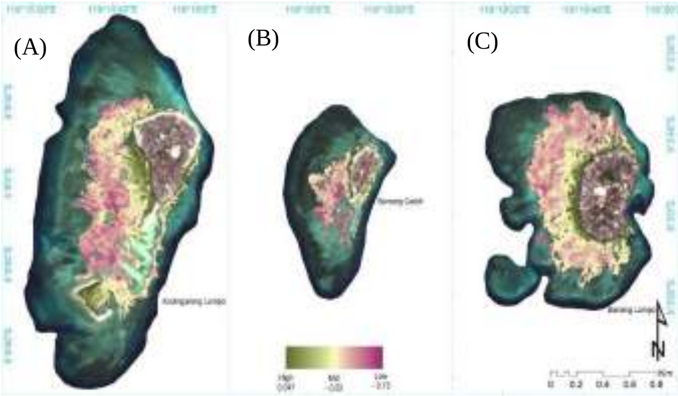

Fig 7. NDVI values derived from Sentinel-2 on Kodingareng Lompo (A), Barrang Caddi (B) and Barrang Lompo (C)

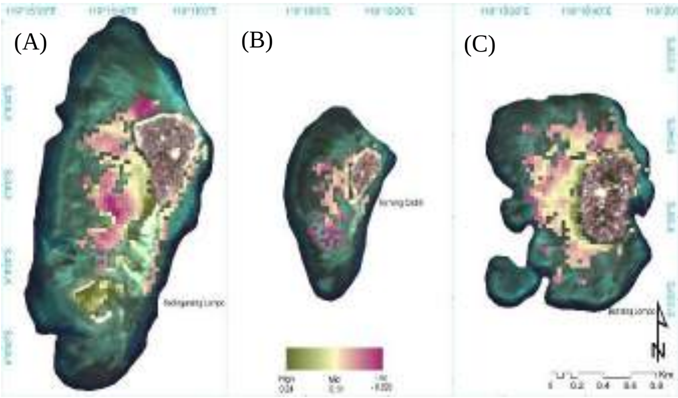

Fig 8. NDVI derived from Landsat 8 on Kodingareng Lompo (A), Barrang Caddi (B) and Barrang Lompo (C)

The relationship between SPC from field measurements and NDVI values was analyzed using algorithmic modeling with linear regression. The regression equation was obtained from the relationship between the NDVI value of S2 images and the value of in situ SPC. The algorithm obtained was y = 0.0053x - 0.785. Regression analysis shows a linear correlation between NDVI and in situ data with R^2 value of 0.8255. The R-value indicates a strong relationship between the *in situ* SPC and the NDVI values of satellite images (Fig. 9).

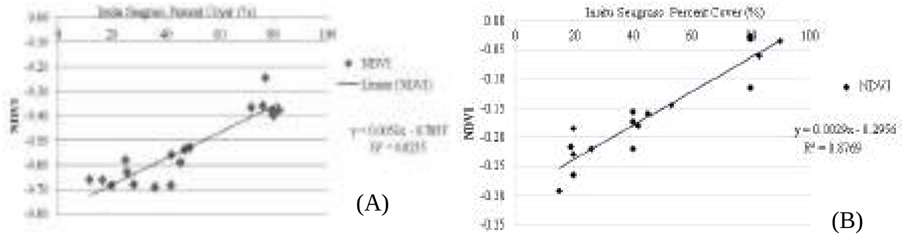

Fig 9. Correlation analysis of SPC between in situ measurement and NDVI values on the three islands; (A) Sentinel-2 imagery, (B) Landsat 8 imagery

3.5 Seagrass Biomass

3.5.1 Total Biomass

Results from laboratory analysis showed seagrass BGB in all islands and in each seagrass cover category were higher than AGB. Seagrass BGB value on BL Island on average was four times higher than AGB. Meanwhile, the ratio was smaller on the other two islands, which was about three to three and a half times higher (Table 3). Biomass stored under the substrate is one of the forms of seagrass adaptation. Seagrass grows in shallow waters, which makes it very vulnerable to the influence of waves. Without specific adaptation, seagrass can be easily uprooted by the waves. Seagrass adapts by storing more photosynthetic products under the ground than above, therefore, it can stay still under the impact of waves.

Among the three islands, the highest average biomass was found on BC Island, either for BGB, AGB, or the total biomass (Table 4). This is more likely due to the large composition of *E. acoroides*, especially in the high-percent cover category (Fig. 6). The percent cover of *E. acoroides* reached 23.2% or about 30% of the total seagrass cover in the high category of the island. *E. acoroides* is a large seagrass species (Waycott et al. 2004) and the largest seagrass species that can be found in Indonesia.

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Table 4. Seagrass biomass in the study locations based on high, medium, and low categories

Location	Category	Biomass (dry weight ton /ha)		
		Above ground	Below ground	Total
Barrang Lompo	High	1.05	3.49	4.55
	Medium	0.58	2.33	2.9
	Low	0.2	0.96	1.17
Kodingareng Lompo	High	0.48	1.28	1.76
	Medium	0.46	1.01	1.47
	Low	0.11	0.49	0.6
Barrang Caddi	High	1.33	4.83	6.16
	Medium	0.75	2.75	3.5
	Low	0.3	1.03	1.33

Fig 10. Field photographs of the low, medium, and high seagrass categories on Kodingareng Lompo and Barrang Lompo

Seagrass BGB was generally weighted higher than ABG in the seagrass categories on the three islands. High categories dominated seagrasses on the three different islands. There was a total of 8.62 ton dry weight/ha seagrass biomass on BL Island, 3.83 ton dry weight/ha on KL Island, and 10.99 ton dry weight/ha on BC Island.

3.5.2 Correlation between Biomass In Situ and NDVI

The correlation between the total biomass and the NDVI values of the three islands was analyzed. R^2 values acquired from regression analysis were 0.40 for Landsat 8, and 0.43 for Sentinel-2. These R^2-values indicate a low correlation between the total biomass value and the NDVI value. Overall, NDVI and carbon biomass of seagrass showed a linear relation (Fig. 11). The higher the total biomass value, the closer the NDVI value will be to 0 (solid seagrass cover condition), while the lower the total biomass value, the closer the NDVI value will be to -1 (low seagrass cover condition).

Moreover, on BL Island, the biomass value has more variation in the high seagrass cover category than in the low and medium categories (Table 4). This is due to the various species composition. Some plots were *T. hemprichii* dominant, while other plots were more *E acoroides* dominant. Morphologically, the two seagrasses have different sizes, therefore at the same cover percentage, they have very different biomass values. In the low and medium seagrass cover categories *T. hemprichii* was consistently the dominant species.

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Furthermore, in the high seagrass cover category, there was quite a lot of overlap between leaves, especially with the *T. hemprichii* species. In some plots (Fig. 10), a large addition of seagrass cover value can only cause a small increase in biomass value. Meanwhile, in other plots, the addition of the same amount of seagrass cover value can add a substantial biomass value. However, in the high and medium seagrass cover categories, the overlap between leaves was less. According to Mallombassi, et al (2020), the high slope value of *T. hemprichii* seagrass regression equation at high percent cover was because of the overlapping leaf canopy, resulting in a high increase of biomass value despite the small addition of the percent cover.

E. acoroides and *C. rotundata* significantly contributed to the medium to sparse percent cover category on KL and BC islands. This causes the biomass values of those two categories to vary largely. The contribution of the two seagrasses was about half of the dominant species *T. hemprichii*, while on BL Island it can reach a quarter in the same category.

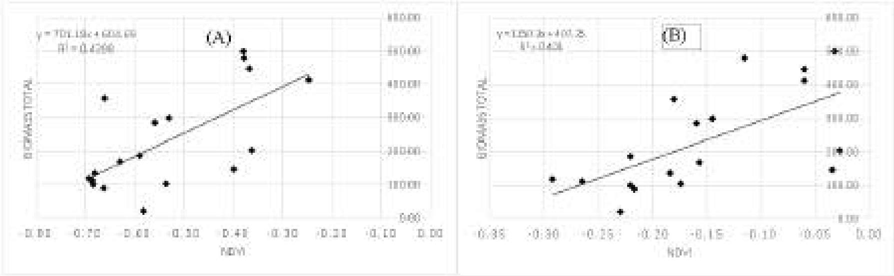

Fig 11. Regression analysis of seagrass biomass and NDVI on Barrang Lompo, Barrang Caddi, and Kodingareng Lompo islands; (A) Sentinel-2 imagery, (B) Landsat 8 imagery

4. Conclusions

The result of this study showed that there is a strong correlation between *in situ* seagrass percent cover and NDVI values derived from the two satellite images. However, the correlation between in situ seagrass total biomass and the NDVI values showed a relatively weak correlation. Image classification showed that seagrass was distributed mostly on the west side of the islands, and there were 6 seagrass species identified on the sites, i.e., *E. acoroides*, *T. hemprichii*, *C. rotundata*, *H. uninervis*, *H. ovalis* and *S. isoetifolium*. In this study we also discovered that there was a disparity of seagrass total cover area between Sentinel-2 and Landsat 8, due to spatial resolution diferrences. Sentinel-2 images were able to classify seagrass distribution up to the seagrass density category, however, they cannot be applied to differentiate seagrass density based on species. Nevertheless, both Sentinel-2 and Landsat 8 are useful for seagrass condition monitoring purposes.

Acknowledgments

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References

Cabaço S, Apostolaki ET, García-Marín P, Gruber R, Hernández I, Martínez-Crego B, Mascaró O, Pérez M, Prathep A, Robinson C, Romero J, Schmidt AL, Short FT, Van Tussenbroek BI, Santos R (2013) Effects of nutrient enrichment on seagrass population dynamics: evidence and synthesis from the biomass-density relationships. J Ecol 101:1552–1562. https://doi.org/10.1111/1365-2745.12134

Chavez PS Jr (1988) An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote Sens Environ 24(3):459–479. https://doi.org/10.1016/0034-4257(88)90019-3

Congalton R, Green K (2008) Assessing the Accuracy of Remotely Sensed Data, Principles and Practices (2nd Edition). CRC Press, Boca Raton, p 200

Duarte CM, Marbà N, Gacia E, Fourqurean JW, Beggins J, Barrón C, and Apostolaki ET (2010) Seagrass community metabolism: Assessing the carbon sink capacity of seagrass meadows. Global Biogeochem Cy 24(4):GB4032. https://doi.org/10.1029/2010GB003793

Hedley JD, Harborne AR, Mumby PJ (2005) Simple and robust removal of sun glint for mapping shallow-water benthos. Int J Remote Sens 26(10):2107–2112. https://doi.org/10.1080/01431160500034086

Hochberg EJ, Atkinson MJ (2003). Spectral reflectance of coral reef bottom-types worldwide and implications for coral reef remote sensing. Remote Sens Environ 85(2):159–173. https://doi.org/10.1016/S0034-4257(02)00201-8

Kennedy H, Beggins J, Duarte CM, Fourqurean JW, Holmer M, Marbà N, and Middelburg JJ (2010) Seagrass sediments as a global carbon sink: Isotopic constraints. Global Biogeochem Cy 24(4):GB4026. https://doi.org/10.1029/2010GB003848

Krause-Jensen D, Duarte C (2016) Substantial role of macroalgae in marine carbon sequestration. Nature Geosci 9:737–742. https://doi.org/10.1038/ngeo2790

Lavery PS, Mateo MÁ, Serrano O, Rozaimi M (2013). Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PloS One 8(9):e73748. https://doi.org/10.1371/journal.pone.0073748

Lyimo LD (2016) Carbon sequestration processes in tropical seagrass beds. Ph.D. Thesis, Stockholm University, p 49

Lyzenga D (1981) Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. Int J Remote Sens 2(1):71–82. https://doi.org/10.1080/01431168108948342

Mallombassi A, Mashoreng S, La Nafie YA (2020) The relationship between seagrass Thalassia hemprichii percentage cover and their biomass. Spermonde 6(1):7–10. https://doi.org/10.20956/jiks.v6i1.9922

McKenzie LJ, Finkbeiner MA, Kirkman H (2001) Methods for mapping seagrass distribution. In: Short FT, Coles RG (eds) Global Seagrass Research Methods. Elsevier Science, pp 101–121. https://doi.org/10.1016/B978-044450891-1/50006-2

Pu R, Bell S, English D (2015) Developing hyperspectral vegetation indices for identifying seagrass species and cover classes. J Coastal Res 31(3):595–615. https://doi.org/10.2112/JCOASTRES-D-12-00272.1

Roca G, Alcoverro T, Krause-Jensen D, Balsby TJS, van Katwijk MM, Marba N, Santos R, Arthur R, Mascaró O, Fernández-Torquemada Y, Pérez M (2016) Response of seagrass indicators to shifts in environmental stressors: a global review and management synthesis. Ecol Indic 63:310–323. https://doi.org/10.1016/j.ecolind.2015.12.007

Rohr ME, Bostrom C, Canal-Vergés P, Holmer M (2018) Blue carbon storage Capacity of Temperate Eelgrass (Zostera marina) meadows. Global Biogeochem Cy 32:1457–1475. https://doi.org/10.1029/2018GB005941

Waycott M, McMahon K, Mellors J, Calladine A, Kleine D (2004) A guide to tropical seagrass of the Indo-West Pacific. James Cook University. Townsville

Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT, William SL (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. P Natl Acad Sci USA 106(30):12377–12381. https://doi.org/10.1073/pnas.0905620106

Zoffoli ML, Gernez P, Rosa P, Le Bris A, Brando VE, Barillé AL, Harin N, Peters S, Poser K, Spaias L, Peralta G (2020). Sentinel-2 remote sensing of Zostera noltei-dominated intertidal seagrass meadows. Remote Sens Environ 251:112020. https://doi.org/10.1016/j.rse.2020.112020

Figure 1

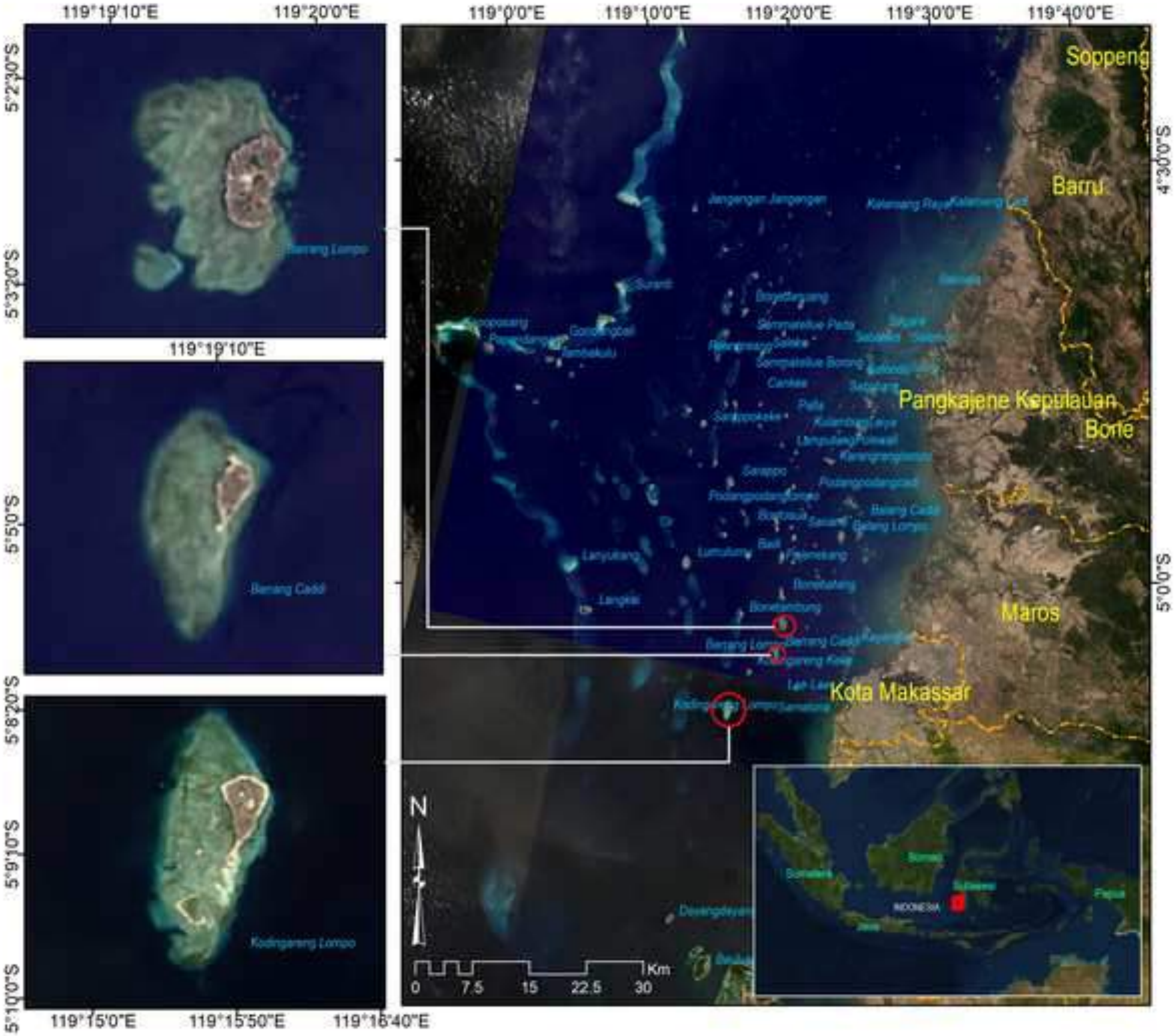
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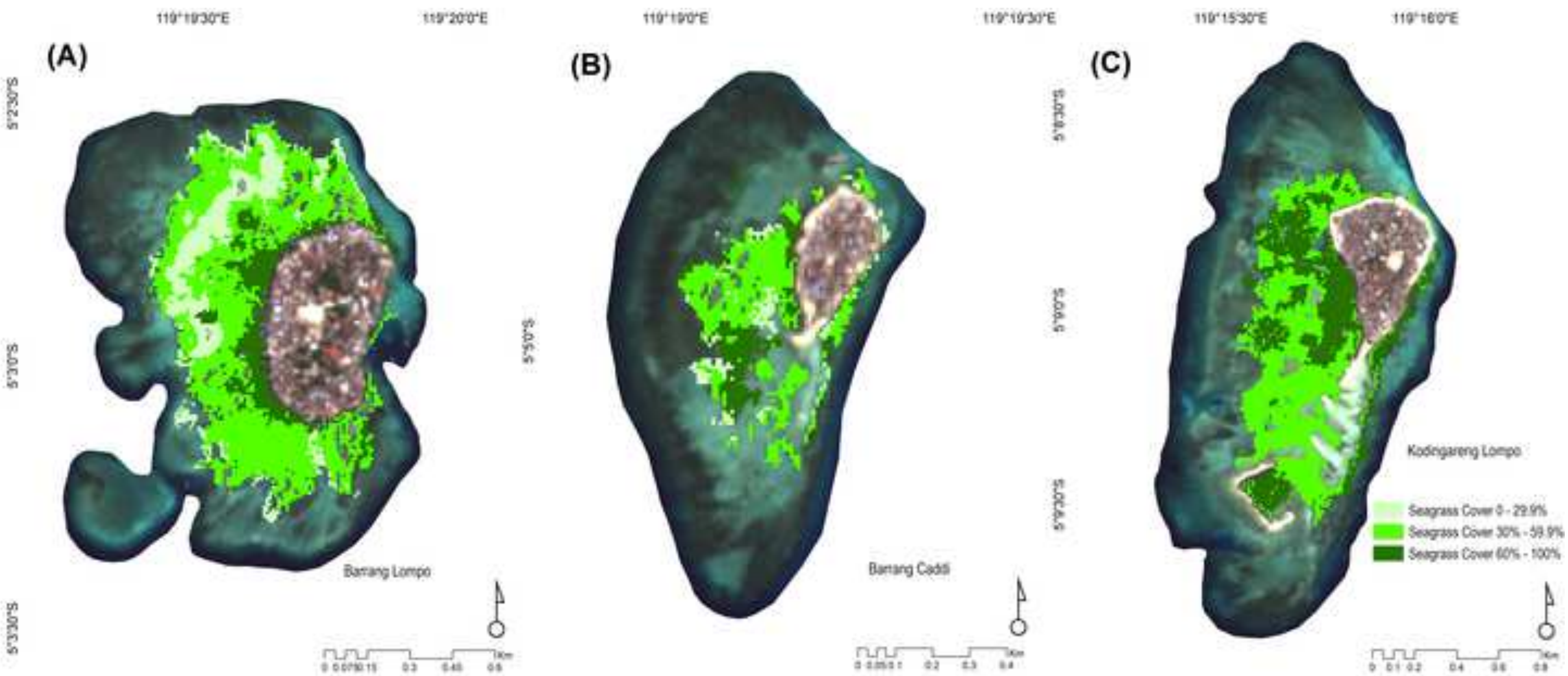
Figure 3



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119°15'30"E
119°16'0"E
Barrang Lompo
Barrang Caddi
Kodingareng Lompo
Seagrass Cover 0 - 29.9%
Seagrass Cover 30% - 59.9%
Seagrass Cover 60% - 100%

Figure 4

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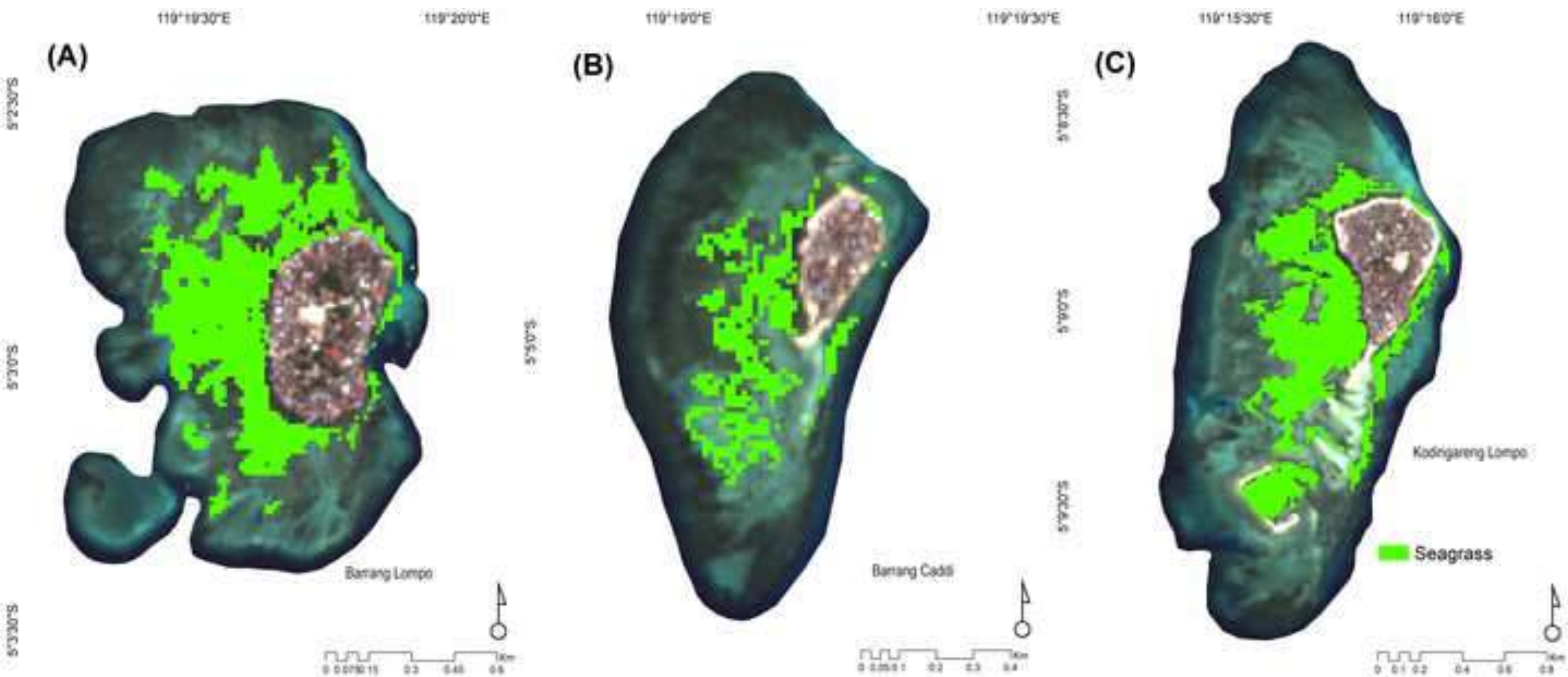

Figure 7

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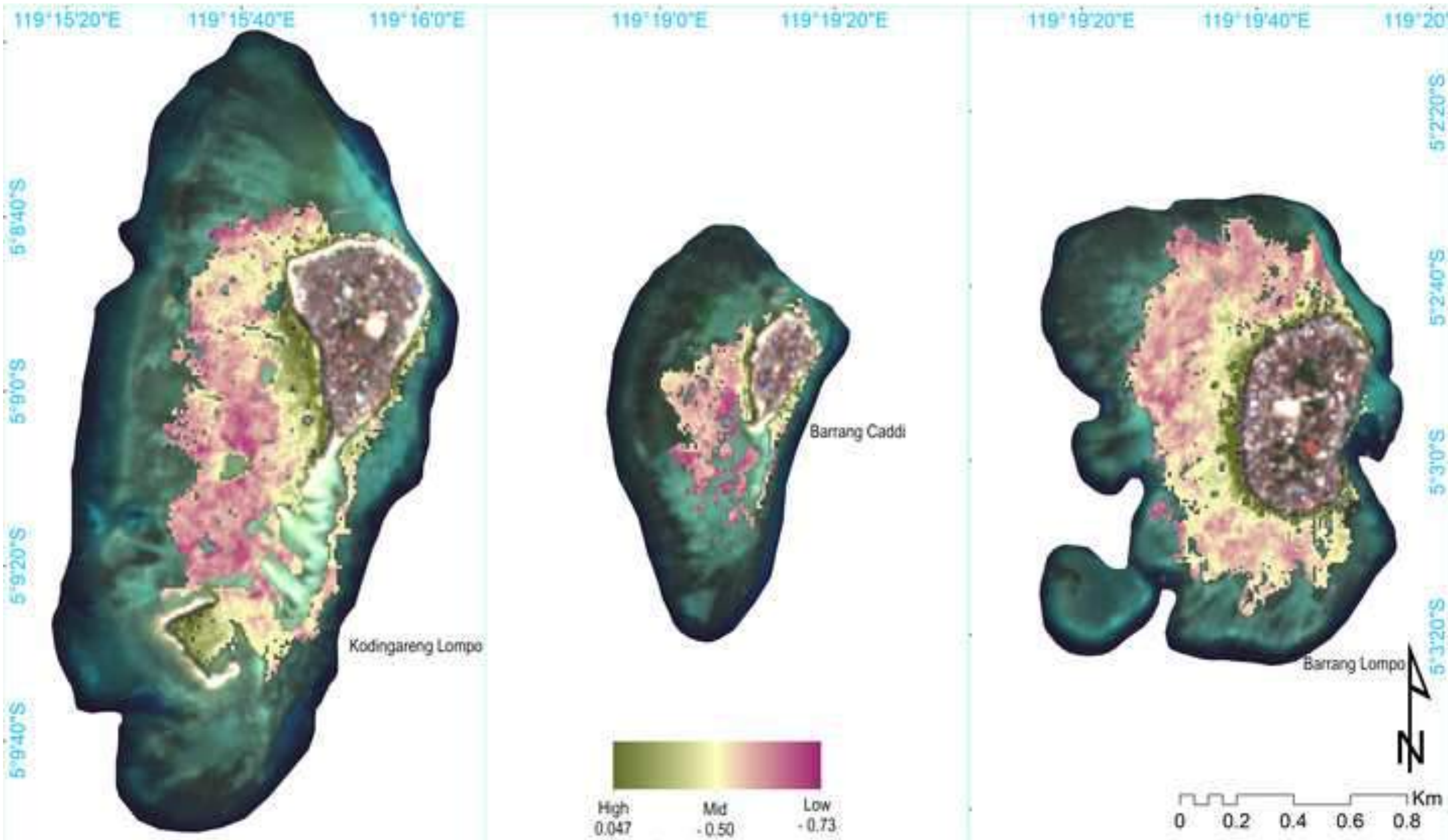

Figure 8

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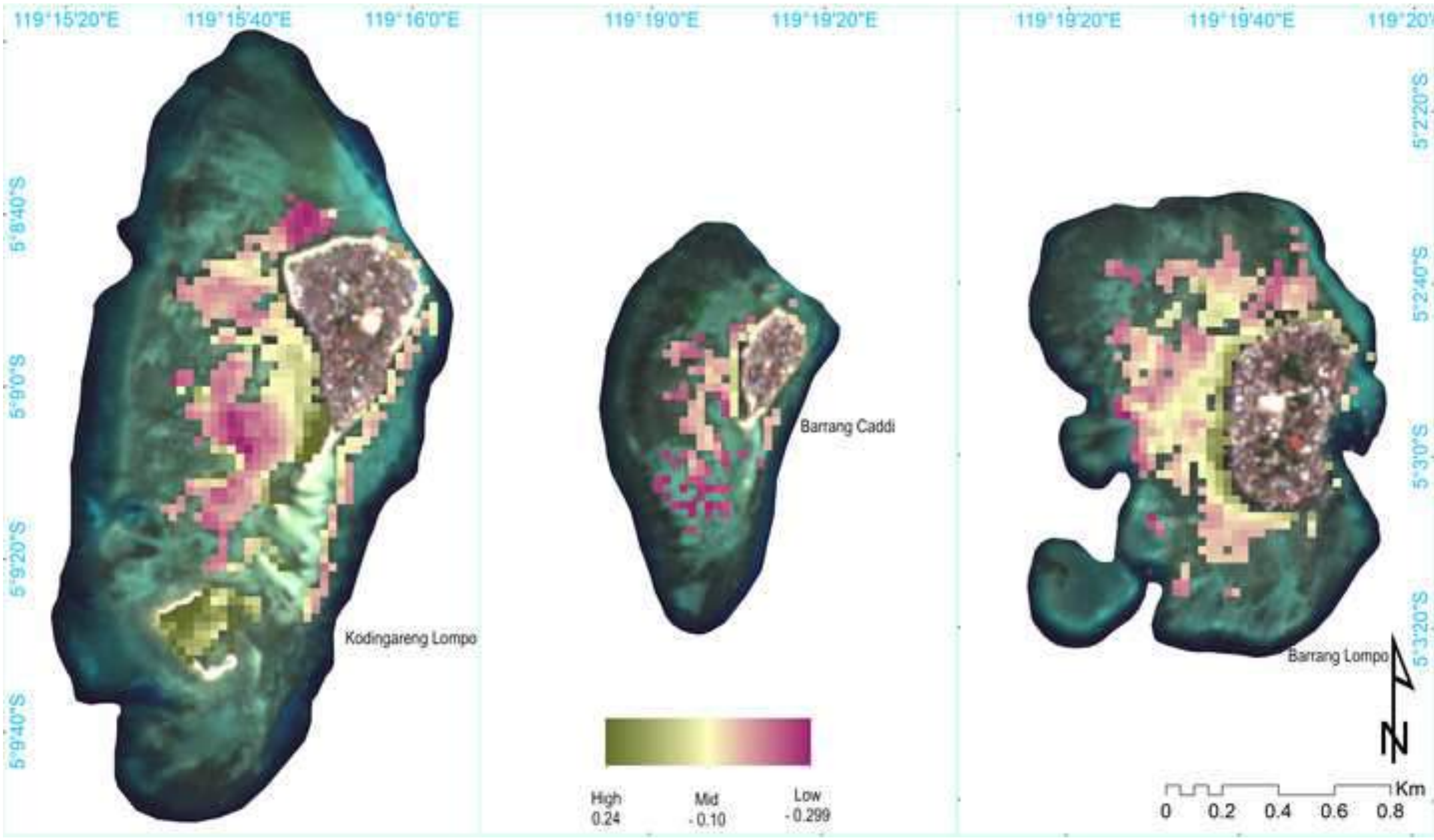

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Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia

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Abstract: As one of the major blue carbon ecosystems, studying, conserving, and monitoring seagrass meadows, especially on small populated islands, has become very important due to their vulnerability to anthropogenic and global environmental factors. In this study, we used satellite image analysis and biological data to map seagrass percent cover (SPC), above-ground biomass (AGB), and below-ground biomass (BGB) on the three most populated islands of the Spermonde Archipelago, Indonesia, *i.e.*, Kodingareng Lompo, Barrang Lompo, and Barrang Caddi. Reflectance and Normalized Difference Vegetation Index (NDVI) values of Sentinel-2 (S2) imagery weres used to classify and calculate SPC and AGB. In situ biological data measurements were carried out from 3 to 14 of June, 2020, on the three islands to measure AGB and BGB. The result from image classification shows a total area of 126.37 Ha of seagrass, which was divided into three SPC categories: medium (30% - 59.9%) with a total area of 78.38 Ha; low (0% -29.9%) with a total area of 13.1 Ha; and high (60% -100%) with a total area of 34.89 Ha. The highest SPC area was observed on Kodingareng Lompo Island with 61.07Ha, followed by Barrang Lompo Island with 53.18Ha, and Barrangcaddi Island with 12.12Ha. The total AGB on Barrang Lompo, Kodingareng Lompo, and Barrangcaddi in tons of dry weight/ha were 1.83 , 1.05, and 2.38, respectively. The highest BGB was reported on Barrangcaddi Island with 8.61 tons of dry weight/ha, followed by Barrang Lompo Island with 6.78 tons of dry weight/ha, and Kodingareng Lompo Island with 2.78 tons of dry weight/ha. Regression analysis showed a linear correlation between NDVI value and *in situ* SPC with R^2 = 0.8255. The framework of this study can be applied to monitor temporal changes of seagrass meadows distribution on small islands to promote a more sustainable ecosystem.

Keywords: biomass, NDVI, seagrass, sentinel-2, small islands

1. Introduction

Seagrass meadows have a high carbon sink capacity that surpasses even highly productive terrestrial ecosystems (Krause-jensen et al. 2019). Seagrass meadows have a carbon fixation ability that exceeds their metabolic needs; hence a large proportion of excess organic carbon is transported to the roots and rhizomes where it is stored and eventually exuded in the sediment to form anaerobic organic-rich soil (autochthonous) (Lyimo. 2016). A study of the carbon sequestered capacity of Australian seagrasses estimates annual organic carbon (C_{org}) accumulation to be between 0.093 and 6.15 Mt, with a most probable estimation of 0.93 Mt y−1 (10.1 t. km−2 y−1) (Lavery et al. 2013). This type of blue carbon ecosystem also has a high global net carbon production (NCP) of 20.73–50.69 Tg C yr−1, which comprises 10–18% of the total carbon storage in the ocean (Duarte et al. 2010; Kennedy et al. 2010).

However, disturbances caused by humans can negatively influence the carbon fixation ability of seagrasses and affect the amount of carbohydrate and starch being stored in their rhizomes. Growing in coastal environments, seagrasses are usually subjected to many anthropogenic activities *e.g.*, sewage disposal, mariculture, propeller boating activities, destructive fishing, construction works, dredging, and eutrophication, which threatens their ecosystems and can lead to extinction (Roca et al. 2016). It is believed that about a third to half of the world's seagrasses have been lost since 1879 and the continuing rate of disappearance is estimated to be 110 km^2 per year with net loss rates of 0.9% per year before 1940 to 7% since 1990 (Waycott et al. 2009). Therefore, the remaining seagrass ecosystems need to be conserved and protected.

Information on seagrass status in terms of percent cover and biomass needs to be acquired as baseline data to efficiently manage and monitor the seagrass ecosystems for conservation purposes. Remote sensing techniques have proven to be efficient and effective tools for seagrass monitoring. Since launched by the European Space Agency (ESA) in 2015, Sentinel-2 (S2) images with higher spatial resolution that are suitable for seagrass mapping, have been available and can be acquired at no cost. The use of S2 imagery for seagrass meadows ecosystem study was recently demonstrated with regard to seagrass beds on the Atlantic coasts of France and Spain (Zoffoli et. al. 2020).

Spermonde Archipelago is a set of small tropical islands between Kalimantan and Sulawesi islands in Indonesia. Three of its most populated islands are Barrang Lompo, Barrang Caddi, and Kodingareng Lompo. Despite high anthropogenic disturbance factors most likely occurring on these islands, there are still significant amounts of seagrass ecosystems that can be found on these islands. However, a study to analyze the percent cover and biomass of these seagrasses has not been done yet. The main objective of this study is to map seagrass distribution and the total areas on the three most populated islands in the Spermonde Archipelago using two different spatial resolution imageries, Sentinel-2 and Landsat 8. Several variables, including seagrass density and biomass, were measured directly in the field in order to find a correlation between *in situ* values and NDVI values derived from Landsat 8 and Sentinel-2 image analysis.

2. Materials and Methods

Study sites

This study was conducted on three islands: Barrang Lompo (BL), Barrang Caddi (BC), and Kodingareng Lompo (KL). These three islands are part of the Spermonde Archipelago, which is located west off the coast of Makassar City, capital of South Sulawesi Province, Indonesia. BL Island is located at 5 ° 2'43,577 "- 5 ° 3'6,491" South Latitude (SL) and 119°19 '38,716 "- 119° 19' 49.21" East Longitude (EL), which is 12.48 Km from Makassar City. Meanwhile, BC Island is located at 5 ° 4'46,558 "- 5 ° 5'0,778" SL and 119 ° 19 '10,557 "- 119 ° 19' 16,21 "EL with a distance of 10.98 Km, while Kodingareng Lompo Island is located at 5 ° 8'42,536" - 5 ° 9'9,434 "SL and 119 ° 15 '45,006" - 119 ° 15' 58,540 "EL with a distance of 15.24 Km. Based on the distance from the mainland, the three islands were included in the middle zone, with the distance from the mainland coastline between 10 -20 km (Fig.1). Field data were taken at BL, BC, and KL islands from 3 to 14 June 2020. Data derived from satellite images used for this study were acquired from S2 on July 29th 2019 and from Landsat 8 (L8) on January 6th 2019.

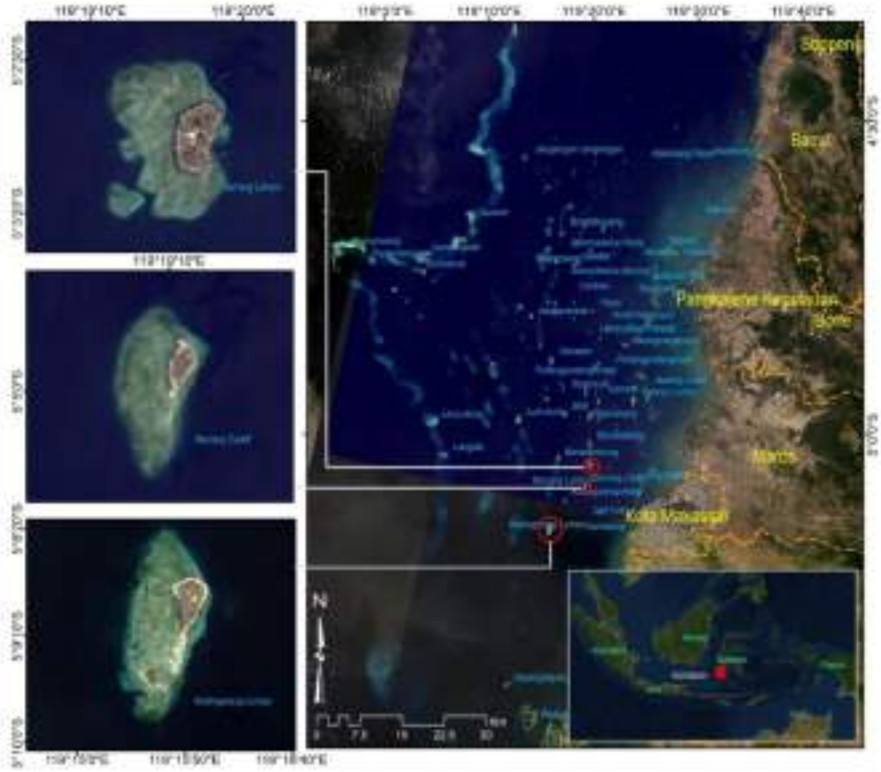

Fig 1. Study site on BL (Barrang Lompo), BC (Barrang Caddi), and KL (Kodingareng Lompo) islands, Spermonde Archipelago, South Sulawesi, Indonesia

Satellite Data

Landsat 8 and Sentinel-2 image pre-processing

Satellite image data used in this study were acquired from S2 on July 29th 2019 and L8 on January 6th 2019. Geometrically corrected S2 images of waters west of South Sulawesi were downloaded from the European Space Agency (ESA) data portal, while images from Landsat 8 were downloaded from USGS Glovis. Atmospheric correction was conducted using radiometric calibration (DN to reflectance) and Dark Object Subtraction (DOS) to remove the atmospheric effect on the images, assuming the darkest pixel value was zero (Chavez. 1988). Sun glint correction was applied on S2 imagery to correct sunlight reflection. This correction was not performed on L8 imagery as the images were clear enough, however a pan-sharpening technique was performed to facilitate interpretation for image classification. Sun glint correction for S2 imagery was carried out using an algorithm developed by Hochberg et al. (2003) and refined by Hedley et al. (2005) as in the following equation:

$$R'i = Ri – bi\ (RNIR – MinNIR)\text{......................................}(1)$$

'R'i = The i channel value after being reduced; Ri = Initial i channel value; bi = The amount of slope of the regression; RNIR = NIR channel value; MinNIR = Minimum NIR channel value.

Athmospheric corrections and water column correction were applied to the images to classify shallow-water habitats and seagrass percent cover (SPC) using supervised classification. The flowchart for spatial data processing and its integration with non-spatial data can be seen in Figure 2.Water column correction method was applied to the images using Depth Invariant Index (DII) algorithm by Lyzenga (1981). The DII method reduces the influence of the water column so that clearer images of shallow water habitats could be obtained. Points on the sand area were used to build a model to obtain the attenuation coefficient of the water column. This is because sand objects are easier to recognize in the images, with the bright white appearance becoming a darker blue color as the water depth increases. The algorithm used in this process was:

$$DII(ij) = In\ (Li) - [(Ki/Kj)\ ln\ (Lj)]\text{................................}(2)$$

$$ki/kj = a - [(Ki/Kj)\ ln\ (Lj)]\text{..}(3)$$

$$\alpha = \frac{\sigma i+\sigma j}{2\sigma ij} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

DII = Depth Invariant Index; Li = i-band reflectance value; Lj = j-band reflectance value; ki/kj = i and j band attenuation coefficient ratio; αi = i-band variant; αj = j-band varian; αij = i and j band covariant.

Image classification based on SPC

Images that have been corrected were then classified using an unsupervised classification method (Isoclass). The results were then reclassified based on ground truth data. The final classification of SPC was divided into three categories i.e., low (0-29.9%), medium (30%-59.9%), and high (60%-100%). These categories were then used to determine biomass sampling points.

The classification mapping accuracy was tested using a confusion matrix method to calculate the accuracy value of seagrass habitat mapping. It was done by using a matrix table that compares classes from satellite image classification with in situ data (Congalton and Green. 2008). The error matrix method used in this study followed the following formula:

$$K = \frac{N\sum_{i=1}^{r} X_{II} - \sum_{i=1}^{r}(X_{i+} * X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} * X_{+i})} \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Image classification based on seagrass density

The NDVI (Normalized Difference Vegetation Index) algorithm has been used to measure vegetation density level (greenness) using the reflectance values of the near-infrared (NIR) and red bands (Pu et al. 2015). Seagrass beds usually grow in shallow waters, with the NDVI index value ranging from -1 to 0. The formula used for NDVI was:

$$\text{NDVI} = \frac{\text{NIR}-\text{Red}}{\text{NIR}+\text{Red}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

NDVI = Normalized difference Vegetation Index; NIR = Short infrared band spectral reflectance; Red = Red band spectral reflectance.

Field data

In situ SPC and biomass sampling

Based on the unsupervised SPC image classification, 60 stations were designated on each island as the sampling points (20 for each SPC categories *i.e.*, low, medium, and high). *In situ* measurements of SPC and seagrass density were carried out by using a 50cm x 50 cm plot (McKenzie et al., 2001). Seagrass species were also identified in every plot. A smaller plot (20cm x 20cm plot) was placed within the bigger plot to measure seagrass biomass. The plot was placed based on the types of seagrasses that exist within the bigger plot so that all types of seagrasses in the plot could be extracted. Seagrass biomass samples were collected with roots up to 40 cm long.-Vined rhizomes were chopped using a machete before picking out any sample. Seagrass samples consisting of roots, rhizomes, leaves, and midribs were collected from each station. Substrate and dirt were cleaned away from the samples and then each of them was put into a labeled plastic bag for further laboratory analysis.

Biomass analysis

In the laboratory, samples were cut into two parts, the biomass above the sediment or above ground biomass (AGB) which consists of leaves and leaf midribs, and the below-ground biomass (BGB) which consists of rhizomes and roots (Rohr et al.2018). The samples were then oven-dried (60^{o}C) until a constant weight was achieved (Lyimo. 2016). Samples were then weighted using a 0.01-gram precision level digital scale. Seagrass biomass per shoot was calculated by dividing the total weight of each sample by the total number of its shoots. The mean biomass per area (gram/m^2) for each seagrass percent cover category was obtained by multiplying the number of biomass per shoots with each type of seagrass density. The result value was then multiplied by the area of each of the percent cover categories to get the total biomass per category.

Regression analysis

The corelation between biomass (AGB, BGB, and total biomass) and the SPC results on every island was determined using regression linear analysis. Regression analysis was also performed to find the corelation between field survey data (*in situ* percent cover and biomass) with spatial data (percent cover and NDVI value).

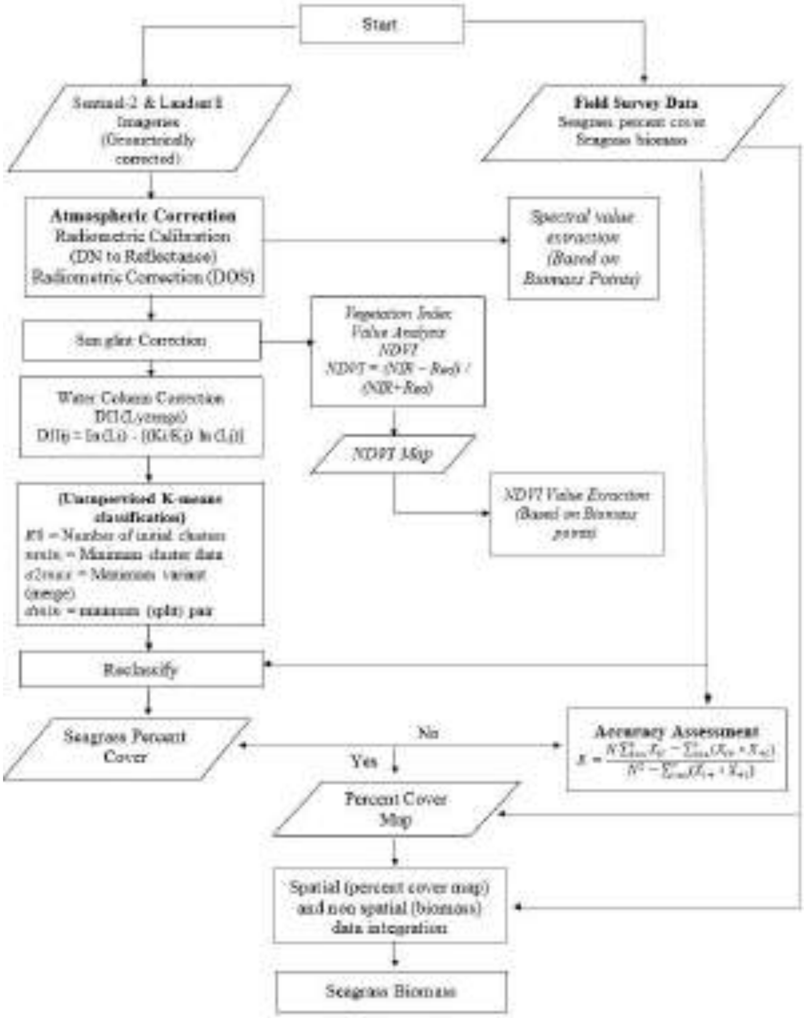

Fig 2. Flowchart analysis of integration image and in situ data to seagrass biomass

3. Result and Discussion

SPC based on image classification

The seagrass maps were generated using a pixel-based classification method (unsupervised classification). 3 highly populated islands in the Spermonde Archipelago were analyzed in this study. Based on the results, SPC in KL was mainly in the range between 30 - 59.9% (medium), which accounts for 60.38% of the total seagrass area on this island. Similarly, SPC on BC and BL islands were also mainly characterized by the medium SPC category, which accounts for 62.71% and 63.74%, respectively, of the total seagrass areas that were identified on each island. Overall, medium SPC category accounts for 62.02% of the total seagrass area identified on these three islands. Spermonde Archipelago has 683.70 hectares of seagrass, so it can be said that these three islands contribute around 18.48% of the total seagrass in the Spermonde Archipelago.

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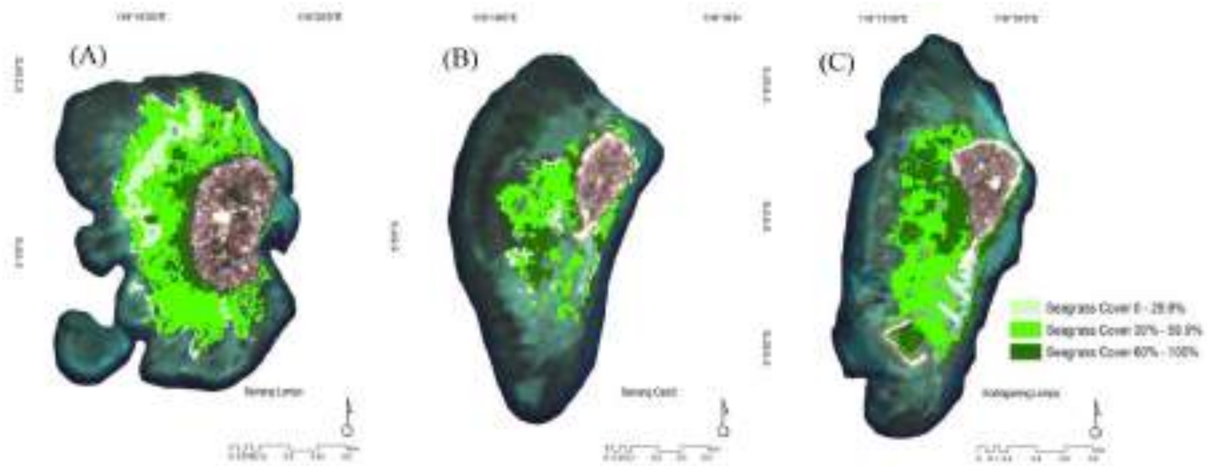

Fig 3. Seagrass distribution maps of (A) Barrang Lompo, (B) Barrang Caddi, and (C) Kodingareng Lompo using 10m spatial resolution Sentinel-2 imagery, with the acquisition date on July 29th 2019. Seagrass were categorized into three classes, i.e., 0 – 29,9% (low), 30-59.9% (medium) and 60-100% (high).

Pixel-based analysis was also applied on L8 images to create seagrass distribution maps on each island (Figure 4). Due to its lower spatial resolution (30 m) seagrass mapping using L8 was only up to the aquatic habitat condition or seagrass distribution that was able to be classified using L8 (Figure 3 & Table 1). Nevertheless, the results between L8 and S2 show similar seagrass spatial distribution. As can be seen in Figure 3 and Figure 4, seagrass is dominantly grown in the western area of the islands, while the eastern part remained barren.

Table 1. Percent cover of seagrass area from Sentinel-2 imagery classification

Seagrass Percent Cover (%)	Area (Ha)
0 - 29.9 (low)	13.1
30 - 59.9 (medium)	78.38
60 – 100 (high)	34.89
Grand Total	**126.37**

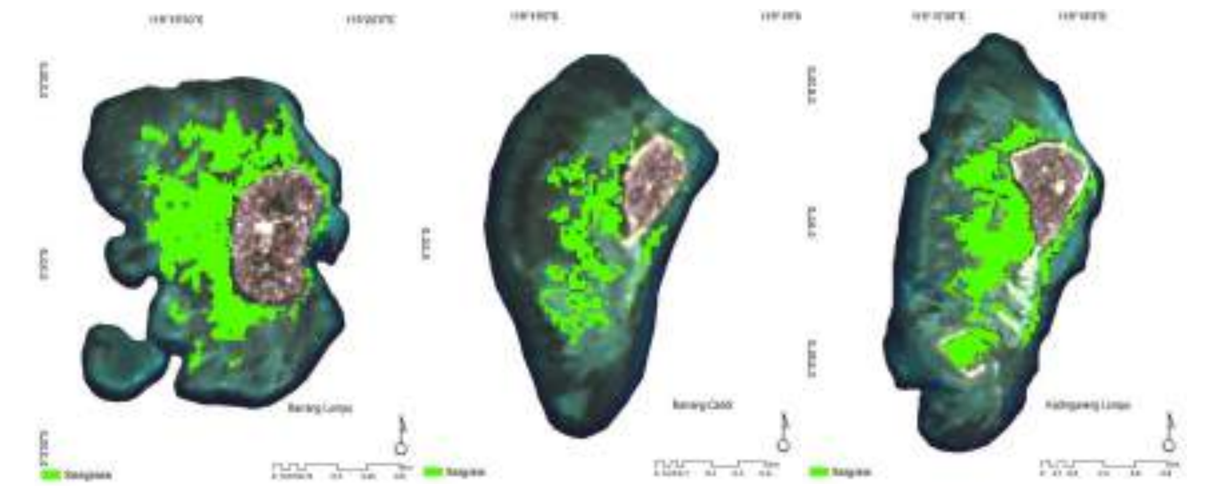

Fig 4. Seagrass distribution maps of (A) Barrang Lompo, (B) Barrang Caddi (C), and (C) Kodingareng Lompo using 30m^2 spatial resolution Landsat 8 OLI Imagery acquired on January 6th 2019

There were differences in total seagrass areas calculated with L8 and S2 image processing. Calculation with S2 resulted in a larger seagrass area by 24.2% on KL Island, 20.7% on BC Island, and 60.9% on BL Island compared with L8. Seagrass maps of KL and BC islands show that each island has several dominant and sparse seagrass distribution spots. The seagrass dominant areas at KL and BC islands were mostly on the west, southwest, to the south of the island, while on the north to the east side of the islands, the seagrass distribution was mostly sparse. Identification from the survey and aerial images indicate that lack of seagrasses on the east sides of the islands was due to water depth and human activities mostly centered on the east side of the island (the side that faces the mainland). This side was the main channel for local passenger ships (Figure 5: A1, B1, C1) and the port area of each island.

Table 2. Total seagrass area by Landsat 8 and Sentinel-2

Island	Area by Landsat		Area by Sentinel-2	
	Area (Ha)	**Years**	**Area (Ha)**	**Years**
BL	37.66	2019	53.18	2019
BC	9.61	2019	12.12	2019
KL	46.30	2019	61.07	2019

The south side of BC and KL islands were mostly covered with white sands which were exposed during low tide and therefore not suitable for seagrass to grow. Seagrass distribution on BL Island was almost evenly distributed on each side of the island, except at the areas around the main port. BL is a highly populated island and packed with house settlements. People often dispose their household organic waste on the west side of the island, with the waste entering straight into the sea and the same thing occurs on the other islands. Hence, due to this activity, disposed organic materials on this side of the island has resulted in increasing organic nutrients inputs which support seagrass growth. As can be seen in the Figures 5A2, 5B2, and 5C2 there are more seagrass beds that can be observed on the west sides of these islands due to the disposal of richer organic materials compared to the east sides (Figures 5A1, 5B1, 5C1). Nutrient enrichment enhanced seagrass biomass density, particularly in increasing the shoot biomass (Cabaco et.al. 2013).

Fig 5. Aerial photographs showing the shallow water condition on the east and the west side of Kodingareng Kompo (A1-A2), Barrang Caddi (B1-B2) and Barrang Lompo (C1-C2) islands. The east sides of the islands (A1, B1 and C1) showed less seagrass beds than the west sides of the islands (A2, B2, C2).

Accuracy test

The accuracy test of the S2 image classification results was obtained using field data. Field data used was a sample of seagrass cover photos that have coordinates. Based on the image analysis results, the overall accuracy of the kappa value of each image was: KL Island 75%, BC Island 82.69%, and BL Island 80.60%.

Seagrass Percent Cover (SPC) and Density from *in situ* measurement

The result from in situ measurement shows that seagrass density and SPC have a synched pattern, from low to high density, and low, medium, and high categories, respectively (Table 3). In some cases, the seagrass density value may be higher in the percent cover high category than in the medium or low category. The consistent pattern of seagrass density in all three islands is more likely due to the relatively similar composition of seagrass species in the three percent cover categories.

Table 3. Seagrass Density and Percent Cover from in situ Measurement

Plot Category	Density (shoots/m^2)			Percent Cover (%)		
	BL	BC	KL	BL	BC	KL
High	418.2	447	310.733	78.25	76.9	77.867
Medium	367.6	411.8	229.6	45.45	38.95	46.267
Low	239.6	178.2	268.235	23.9	18.6	20

Note: BL = Barrrang Lompo, BC = Barrang Caddi, KL = Kodingareng Lompo

Six species of seagrass were found on the three islands, i.e., *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Halodule uninervis*, *Halophila ovalis* dan *Syringodium isoetifolium*. Seagrass composition was dominated by *T. hemprichii* in all categories. An exception was found on KL Island where *C. rotundata* dominated the low category (Figure 6).

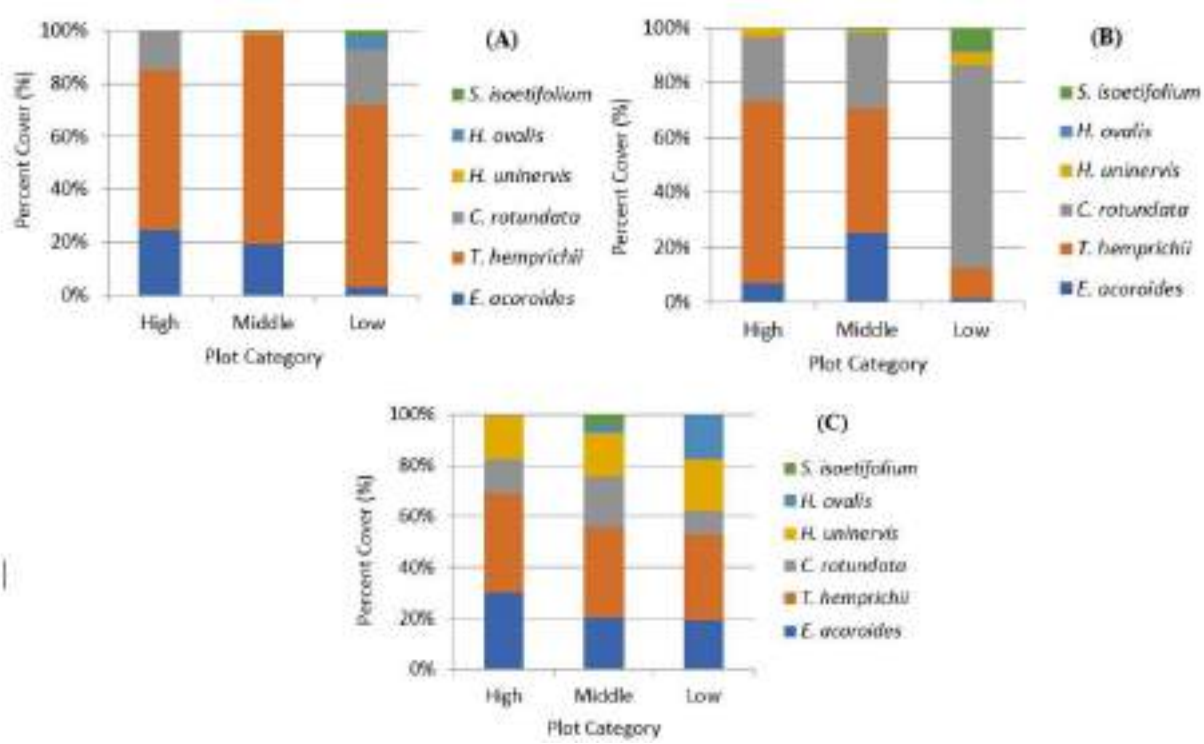

Fig 6. Percent cover of each seagrass 'species' based on plot categories in (A) Barrang Lompo, (B) Kodingareng Lompo, and (C) Barrang Caddi.

Correlation between Density of Seagrass using NDVI Algorithm and Percent Cover of Seagrass using In situ Data

NDVI has been widely used in several studies in Indonesia to estimate vegetation biomass, greenness level, primary production, and dominant species in vegetation. The NDVI index value ranges from -1.00 - 1.00. The principle of NDVI is to measure the level of greenness intensity. The intensity of greenness in Sentinel-2 (Figure 7) and Landsat 8 (Figure 8) images correlates with the level of density of the vegetation canopy.

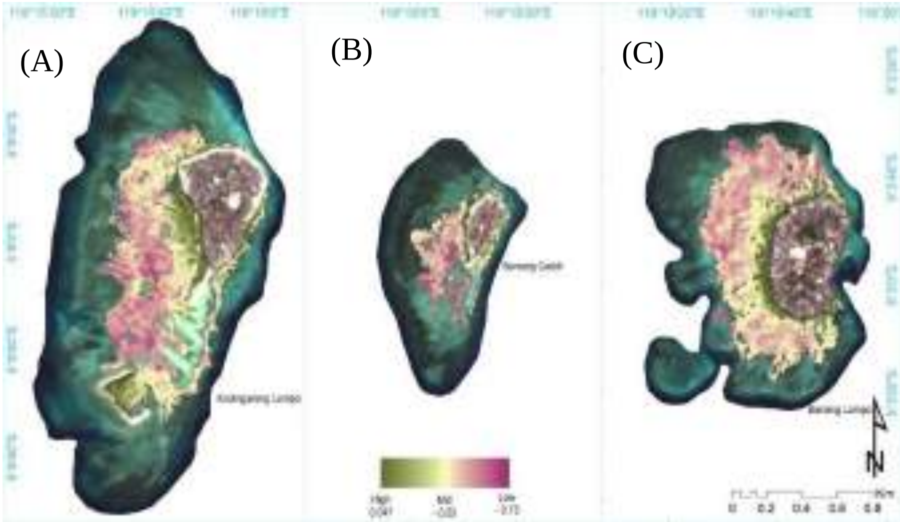

Fig 7. NDVI values derived from Sentinel-2 on Kodingareng Lompo (A), Barrang Caddi (B) and Barrang Lompo (C)

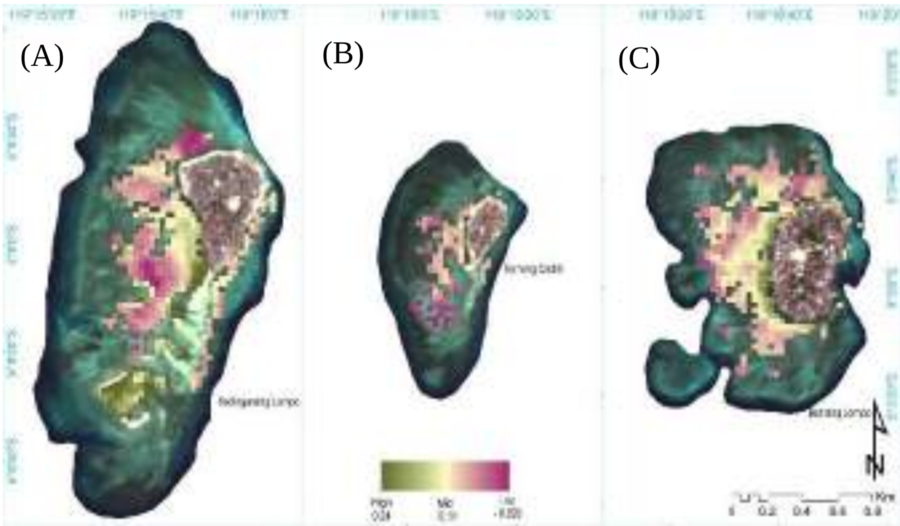

Fig 8. NDVI derived from Landsat 8 on Kodingareng Lompo (A), Barrang Caddi (B) and Barrang Lompo (C)

The relationship between SPC from field measurements and NDVI values was analyzed using algorithmic modeling with linear regression. The regression equation was obtained from the relationship between the NDVI value of S2 images and the value of in situ SPC. The algorithm obtained was y = 0.0053x-0.785. Regression analysis shows a linear correlation between NDVI and in situ data with R^2 value of 0.8255. The R-value indicates a strong relationship between the *in situ* SPC and the NDVI values of satellite images (Figure 9).

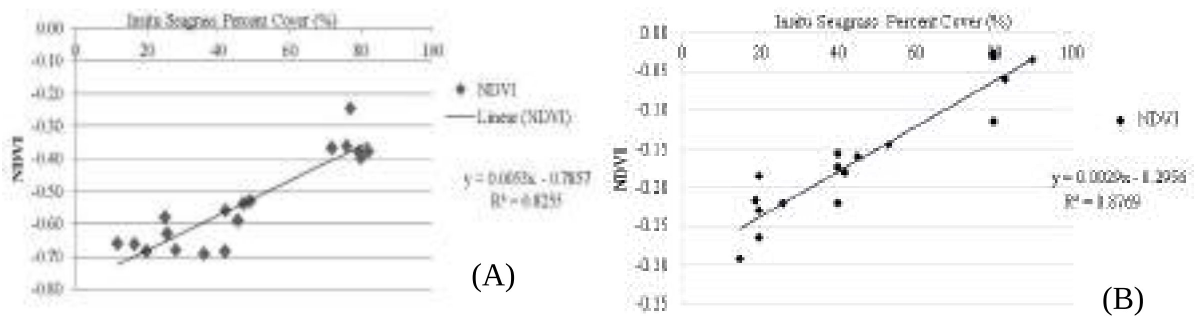

Fig 9. Correlation analysis of SPC between in situ measurement and NDVI values on the three islands; (A) Sentinel-2 imagery, (B) Landsat 8 imagery

Seagrass Biomass

Total Biomass

Results from laboratory analysis showed seagrass BGB in all islands and in each seagrass cover category were higher than AGB. Seagrass BGB value on BL Island on average was four times higher than AGB. Meanwhile, the ratio was smaller on the other two islands, which was about three to three and a half times higher (Table 3). Biomass stored under the substrate is one of the forms of seagrass adaptation. Seagrass grows in shallow waters, which makes it very vulnerable to the influence of waves. Without specific adaptation, seagrass can be easily uprooted by the waves. Seagrass adapts by storing more photosynthetic products under the ground than above, therefore, it can stay still under the impact of waves.

Among the three islands, the highest average biomass was found on BC Island, either for BGB, AGB, or the total biomass (Table 4). This is more likely due to the large composition of *E. acoroides*, especially in the high-percent cover category (Figure 6). The percent cover of *E. acoroides* reached 23.2% or about 30% of the total seagrass cover in the solid category of the island. *E. acoroides* is a large seagrass species (Waycott et al. 2004) and the largest seagrass species that can be found in Indonesia.

Table 4. Seagrass biomass in the study locations based on high, medium, and low categories

Location	Category	Biomass (dry weight ton /ha)		
		Above ground	Below ground	Total
Barrang Lompo	High	1.05	3.49	4.55
	Medium	0.58	2.33	2.9
	Low	0.2	0.96	1.17
Kodingareng Lompo	High	0.48	1.28	1.76
	Medium	0.46	1.01	1.47
	Low	0.11	0.49	0.6
Barrang Caddi	High	1.33	4.83	6.16
	Medium	0.75	2.75	3.5
	Low	0.3	1.03	1.33

Fig 10. Field photographs of the low, medium, and high seagrass categories on Kodingareng Lompo and Barrang Lompo

Seagrass BGB was generally weighted higher than ABG in the seagrass categories on the three islands. High or high categories dominated seagrasses on the three different islands. There was a total of 8.62 ton dry weight/ha seagrass biomass on BL Island, 3.83 ton dry weight/ha on KL Island, and 10.99 ton dry weight/ha on BC Island.

Correlation between Biomass in situ and NDVI

The correlation between the total biomass and the NDVI values of the three islands was analyzed. R^2 values acquired from regression analysis were 0.40 for Landsat 8, and 0.43 for Sentinel-2. These R^2-values indicate a low correlation between the total biomass value and the NDVI value. Overall, NDVI and carbon biomass of seagrass showed a linear relation (Figure 11). The higher the total biomass value, the closer the NDVI value will be to 0 (solid seagrass cover condition), while the lower the total biomass value, the closer the NDVI value will be to -1 (low seagrass cover condition).

Moreover, on BL Island, the biomass value has more variation in the high seagrass cover category than in the low and medium (Table 4). This is due to the various species composition. Some plots were *T. hemprichii* dominant, while other plots were more *E acoroides* dominant. Morphologically, the two seagrasses have different sizes, therefore at the same cover percentage, they have very different biomass values. In the low and medium seagrass cover categories *T. hemprichii* was consistently the dominant species.

Furthermore, in the high seagrass cover category, there was quite a lot of overlap between leaves, especially with the *T. hemprichii* species. In some plots (Figure 10), a large addition of seagrass cover value can only cause a small increase in biomass value. Meanwhile, in other plots, the addition of the same amount of seagrass cover value can add a substantial biomass value. However, in the high and medium seagrass cover categories, the overlap between leaves was less. According to Mallombassi, et al (2020), the high slope value of *T. hemprichii* seagrass regression equation at high percent cover was because of the overlapping leaf canopy, resulting in a high increase of biomass value despite the small addition of the percent cover.

E. acoroides and *C. rotundata* significantly contributed to the medium to sparse percent cover category on KL and BC islands. This causes the biomass values of those two categories to vary largely. The contribution of the two seagrasses was about half of the dominant species *T. hemprichii*, while on BL Island it can reach a quarter in the same category.

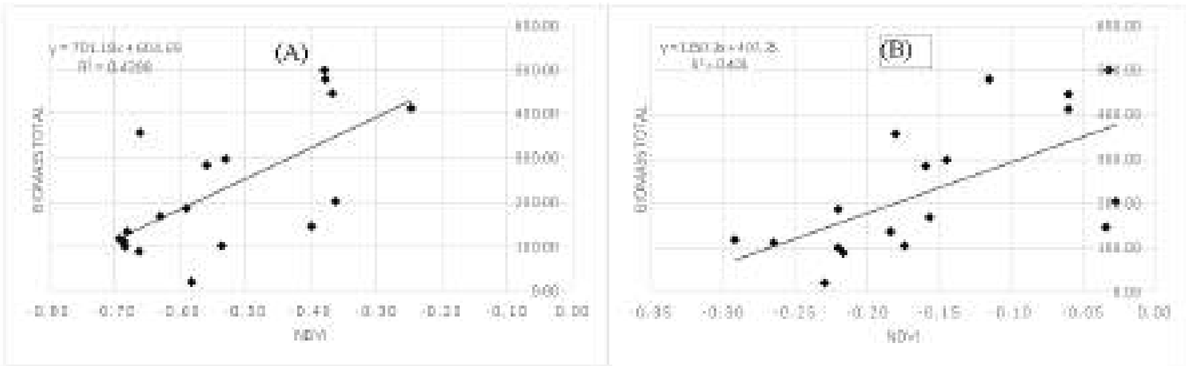

Fig 11. Regression analysis of seagrass biomass and NDVI on Barrang Lompo, Barrang Caddi, and Kodingareng Lompo islands; (A) Sentinel-2 imagery, (B) Landsat 8 imagery

4. Conclusions

The result of this study showed that there is a strong correlation between *in situ* seagrass percent cover and NDVI values derived from the two satellite images. However, the correlation between in situ seagrass total biomass and the NDVI values showed a relatively weak correlation. Image classification showed that seagrass was distributed mostly on the west side of the islands, and there were 6 seagrass species identified on the sites, i.e., *E. acoroides*, *T. hemprichii*, *C. rotundata*, *H. uninervis*, *H. ovalis* and *S. isoetifolium*. In this study we also discovered that there was a disparity of seagrass total cover area between Sentinel-2 and Landsat 8, due to spatial resolution diferrences. Sentinel-2 images were able to classify seagrass distribution up to the seagrass density category, however, they cannot be applied to differentiate seagrass density based on species. Nevertheless, both Sentinel-2 and Landsat 8 are useful for seagrass condition monitoring purposes.

References

Cabaço S, Apostolaki ET, García-Marín P, Gruber R, Hernández I, Martínez-Crego B, Mascaró O, Pérez M, Prathep A, Robinson C, Romero J, Schmidt AL, Short FT, Van Tussenbroek BI, Santos R (2013) Effects of nutrient enrichment on seagrass population dynamics: evidence and synthesis from the biomass-density relationships. Journal of Ecology 101: 1552–1562

Chavez PS Jr (1988) An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote sensing of environment 24(3) 459-479. https://doi.org/10.1016/0034-4257(88)90019-3

Congalton R, Green K (2008) Assessing the Accuracy of Remotely Sensed Data, Principles and Practices (secondendn). Taylor & Francis Group. CRC Press.

Duarte CM, Marbà N, Gacia E, Fourqurean JW, Beggins J, Barrón C, and Apostolaki ET (2010) Seagrass community metabolism: Assessing the carbon sink capacity of seagrass meadows. Global Biogeochemical Cycles 24(4). https://doi.org/10.1029/2010GB003793

Hedley JD, Harborne AR, Mumby PJ (2005). Simple and robust removal of sun glint for mapping shallow-water benthos. Int. J. of Remote Sensing 26(10): 2107–2112

Hochberg EJ, Atkinson MJ (2003). Spectral reflectance of coral reef bottom-types worldwide and implications for coral reef remote sensing. Remote Sensing of Environment 85(2):159-173. DOI: 10.1016/S0034-4257(02)00201-8

Kennedy H, Beggins J, Duarte CM, Fourqurean JW, Holmer M, Marbà N, and Middelburg JJ (2010). Seagrass sediments as a global carbon sink: Isotopic constraints. Global Biogeochemical Cycles 24(4). https://doi.org/10.1029/2010GB003848

Krause-Jensen D, Duarte C (2016) Substantial role of macroalgae in marine carbon sequestration. Nature Geosci 9**,** 737–742. https://doi.org/10.1038/ngeo2790

Lavery PS, Mateo MÁ, Serrano O, Rozaimi M (2013). Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PloS one 8(9) p.e73748. https://doi.org/10.1371/journal.pone.0073748.

Lyimo LD (2016). Carbon sequestration processes in tropical seagrass beds.Doctoral dissertation, Department of Ecology, Environment and Plant Sciences, Stockholm University

Lyzenga D. (1981) Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. International journal of remote sensing 2(1) 71-82. https://doi.org/10.1080/01431168108948342

Mallombassi A, Mashoreng S, La Nafie YA (2020) The relationship between seagrass Thalassia hemprichii percentage cover and their biomass. Spermonde 6 (1): 7-10. https://doi.org/10.20956/jiks.v6i1.9922

McKenzie LJ, Finkbeiner MA, Kirkman H (2001) Methods for mapping seagrass distribution. Global seagrass research methods 101-121.

Pu R, Bell S, English D (2015) Developing hyperspectral vegetation indices for identifying seagrass species and cover classes. Journal of Coastal Research 31(3) 595-615. https://doi.org/10.2112/JCOASTRES-D-12-00272.1

Roca G, Alcoverro T, Krause-Jensen D, Balsby TJS, van Katwijk MM, Marba N, Santos R, Arthur R, Mascaró O, Fernández-Torquemada Y, Pérez M (2016) Response of seagrass indicators to shifts in environmental stressors: a global review and management synthesis. Ecological Indicators 63, pp 310-323. https://doi.org/10.1016/j.ecolind.2015.12.007

Rohr ME, Bostrom C, Canal-Vergés P, Holmer M (2018) Blue carbon storage Capacity of Temperate Eeelgrass (Zostera marina) meadows. Global Biogeochemical Cycles. https://doi.org/10.1029/2018GB005941

Waycott M, McMahon K, Mellors J, Calladine A, Kleine D (2004) A guide to tropical seagrass of the Indo-West Pacific. James Cook University. Townsville.

Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT, William SL (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. PNAS 106 (30):12377-12381. http:/ www. pnas.org/ cgi/doi/10.1073/pnas.0905620106.

Zoffoli ML, Gernez P, Rosa P, Le Bris A, Brando VE, Barillé AL, Harin N, Peters S, Poser K, Spaias L, Peralta G (2020). Sentinel-2 remote sensing of Zostera noltei-dominated intertidal seagrass meadows. Remote Sensing of Environment 251, p112020. https://doi.org/10.1016/j.rse.2020.112020.

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ARTICLE

Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia

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Abstract

As one of the major blue carbon ecosystems, studying, conserving, and monitoring seagrass meadows, especially on small populated islands, has become very important due to their vulnerability to anthropogenic and global environmental factors. In this study, we used satellite image analysis and biological data to map seagrass percent cover (SPC), above-ground biomass (AGB), and below-ground biomass (BGB) on the three most populated islands of the Spermonde Archipelago, Indonesia, i.e., Kodingareng Lompo, Barrang Lompo, and Barrang Caddi. Reflectance and Normalized Difference Vegetation Index (NDVI) values of Sentinel-2 (S2) imagery were used to classify and calculate SPC and AGB. In situ biological data measurements were carried out from 3 to 14 of June, 2020, on the three islands to measure AGB and BGB. The result from image classification shows a total area of 126.37 Ha of seagrass, which was divided into three SPC categories: medium (30–59.9%) with a total area of 78.38 Ha; low (0–29.9%) with a total area of 13.1 Ha; and high (60–100%) with a total area of 34.89 Ha. The highest SPC area was observed on Kodingareng Lompo Island with 61.07Ha, followed by Barrang Lompo Island with 53.18Ha, and Barrangcaddi Island with 12.12Ha. The total AGB on Barrang Lompo, Kodingareng Lompo, and Barrangcaddi in tons of dry weight/ha were 1.83, 1.05, and 2.38, respectively. The highest BGB was reported on Barrangcaddi Island with 8.61 tons of dry weight/ha, followed by Barrang Lompo Island with 6.78 tons of dry weight/ha, and Kodingareng Lompo Island with 2.78 tons of dry weight/ha. Regression analysis showed a linear correlation between NDVI value and in situ SPC with $R^2 = 0.8255$. The framework of this study can be applied to monitor temporal changes of seagrass meadows distribution on small islands to promote a more sustainable ecosystem.

Keywords Biomass · NDVI · Seagrass · Sentinel-2 · Small islands

1 Introduction

Seagrass meadows have a high carbon sink capacity that surpasses even highly productive terrestrial ecosystems (Krause-Jensen and Duarte 2016). Seagrass meadows have a carbon fixation ability that exceeds their metabolic needs; hence, a large proportion of excess organic carbon is transported to the roots and rhizomes where it is stored and eventually exuded in the sediment to form anaerobic organic-rich soil (autochthonous) (Lyimo 2016). A study of the carbon sequestered capacity of Australian seagrasses estimates annual organic carbon (C_{org}) accumulation to be between 0.093 and 6.15 Mt, with a most probable estimation of 0.93 Mt year^{1} (10.1 t km^{-2} year^{-1}) (Lavery et al. 2013). This type of blue carbon ecosystem also has a high global net carbon production (NCP) of 20.73–50.69 Tg C year^{-1}, which comprises 10–18% of the total carbon storage in the ocean (Duarte et al. 2010; Kennedy et al. 2010).

However, disturbances caused by humans can negatively influence the carbon fixation ability of seagrasses and affect the amount of carbohydrate and starch being stored in their rhizomes. Growing in coastal environments, seagrasses are

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usually subjected to many anthropogenic activities e.g., sewage disposal, mariculture, propeller boating activities, destructive fishing, construction works, dredging, and eutrophication, which threatens their ecosystems and can lead to extinction (Roca et al. 2016). It is believed that about a third to half of the world's seagrasses have been lost since 1879 and the continuing rate of disappearance is estimated to be 110 km^2 per year with net loss rates of 0.9% per year before 1940 to 7% since 1990 (Waycott et al. 2009). Therefore, the remaining seagrass ecosystems need to be conserved and protected.

Information on seagrass status in terms of percent cover and biomass needs to be acquired as baseline data to efficiently manage and monitor the seagrass ecosystems for conservation purposes. Remote sensing techniques have proven to be efficient and effective tools for seagrass monitoring. Since launched by the European Space Agency (ESA) in 2015, Sentinel-2 (S2) images with higher spatial resolution that are suitable for seagrass mapping, have been available and can be acquired at no cost. The use of S2 imagery for seagrass meadows ecosystem study was recently demonstrated with regard to seagrass beds on the Atlantic coasts of France and Spain (Zoffoli et al. 2020).

Spermonde Archipelago is a set of small tropical islands between Kalimantan and Sulawesi islands in Indonesia. Three of its most populated islands are Barrang Lompo, Barrang Caddi, and Kodingareng Lompo. Despite high anthropogenic disturbance factors most likely occurring on these islands, there are still significant amounts of seagrass ecosystems that can be found on these islands. However, a study to analyze the percent cover and biomass of these seagrasses has not been done yet. The main objective of this study is to map seagrass distribution and the total areas on the three most populated islands in the Spermonde Archipelago using two different spatial resolution imageries, Sentinel-2 and Landsat 8. Several variables, including seagrass density and biomass, were measured directly in the field to find a correlation between in situ values and NDVI values derived from Landsat 8 and Sentinel-2 image analysis.

2 Materials and Methods

2.1 Study Sites

This study was conducted on three islands: Barrang Lompo (BL), Barrang Caddi (BC), and Kodingareng Lompo (KL). These three islands are part of the Spermonde Archipelago, which is located west off the coast of Makassar City, capital of South Sulawesi Province, Indonesia. BL Island is located at 5° 2′ 43.577″–5° 3′ 6.491″ South latitude (SL) and 119° 19′ 38.716″–119° 19′ 49.21″ East longitude (EL), which is 12.48 km from Makassar City. Meanwhile, BC Island is located at 5° 4′ 46.558″–5° 5′ 0.778″ SL and 119° 19′ 10.557″–119° 19′ 16.21″ EL with a distance of 10.98 km from Makassar City, while Kodingareng Lompo Island is located at 5° 8′ 42.536″–5° 9′ 9.434″ SL and 119° 15′ 45.006″–119° 15′ 58.540″ EL with a distance of 15.24 km from Makassar City. Based on the distance from the mainland, the three islands were included in the middle zone, with the distance from the mainland coastline between 10 and 20 km (Fig. 1). Field data were taken at BL, BC, and KL islands from 3 to 14 June 2020. Data derived from satellite images used for this study were acquired from S2 on July 29th 2019 and from Landsat 8 (L8) on January 6th 2019.

2.2 Satellite Data

2.2.1 Landsat 8 and Sentinel-2 Image Pre-processing

Satellite image data used in this study were acquired from S2 on July 29th 2019 and L8 on January 6th 2019. Geometrically corrected S2 images of waters west of South Sulawesi were downloaded from the European Space Agency (ESA) data portal, while images from Landsat 8 were downloaded from USGS Glovis. Atmospheric correction was conducted using radiometric calibration (DN to reflectance) and DARK OBJECT SUBTRAction (DOS) to remove the atmospheric effect on the images, assuming the darkest pixel value was zero (Chavez. 1988). Sun glint correction was applied on S2 imagery to correct sunlight reflection. This correction was not performed on L8 imagery as the images were clear enough; however, a pan-sharpening technique was performed to facilitate interpretation for image classification. Sun glint correction for S2 imagery was carried out using an algorithm developed by Hochberg and Atkinson(2003) and refined by Hedley et al. (2005) as in the following equation:

$$R'_i = R_i – b_i(\text{RNIR} - \text{MinNIR}), \quad (1)$$

R'_i is the i channel value after being reduced; R_i is the initial i channel value; b_i is the amount of slope of the regression; RNIR is the NIR channel value; MinNIR is the minimum NIR channel value.

Athmospheric corrections and water column correction were applied to the images to classify shallow-water habitats and seagrass percent cover (SPC) using supervised classification. The flowchart for spatial data processing and its integration with non-spatial data can be seen in Fig. 2.Water column correction method was applied to the images using depth invariant index (DII) algorithm by Lyzenga (1981). The DII method reduces the influence of the water column so that clearer images of shallow water habitats could be obtained. Points on the sand area were used to build a model to obtain the attenuation coefficient of the water column. This is because sand objects are easier to recognize in the images, with the bright white appearance

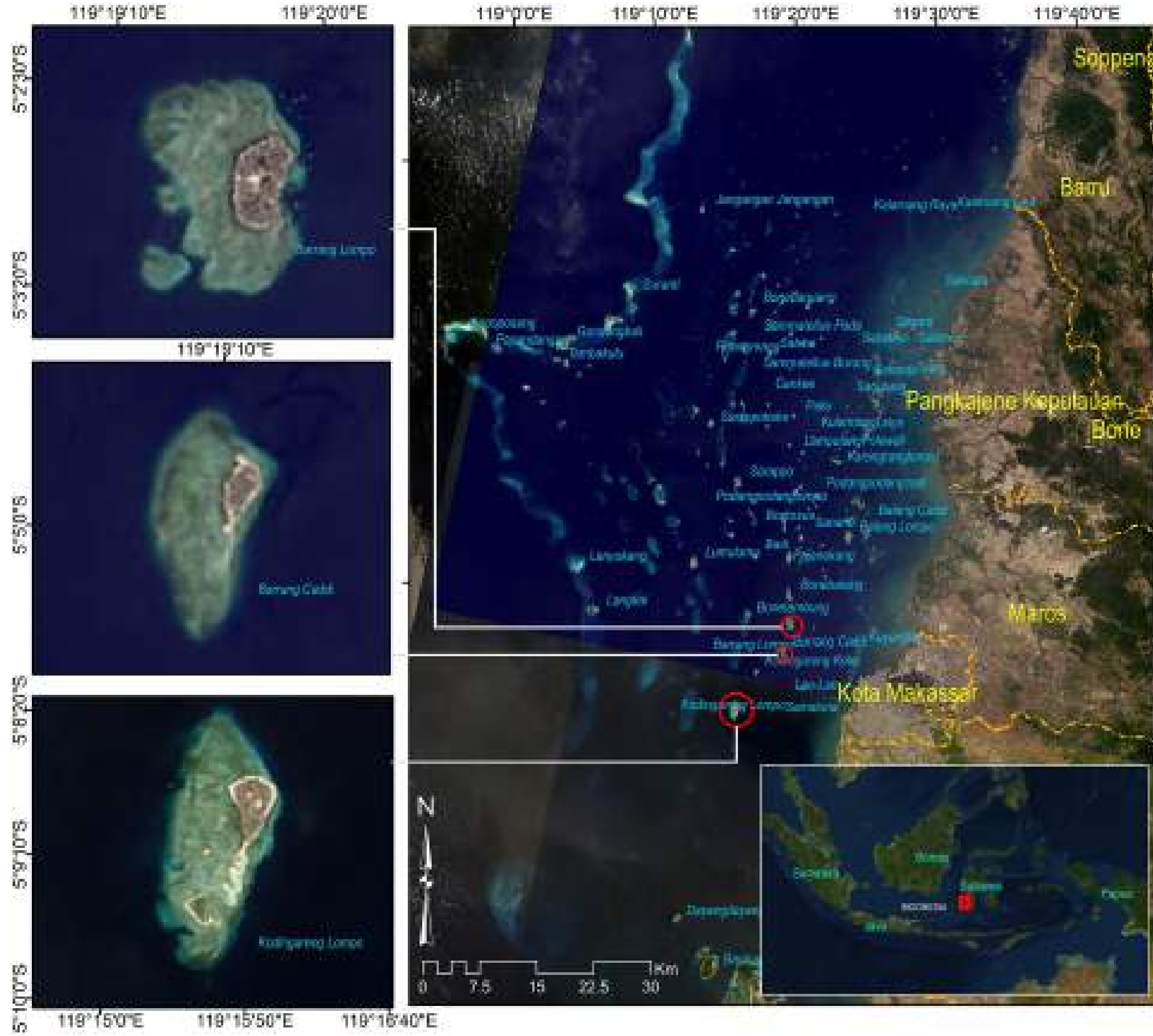

Fig. 1 Study site on BL (Barrang Lompo), BC (Barrang Caddi), and KL (Kodingareng Lompo) islands, Spermonde Archipelago, South Sulawesi, Indonesia

becoming a darker blue color as the water depth increases. The algorithm used in this process was:

$$\mathrm{DII}(ij) = \ln\left(L_i\right) - \left[\left(K_i/K_j\right)\ln\left(L_j\right)\right], \tag{2}$$

$$k_i/k_j = a - \left[\left(K_i/K_j\right)\ln\left(L_j\right)\right], \tag{3}$$

$\alpha = \frac{\sigma_i+\sigma_j}{2\sigma_{ij}}$. (4)

DII is the depth invariant index; L_i is the i-band reflectance value; L_j is the j-band reflectance value; k_i/k_j is the i and j band attenuation coefficient ratio; α_i is the i-band variant; α_j is the j-band varian; α_{ij} is the i and j band covariant.

2.2.2 Image Classification Based on SPC

Images that have been corrected were then classified using an unsupervised classification method (Isoclass). The results were then reclassified based on ground truth data. The final classification of SPC was divided into three categories i.e., low (0–29.9%), medium (30–59.9%), and high (60–100%). These categories were then used to determine biomass sampling points.

The classification mapping accuracy was tested using a confusion matrix method to calculate the accuracy value of

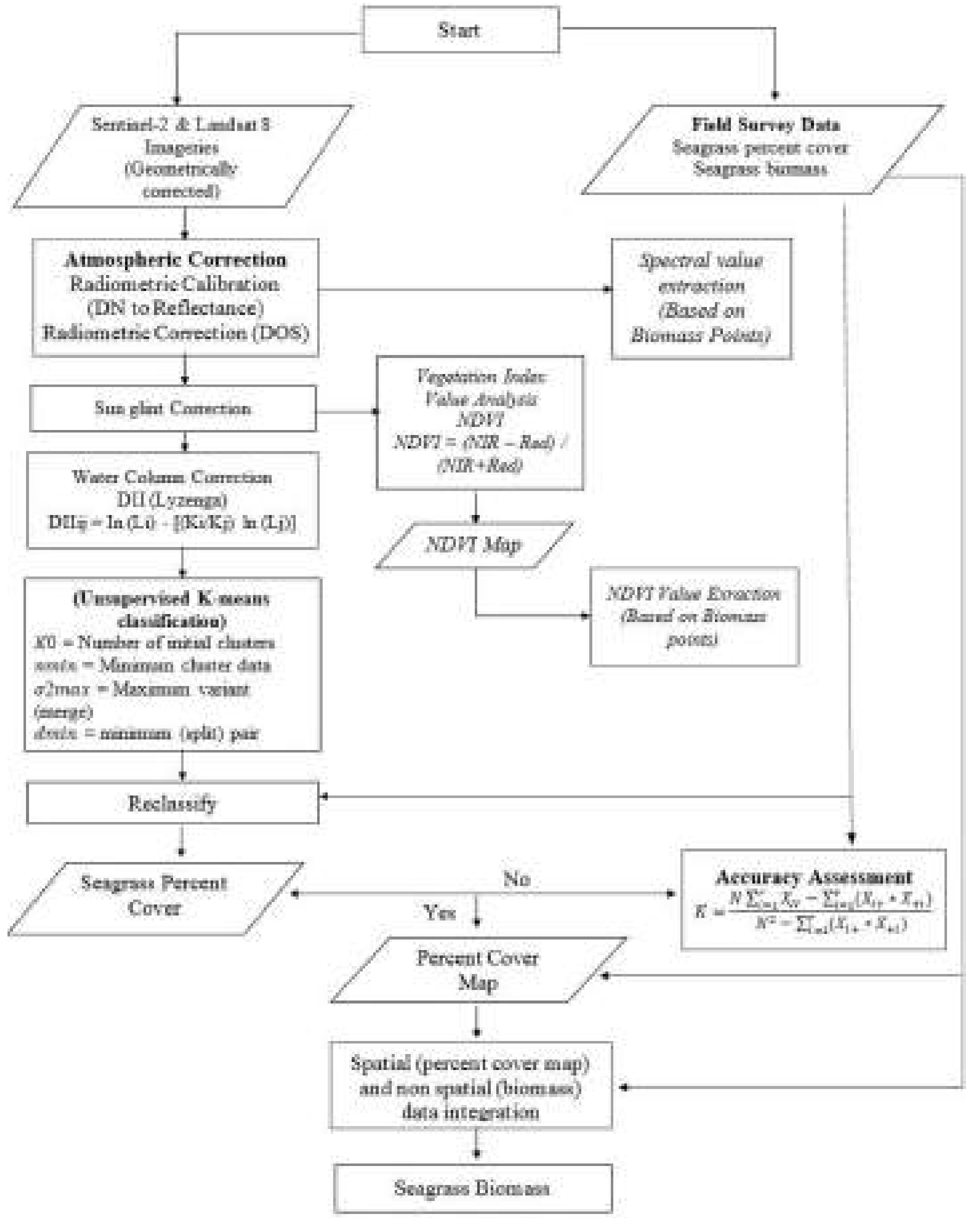

Fig. 2 Flowchart analysis of integration image and in situ data to seagrass biomass

seagrass habitat mapping. It was done using a matrix table that compares classes from satellite image classification with in situ data (Congalton and Green 2008). The error matrix method used in this study followed the following formula:

$$K = \frac{N\sum_{i=1}^{r} X_{II} - \sum_{i=1}^{r}\left(X_{i+} \times X_{+i}\right)}{N^2 - \sum_{i=1}^{r}(X_{i+} \times X_{+i})}. \quad (5)$$

2.2.3 Image Classification Based on Seagrass Density

The NDVI (normalized difference vegetation index) algorithm has been used to measure vegetation density level (greenness) using the reflectance values of the near-infrared (NIR) and red bands (Pu et al. 2015). Seagrass beds usually grow in shallow waters, with the NDVI index value ranging from − 1 to 0. The formula used for NDVI was:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}. \quad (6)$$

NDVI is the normalized difference vegetation index; NIR is the short infrared band spectral reflectance; Red is the red band spectral reflectance.

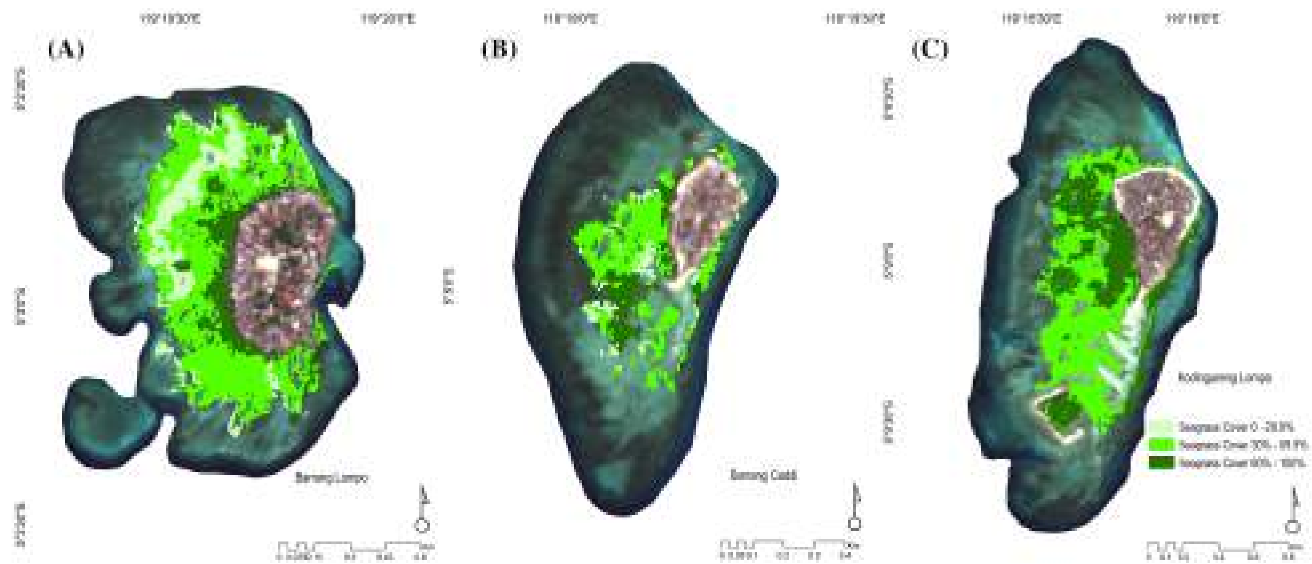

Fig. 3 Seagrass distribution maps of **A** Barrang Lompo, **B** Barrang Caddi, and **C** Kodingareng Lompo using 10 m spatial resolution Sentinel-2 imagery, with the acquisition date on July 29th 2019. Seagrass were categorized into three classes, i.e., 0–29.9% (low), 30–59.9% (medium) and 60–100% (high)

2.3 Field Data

2.3.1 In Situ SPC and Biomass Sampling

Based on the unsupervised SPC image classification, 60 stations were designated on each island as the sampling points (20 for each SPC categories i.e., low, medium, and high). In situ measurements of SPC and seagrass density were carried out using a 50 cm × 50 cm plot (McKenzie et al. 2001). Seagrass species were also identified in every plot. A smaller plot (20 cm × 20 cm plot) was placed within the bigger plot to measure seagrass biomass. The plot was placed based on the types of seagrasses that exist within the bigger plot so that all types of seagrasses in the plot could be extracted. Seagrass biomass samples were collected with roots up to 40 cm long. Vined rhizomes were chopped using a machete before picking out any sample. Seagrass samples consisting of roots, rhizomes, leaves, and midribs were collected from each station. Substrate and dirt were cleaned away from the samples and then each of them was put into a labeled plastic bag for further laboratory analysis.

2.3.2 Biomass Analysis

In the laboratory, samples were cut into two parts, the biomass above the sediment or above ground biomass (AGB) which consists of leaves and leaf midribs, and the below-ground biomass (BGB) which consists of rhizomes and roots (Rohr et al. 2018). The samples were then oven-dried (60 °C) until a constant weight was achieved (Lymo 2016). Samples were then weighted using a 0.01-g precision level digital scale. Seagrass biomass per shoot was calculated by dividing the total weight of each sample by the total number of its shoots. The mean biomass per area (g/m^2) for each seagrass percent cover category was obtained by multiplying the number of biomass per shoots with each type of seagrass density. The result value was then multiplied by the area of each of the percent cover categories to get the total biomass per category.

2.3.3 Regression Analysis

The corelation between biomass (AGB, BGB, and total biomass) and the SPC results on every island was determined using regression linear analysis. Regression analysis was also performed to find the corelation between field survey data (in situ percent cover and biomass) with spatial data (percent cover and NDVI value).

3 Result and Discussion

3.1 SPC Based on Image Classification

The seagrass maps were generated using a pixel-based classification method (unsupervised classification). 3 highly populated islands in the Spermonde Archipelago were analyzed in this study. Based on the results, SPC in KL was mainly in the range between 30 and 59.9% (medium), which accounts for 60.38% of the total seagrass area on this island. Similarly, SPC on BC and BL islands were also mainly characterized by the medium SPC category, which accounts for 62.71% and 63.74%, respectively, of the total seagrass areas that were

Table 1 Percent cover of seagrass area from Sentinel-2 imagery classification

Seagrass percent cover (%)	Area (ha)
0–29.9 (low)	13.1
30–59.9 (medium)	78.38
60–100 (high)	34.89
Grand total	126.37

Table 2 Total seagrass area by Landsat 8 and Sentinel-2

Island	Area by Landsat		Area by Sentinel-2	
	Area (ha)	Years	Area (ha)	Years
BL	37.66	2019	53.18	2019
BC	9.61	2019	12.12	2019
KL	46.30	2019	61.07	2019

identified on each island. Overall, medium SPC category accounts for 62.02% of the total seagrass area identified on these three islands (Fig. 3; Table 1). Spermonde Archipelago has 683.70 ha of seagrass, so it can be said that these three islands contribute around 18.48% of the total seagrass in the Spermonde Archipelago.

Pixel-based analysis was also applied on L8 images to create seagrass distribution maps on each island (Fig. 4). Due to its lower spatial resolution (30 m), seagrass mapping using L8 was only up to the aquatic habitat condition or seagrass distribution that was able to be classified using L8 (Fig. 4; Table 2). Nevertheless, the results between L8 and S2 show similar seagrass spatial distribution. As can be seen in Figs. 3 and 4, seagrass is dominantly grown in the western area of the islands, while the eastern part remained barren.

There were differences in total seagrass areas calculated with L8 and S2 image processing. Calculation with S2 resulted in a larger seagrass area by 24.2% on KL Island, 20.7% on BC Island, and 60.9% on BL Island compared with L8. Seagrass maps of KL and BC islands show that each island has several dominant and sparse seagrass distribution spots (Table 1). The seagrass-dominant areas at KL and BC islands were mostly on the west, southwest, to the south of the island, while on the north to the east side of the islands, the seagrass distribution was mostly sparse. Identification from the survey and aerial images indicate that lack of seagrasses on the east sides of the islands was due to water depth and human activities mostly centered on the east side of the island (the side that faces the mainland). This side was the main channel for local passenger ships (Fig. 5: A1, B1, C1) and the port area of each island.

The south side of BC and KL islands were mostly covered with white sands which were exposed during low tide and, therefore, not suitable for seagrass to grow. Seagrass distribution on BL Island was almost evenly distributed on each side of the island, except at the areas around the main port. BL is a highly populated island and packed with house settlements. People often dispose their household organic waste on the west side of the island, with the waste entering straight into the sea and the same thing occurs on the other islands. Hence, due to this activity, disposed organic materials on this side of the island has resulted in increasing organic nutrients inputs which support seagrass growth. As can be seen in the Fig. 5A2, 5B2, and 5C2 there are

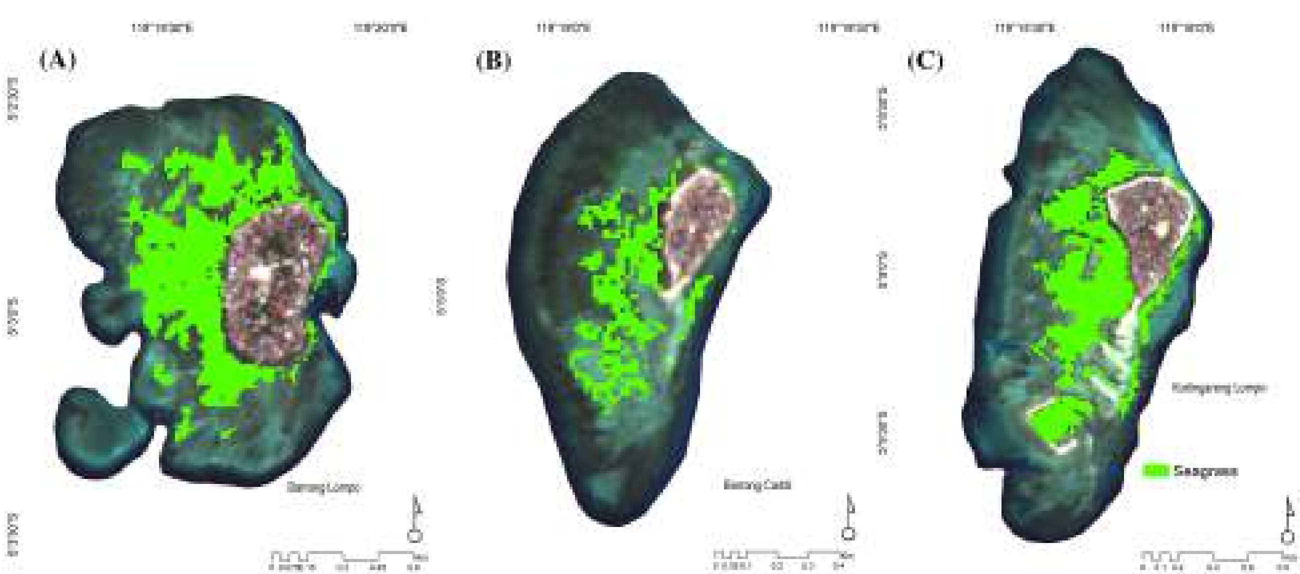

Fig. 4 Seagrass distribution maps of **A** Barrang Lompo, **B** Barrang Caddi, and **C** Kodingareng Lompo using 30 m^2 spatial resolution Landsat 8 OLI Imagery acquired on January 6th 2019

Fig. 5 Aerial photographs showing the shallow water condition on the east and the west side of Kodingareng Kompo (**A1**–**A2**), Barrang Caddi (**B1**–**B2**) and Barrang Lompo (**C1**–**C2**) islands. The east sides of the islands (**A1**, **B1** and **C1**) showed less seagrass beds than the west sides of the islands (**A2**, **B2**, **C2**)

more seagrass beds that can be observed on the west sides of these islands due to the disposal of richer organic materials compared to the east sides (Fig. 5A1, 5B1, 5C1). Nutrient enrichment enhanced seagrass biomass density, particularly in increasing the shoot biomass (Cabaco et al. 2013).

3.2 Accuracy Test

The accuracy test of the S2 image classification results was obtained using field data. Field data used was a sample of seagrass cover photos that have coordinates. Based on the image analysis results, the overall accuracy of the kappa value of each image was: KL Island 75%, BC Island 82.69%, and BL Island 80.60%.

3.3 Seagrass Percent Cover (SPC) and Density from In Situ Measurement

The result from in situ measurement shows that seagrass density and SPC have a synched pattern, from low to high density, and low, medium, and high categories, respectively (Table 3). In some cases, the seagrass density value may be higher in the percent cover high category than in the medium or low category. The consistent pattern of seagrass density in all three islands is more likely due to the relatively similar composition of seagrass species in the three percent cover categories.

Six species of seagrass were found on the three islands, i.e., *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Halodule uninervis*, *Halophila ovalis* dan *Syringodium isoetifolium*. Seagrass composition was dominated by *T. hemprichii* in all categories. An exception was found on KL Island where *C. rotundata* dominated the low category (Fig. 6).

3.4 Correlation Between Density of Seagrass Using NDVI Algorithm and Percent Cover of Seagrass Using In situ Data

NDVI has been widely used in several studies in Indonesia to estimate vegetation biomass, greenness level, primary production, and dominant species in vegetation. The NDVI index value

Table 3 Seagrass density and percent cover from in situ measurement

Plot Category	Density (shoots/m^2)			Percent cover (%)		
	BL	BC	KL	BL	BC	KL
High	418.2	447	310.733	78.25	76.9	77.867
Medium	367.6	411.8	229.6	45.45	38.95	46.267
Low	239.6	178.2	268.235	23.9	18.6	20

BL Barrrang Lompo, *BC* Barrang Caddi, *KL* Kodingareng Lompo

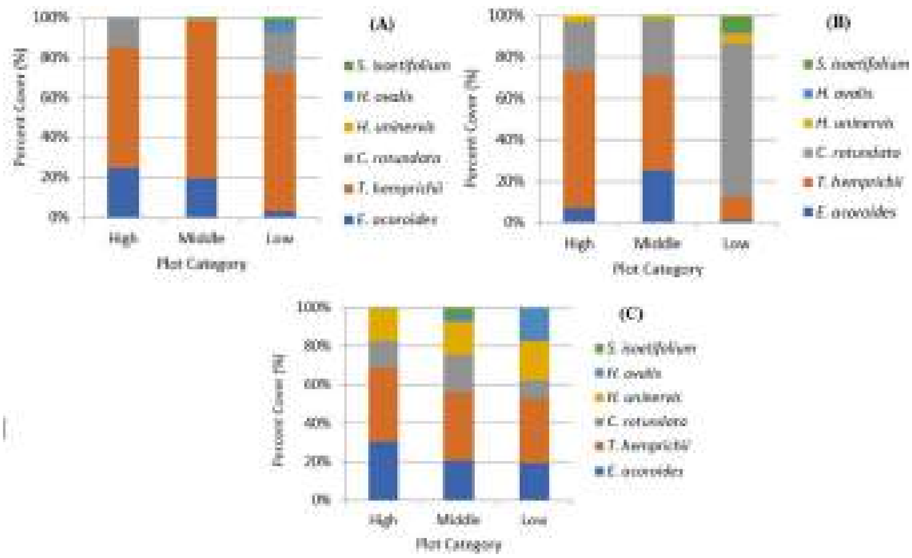

Fig. 6 Percent cover of each seagrass 'species' based on plot categories in **A** Barrang Lompo, **B** Kodingareng Lompo, and **C** Barrang Caddi

ranges from -1.00 to 1.00. The principle of NDVI is to measure the level of greenness intensity. The intensity of greenness in Sentinel-2 (Fig. 7) and Landsat 8 (Fig. 8) images correlates with the level of density of the vegetation canopy.

The relationship between SPC from field measurements and NDVI values was analyzed using algorithmic modeling with linear regression. The regression equation was obtained from the relationship between the NDVI value of S2 images and the value of in situ SPC. The algorithm obtained was $y = 0.0053x - 0.785$. Regression analysis shows a linear correlation between NDVI and in situ data with R^2 value of 0.8255. The R value indicates a strong relationship between the in situ SPC and the NDVI values of satellite images (Fig. 9).

3.5 Seagrass Biomass

3.5.1 Total Biomass

Results from laboratory analysis showed seagrass BGB in all islands and in each seagrass cover category were higher than AGB. Seagrass BGB value on BL island on average was four times higher than AGB. Meanwhile, the ratio was smaller on the other two islands, which was about three to three and a half times higher (Table 3). Biomass stored under the substrate is one of the forms of seagrass adaptation. Seagrass grows in shallow waters, which makes it very vulnerable to the influence of waves. Without specific adaptation, seagrass can be easily uprooted by the waves. Seagrass adapts by storing more photosynthetic products under the ground than above, therefore, it can stay still under the impact of waves.

Among the three islands, the highest average biomass was found on BC Island, either for BGB, AGB, or the total biomass (Table 4). This is more likely due to the large composition of *E. acoroides,* especially in the high-percent cover category. The percent cover of *E. acoroides* reached 23.2% or about 30% of the total seagrass cover in the high category of the island. *E. acoroides* is a large seagrass species (Waycott et al. 2004) and the largest seagrass species that can be found in Indonesia.

Seagrass BGB was generally weighted higher than ABG in the seagrass categories on the three islands. High categories dominated seagrasses on the three different islands. There was a total of 8.62 ton dry weight/ha seagrass biomass on BL Island, 3.83 ton dry weight/ha on KL Island, and 10.99 ton dry weight/ha on BC Island (Fig. 10).

3.5.2 Correlation Between Biomass In Situ and NDVI

The correlation between the total biomass and the NDVI values of the three islands was analyzed. R^2 values acquired from regression analysis were 0.40 for Landsat 8, and 0.43

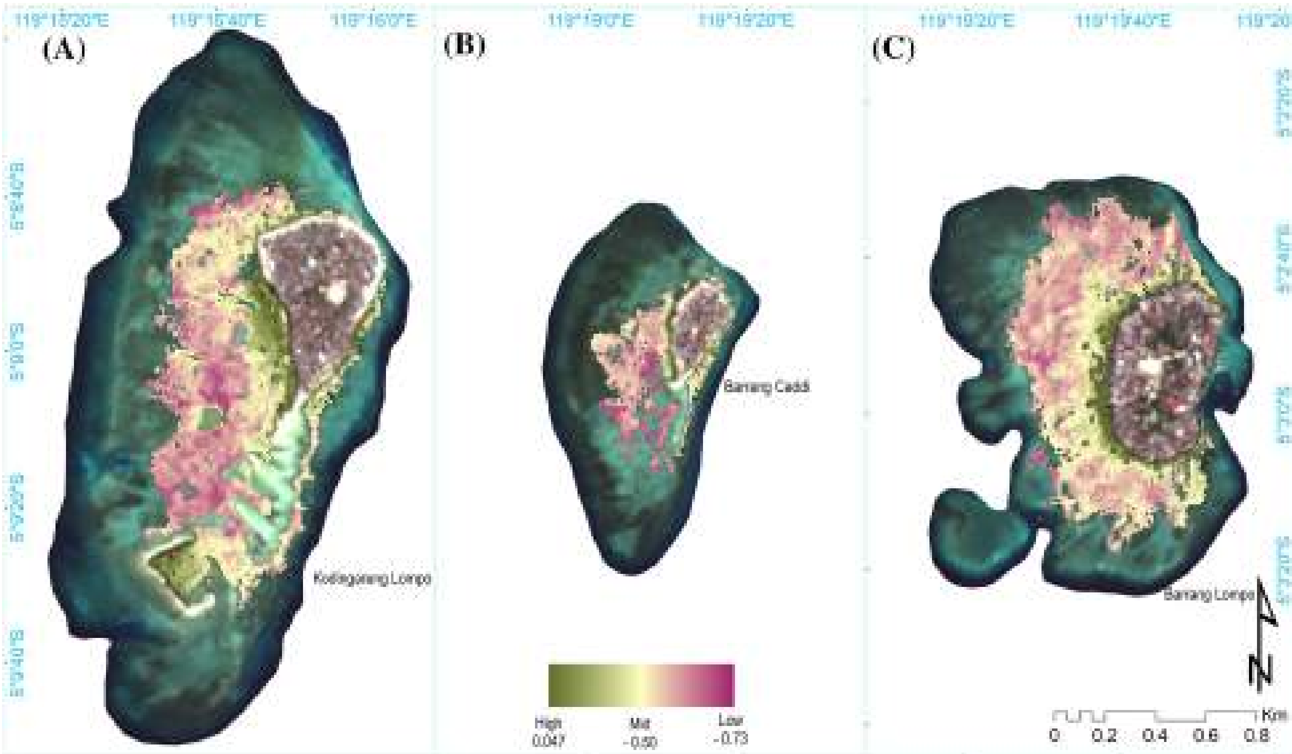

Fig. 7 NDVI values derived from Sentinel-2 on Kodingareng Lompo (**A**), Barrang Caddi (B) and Barrang Lompo (**C**)

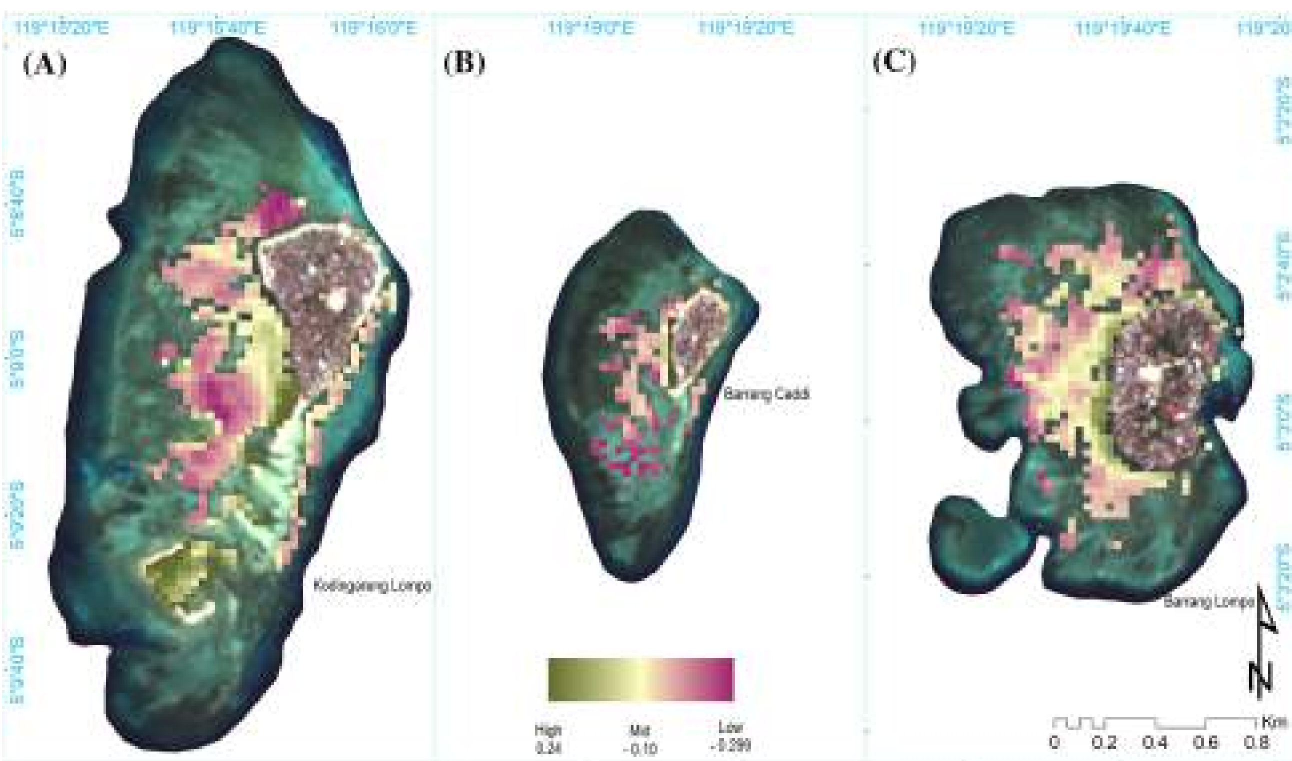

Fig. 8 NDVI derived from Landsat 8 on Kodingareng Lompo (**A**), Barrang Caddi (**B**) and Barrang Lompo (**C**)

Fig. 9 Correlation analysis of SPC between in situ measurement and NDVI values on the three islands; **A** Sentinel-2 imagery, **B** Landsat 8 imagery

Table 4 Seagrass biomass in the study locations based on high, medium, and low categories

Location	Category	Biomass (dry weight ton /ha)		
		Above ground	Below ground	Total
Barrang Lompo	High	1.05	3.49	4.55
	Medium	0.58	2.33	2.9
	Low	0.2	0.96	1.17
Kodingareng Lompo	High	0.48	1.28	1.76
	Medium	0.46	1.01	1.47
	Low	0.11	0.49	0.6
Barrang Caddi	High	1.33	4.83	6.16
	Medium	0.75	2.75	3.5
	Low	0.3	1.03	1.33

for Sentinel-2. These R^2-values indicate a low correlation between the total biomass value and the NDVI value. Overall, NDVI and carbon biomass of seagrass showed a linear relation (Fig. 11). The higher the total biomass value, the closer the NDVI value will be to 0 (solid seagrass cover condition), while the lower the total biomass value, the closer the NDVI value will be to -1 (low seagrass cover condition).

Moreover, on BL Island, the biomass value has more variation in the high seagrass cover category than in the low and medium categories (Table 4). This is due to the various species composition. Some plots were *T. hemprichii* dominant, while other plots were more *E acoroides* dominant. Morphologically, the two seagrasses have different sizes, therefore, at the same cover percentage, they have very different biomass values. In the low and medium seagrass cover categories, *T. hemprichii* was consistently the dominant species.

Furthermore, in the high seagrass cover category, there was quite a lot of overlap between leaves, especially with the *T. hemprichii* species. In some plots (Fig. 10), a large addition of seagrass cover value can only cause a small increase in biomass value. Meanwhile, in other plots, the addition of the same amount of seagrass cover value can add a substantial biomass value. However, in the high and medium seagrass cover categories, the overlap between leaves was less. According to Mallombassi, et al (2020), the high slope value of *T. hemprichii* seagrass regression equation at high percent cover was because of the overlapping leaf canopy, resulting in a high increase of biomass value despite the small addition of the percent cover.

E. acoroides and *C. rotundata* significantly contributed to the medium to sparse percent cover category on KL and BC islands. This causes the biomass values of those two

Fig. 10 Field photographs of the low, medium, and high seagrass categories on Kodingareng Lompo and Barrang Lompo

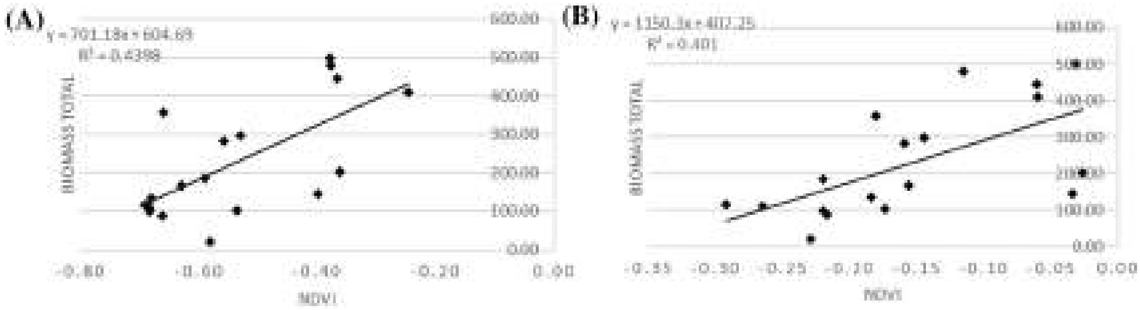

Fig. 11 Regression analysis of seagrass biomass and NDVI on Barrang Lompo, Barrang Caddi, and Kodingareng Lompo islands; **A** Sentinel-2 imagery, **B** Landsat 8 imagery

categories to vary largely. The contribution of the two seagrasses was about half of the dominant species *T. hemprichii*, while on BL Island, it can reach a quarter in the same category.

4 Conclusions

The result of this study showed that there is a strong correlation between in situ seagrass percent cover and NDVI values derived from the two satellite images. However, the correlation between in situ seagrass total biomass and the NDVI values showed a relatively weak correlation. Image classification showed that seagrass was distributed mostly on the west side of the islands, and there were six seagrass species identified on the sites, i.e., *E. acoroides*, *T. hemprichii*, *C. rotundata*, *H. uninervis*, *H. ovalis* and *S. isoetifolium.* In this study, we also discovered that there was a disparity of seagrass total cover area between Sentinel-2 and Landsat 8, due to spatial resolution diferrences. Sentinel-2 images were able to classify seagrass distribution up to the seagrass density category, however, they cannot be applied to differentiate seagrass density based on species. Nevertheless, both Sentinel-2 and Landsat 8 are useful for seagrass condition monitoring purposes.

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References

Cabaço S, Apostolaki ET, García-Marín P, Gruber R, Hernández I, Martínez-Crego B, Mascaró O, Pérez M, Prathep A, Robinson C, Romero J, Schmidt AL, Short FT, Van Tussenbroek BI, Santos R (2013) Effects of nutrient enrichment on seagrass population dynamics: evidence and synthesis from the biomass-density relationships. J Ecol 101:1552–1562. https://doi.org/10.1111/1365-2745.12134

Chavez PS Jr (1988) An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote Sens Environ 24(3):459–479. https://doi.org/10.1016/0034-4257(88)90019-3

Congalton R, Green K (2008) Assessing the accuracy of remotely sensed data, principles and practices, 2nd edn. CRC Press, Boca Raton, p 200

Duarte CM, Marbà N, Gacia E, Fourqurean JW, Beggins J, Barrón C, Apostolaki ET (2010) Seagrass community metabolism: assessing the carbon sink capacity of seagrass meadows. Glob Biogeochem CyCles 24(4):GB4032. https://doi.org/10.1029/2010GB003793

Hedley JD, Harborne AR, Mumby PJ (2005) Simple and robust removal of sun glint for mapping shallow-water benthos. Int J Remote Sens 26(10):2107–2112. https://doi.org/10.1080/01431160500034086

Hochberg EJ, Atkinson MJ (2003) Spectral reflectance of coral reef bottom-types worldwide and implications for coral reef remote sensing. Remote Sens Environ 85(2):159–173. https://doi.org/10.1016/S0034-4257(02)00201-8

Kennedy H, Beggins J, Duarte CM, Fourqurean JW, Holmer M, Marbà N, Middelburg JJ (2010) Seagrass sediments as a global carbon sink: Isotopic constraints. Glob Biogeochem Cycles 24(4):GB4026. https://doi.org/10.1029/2010GB003848

Krause-Jensen D, Duarte C (2016) Substantial role of macroalgae in marine carbon sequestration. Nat Geosci 9:737–742. https://doi.org/10.1038/ngeo2790

Lavery PS, Mateo MÁ, Serrano O, Rozaimi M (2013) Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PLoS ONE 8(9):e73748. https://doi.org/10.1371/journal.pone.0073748

Lyimo LD (2016) Carbon sequestration processes in tropical seagrass beds. Ph.D. Thesis, Stockholm University, p 49

Lyzenga D (1981) Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. Int J Remote Sens 2(1):71–82. https://doi.org/10.1080/01431168108948342

Mallombassi A, Mashoreng S, La Nafie YA (2020) The relationship between seagrass Thalassia hemprichii percentage cover and their biomass. Spermonde 6(1):7–10. https://doi.org/10.20956/jiks.v6i1.9922

McKenzie LJ, Finkbeiner MA, Kirkman H (2001) Methods for mapping seagrass distribution. In: Short FT, Coles RG (eds) Global seagrass research methods. Elsevier Science, pp 101–121. https://doi.org/10.1016/B978-044450891-1/50006-2

Pu R, Bell S, English D (2015) Developing hyperspectral vegetation indices for identifying seagrass species and cover classes. J Coast Res 31(3):595–615. https://doi.org/10.2112/JCOASTRES-D-12-00272.1

Roca G, Alcoverro T, Krause-Jensen D, Balsby TJS, van Katwijk MM, Marba N, Santos R, Arthur R, Mascaró O, Fernández-Torquemada Y, Pérez M (2016) Response of seagrass indicators to shifts in environmental stressors: a global review and management synthesis. Ecol Indic 63:310–323. https://doi.org/10.1016/j.ecolind.2015.12.007

Rohr ME, Bostrom C, Canal-Vergés P, Holmer M (2018) Blue carbon storage capacity of temperate Eeelgrass (*Zostera marina*) meadows. Glob Biogeochem Cy 32:1457–1475. https://doi.org/10.1029/2018GB005941

Waycott M, McMahon K, Mellors J, Calladine A, Kleine D (2004) A guide to tropical seagrass of the Indo-West Pacific. James Cook University, Townsville

Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT, William SL (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc Natl Acad Sci USA 106(30):12377–12381. https://doi.org/10.1073/pnas.0905620106

Zoffoli ML, Gernez P, Rosa P, Le Bris A, Brando VE, Barillé AL, Harin N, Peters S, Poser K, Spaias L, Peralta G (2020) Sentinel-2 remote sensing of Zostera noltei-dominated intertidal seagrass meadows. Remote Sens Environ 251:112020. https://doi.org/10.1016/j.rse.2020.112020

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ARTICLE

Estimation of Seagrass Biomass by In Situ Measurement and Remote Sensing Technology on Small Islands, Indonesia

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Abstract

As one of the major blue carbon ecosystems, studying, conserving, and monitoring seagrass meadows, especially on small populated islands, has become very important due to their vulnerability to anthropogenic and global environmental factors. In this study, we used satellite image analysis and biological data to map seagrass percent cover (SPC), above-ground biomass (AGB), and below-ground biomass (BGB) on the three most populated islands of the Spermonde Archipelago, Indonesia, i.e., Kodingareng Lompo, Barrang Lompo, and Barrang Caddi. Reflectance and Normalized Difference Vegetation Index (NDVI) values of Sentinel-2 (S2) imagery were used to classify and calculate SPC and AGB. In situ biological data measurements were carried out from 3 to 14 of June, 2020, on the three islands to measure AGB and BGB. The result from image classification shows a total area of 126.37 Ha of seagrass, which was divided into three SPC categories: medium (30–59.9%) with a total area of 78.38 Ha; low (0–29.9%) with a total area of 13.1 Ha; and high (60–100%) with a total area of 34.89 Ha. The highest SPC area was observed on Kodingareng Lompo Island with 61.07Ha, followed by Barrang Lompo Island with 53.18Ha, and Barrangcaddi Island with 12.12Ha. The total AGB on Barrang Lompo, Kodingareng Lompo, and Barrangcaddi in tons of dry weight/ha were 1.83, 1.05, and 2.38, respectively. The highest BGB was reported on Barrangcaddi Island with 8.61 tons of dry weight/ha, followed by Barrang Lompo Island with 6.78 tons of dry weight/ha, and Kodingareng Lompo Island with 2.78 tons of dry weight/ha. Regression analysis showed a linear correlation between NDVI value and in situ SPC with $R^2 = 0.8255$. The framework of this study can be applied to monitor temporal changes of seagrass meadows distribution on small islands to promote a more sustainable ecosystem.

Keywords Biomass · NDVI · Seagrass · Sentinel-2 · Small islands

1 Introduction

Seagrass meadows have a high carbon sink capacity that surpasses even highly productive terrestrial ecosystems (Krause-Jensen and Duarte 2016). Seagrass meadows have a carbon fixation ability that exceeds their metabolic needs; hence, a large proportion of excess organic carbon is transported to the roots and rhizomes where it is stored and eventually exuded in the sediment to form anaerobic organic-rich soil (autochthonous) (Lyimo 2016). A study of the carbon sequestered capacity of Australian seagrasses estimates annual organic carbon (C_{org}) accumulation to be between 0.093 and 6.15 Mt, with a most probable estimation of 0.93 Mt year^{-1} (10.1 t km^{-2} year^{-1}) (Lavery et al. 2013). This type of blue carbon ecosystem also has a high global net carbon production (NCP) of 20.73–50.69 Tg C year^{-1}, which comprises 10–18% of the total carbon storage in the ocean (Duarte et al. 2010; Kennedy et al. 2010).

However, disturbances caused by humans can negatively influence the carbon fixation ability of seagrasses and affect the amount of carbohydrate and starch being stored in their rhizomes. Growing in coastal environments, seagrasses are

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usually subjected to many anthropogenic activities e.g., sewage disposal, mariculture, propeller boating activities, destructive fishing, construction works, dredging, and eutrophication, which threatens their ecosystems and can lead to extinction (Roca et al. 2016). It is believed that about a third to half of the world's seagrasses have been lost since 1879 and the continuing rate of disappearance is estimated to be 110 km^2 per year with net loss rates of 0.9% per year before 1940 to 7% since 1990 (Waycott et al. 2009). Therefore, the remaining seagrass ecosystems need to be conserved and protected.

Information on seagrass status in terms of percent cover and biomass needs to be acquired as baseline data to efficiently manage and monitor the seagrass ecosystems for conservation purposes. Remote sensing techniques have proven to be efficient and effective tools for seagrass monitoring. Since launched by the European Space Agency (ESA) in 2015, Sentinel-2 (S2) images with higher spatial resolution that are suitable for seagrass mapping, have been available and can be acquired at no cost. The use of S2 imagery for seagrass meadows ecosystem study was recently demonstrated with regard to seagrass beds on the Atlantic coasts of France and Spain (Zoffoli et al. 2020).

Spermonde Archipelago is a set of small tropical islands between Kalimantan and Sulawesi islands in Indonesia. Three of its most populated islands are Barrang Lompo, Barrang Caddi, and Kodingareng Lompo. Despite high anthropogenic disturbance factors most likely occurring on these islands, there are still significant amounts of seagrass ecosystems that can be found on these islands. However, a study to analyze the percent cover and biomass of these seagrasses has not been done yet. The main objective of this study is to map seagrass distribution and the total areas on the three most populated islands in the Spermonde Archipelago using two different spatial resolution imageries, Sentinel-2 and Landsat 8. Several variables, including seagrass density and biomass, were measured directly in the field to find a correlation between in situ values and NDVI values derived from Landsat 8 and Sentinel-2 image analysis.

2 Materials and Methods

2.1 Study Sites

This study was conducted on three islands: Barrang Lompo (BL), Barrang Caddi (BC), and Kodingareng Lompo (KL). These three islands are part of the Spermonde Archipelago, which is located west off the coast of Makassar City, capital of South Sulawesi Province, Indonesia. BL Island is located at 5° 2′ 43.577″–5° 3′ 6.491″ South latitude (SL) and 119° 19′ 38.716″–119° 19′ 49.21″ East longitude (EL), which is 12.48 km from Makassar City. Meanwhile, BC Island is located at 5° 4′ 46.558″–5° 5′ 0.778″ SL and 119° 19′ 10.557″–119° 19′ 16.21″ EL with a distance of 10.98 km from Makassar City, while Kodingareng Lompo Island is located at 5° 8′ 42.536″–5° 9′ 9.434″ SL and 119° 15′ 45.006″–119° 15′ 58.540″ EL with a distance of 15.24 km from Makassar City. Based on the distance from the mainland, the three islands were included in the middle zone, with the distance from the mainland coastline between 10 and 20 km (Fig. 1). Field data were taken at BL, BC, and KL islands from 3 to 14 June 2020. Data derived from satellite images used for this study were acquired from S2 on July 29th 2019 and from Landsat 8 (L8) on January 6th 2019.

2.2 Satellite Data

2.2.1 Landsat 8 and Sentinel-2 Image Pre-processing

Satellite image data used in this study were acquired from S2 on July 29th 2019 and L8 on January 6th 2019. Geometrically corrected S2 images of waters west of South Sulawesi were downloaded from the European Space Agency (ESA) data portal, while images from Landsat 8 were downloaded from USGS Glovis. Atmospheric correction was conducted using radiometric calibration (DN to reflectance) and DARK OBJECT SUBTRAction (DOS) to remove the atmospheric effect on the images, assuming the darkest pixel value was zero (Chavez, 1988). Sun glint correction was applied on S2 imagery to correct sunlight reflection. This correction was not performed on L8 imagery as the images were clear enough; however, a pan-sharpening technique was performed to facilitate interpretation for image classification. Sun glint correction for S2 imagery was carried out using the algorithm developed by Hochberg and Atkinson (2003) and refined by Hedley et al. (2005) as in the following equation:

$$R'_i = R_i - b_i(\mathrm{RNIR} - \mathrm{MinNIR}), \quad (1)$$

R'_i is the i channel value after being reduced; R_i is the initial i channel value; b_i is the amount of slope of the regression; RNIR is the NIR channel value; MinNIR is the minimum NIR channel value.

Atmospheric corrections and water column correction were applied to the images to classify shallow-water habitats and seagrass percent cover (SPC) using supervised classification. The flowchart for spatial data processing and its integration with non-spatial data can be seen in Fig. 2. Water column correction method was applied to the images using depth invariant index (DII) algorithm by Lyzenga (1981). The DII method reduces the influence of the water column so that clearer images of shallow water habitats could be obtained. Points on the sand area were used to build a model to obtain the attenuation coefficient of the water column. This is because sand objects are easier to recognize in the images, with the bright white appearance

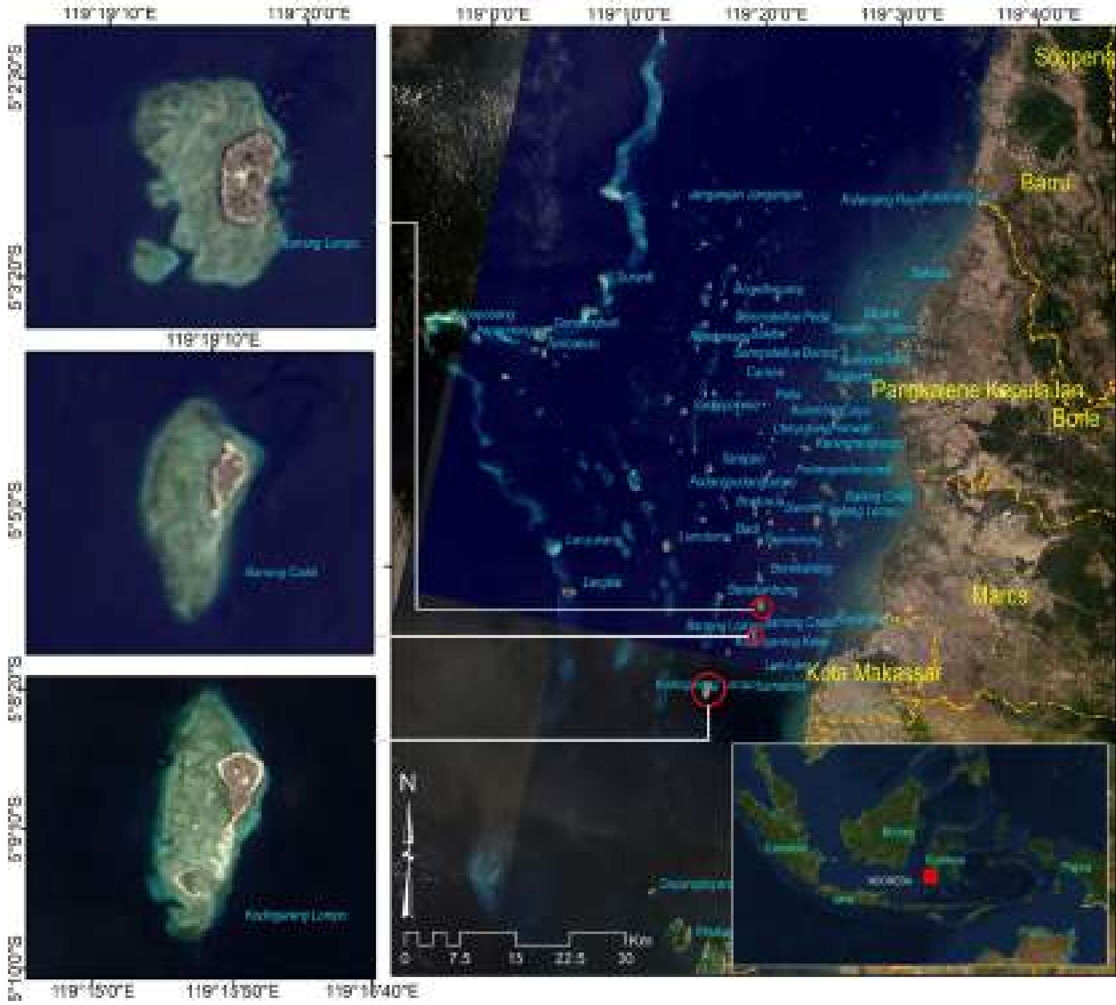

Fig. 1 Study site on BL (Barrang Lompo), BC (Barrang Caddi), and KL (Kodingareng Lompo) islands, Spermonde Archipelago, South Sulawesi, Indonesia

becoming a darker blue color as the water depth increases. The algorithm used in this process was:

$$\mathrm{DII}(ij) = \ln(L_i) - [(K_i/K_j)\ln(L_j)]. \quad (2)$$

$$k_i/k_j = a - [(K_i/K_j)\ln(L_j)]. \quad (3)$$

$$\alpha = \frac{\alpha_i + \alpha_j}{2\alpha_{ij}}. \quad (4)$$

DII is the depth invariant index; L_i is the i-band reflectance value; L_j is the j-band reflectance value; k_i/k_j is the i and j band attenuation coefficient ratio; α_i is the i-band variant; α_j is the j-band varian; α_{ij} is the i and j band covariant.

2.2.2 Image Classification Based on SPC

Images that have been corrected were then classified using an unsupervised classification method (Isoclass). The results were then reclassified based on ground truth data. The final classification of SPC was divided into three categories i.e., low (0–29.9%), medium (30–59.9%), and high (60–100%). These categories were then used to determine biomass sampling points.

The classification mapping accuracy was tested using a confusion matrix method to calculate the accuracy value of

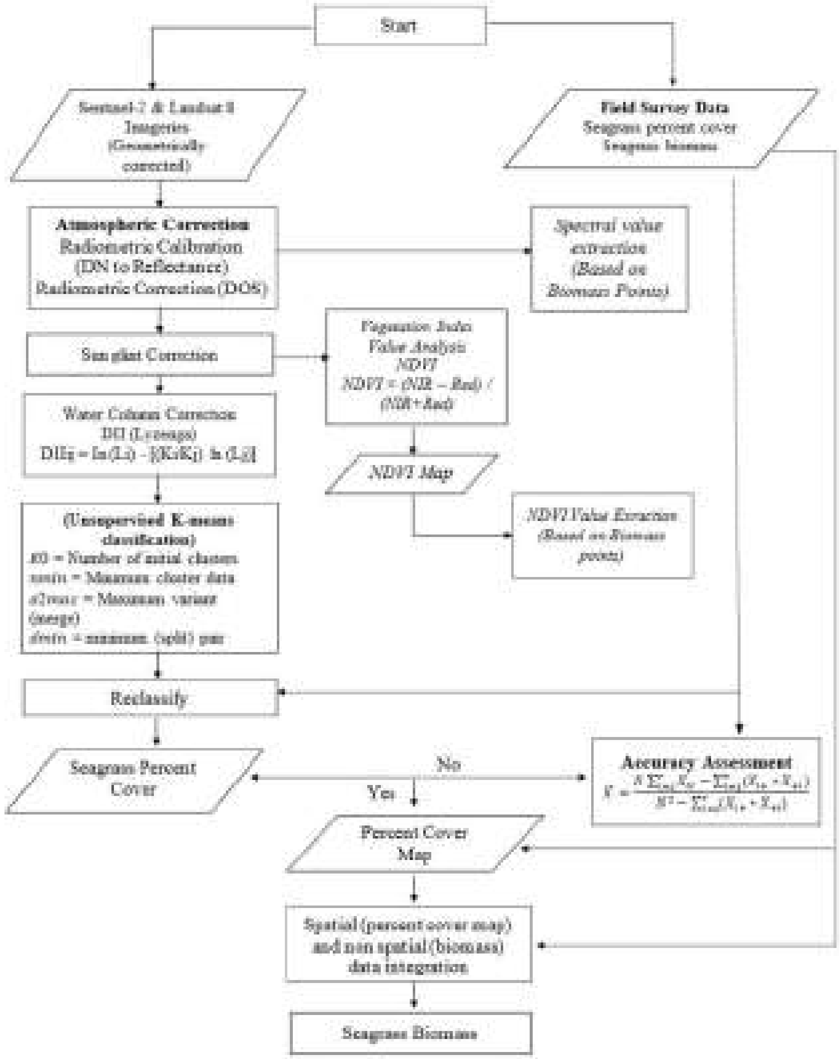

Fig. 2 Flowchart analysis of integration image and in situ data to seagrass biomass

seagrass habitat mapping. It was done using a matrix table that combines classes from satellite image classification with in situ data (Congalton and Green 2008). The error matrix method used in this study followed the following formula:

$$K = \frac{N \sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} (X_{i+} \times X_{+i})}{N^2 - \sum_{i=1}^{r} (X_{i+} \times X_{+i})}, \quad (5)$$

2.2.3 Image Classification Based on Seagrass Density

The NDVI (normalized difference vegetation index) algorithm has been used to measure vegetation density level (greenness) using the reflectance values of the near-infrared (NIR) and red bands (Pu et al. 2015). Seagrass beds usually grow in shallow waters, with the NDVI index value ranging from −1 to 0. The formula used for NDVI was:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}, \quad (6)$$

NDVI is the normalized difference vegetation index; NIR is the short infrared band spectral reflectance; Red is the red band spectral reflectance.

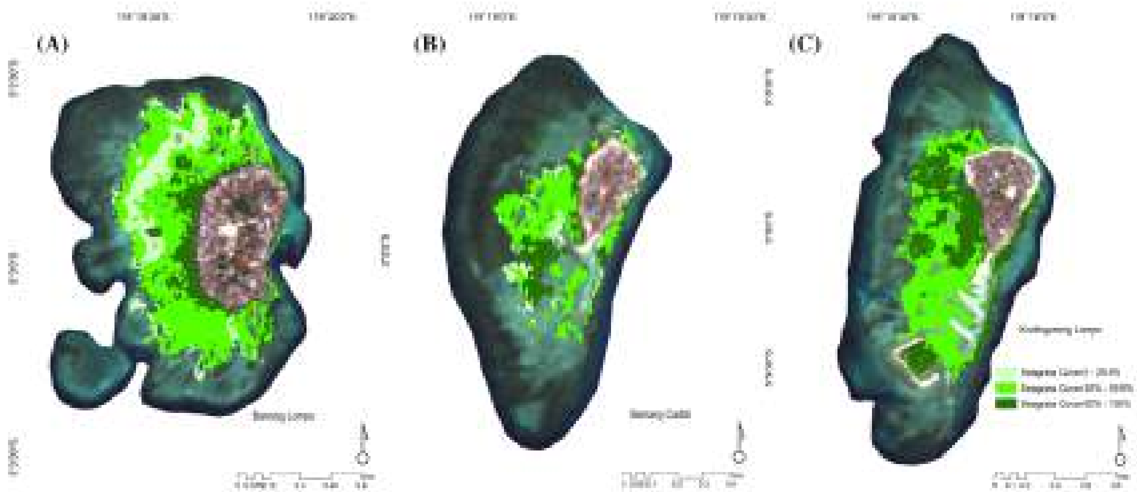

Fig. 3 Seagrass distribution maps of **A** Barrang Lompo, **B** Barrang Caddi, and **C** Kodingareng Lompo using 10 m spatial resolution Sentinel-2 imagery, with the acquisition date on July 29th 2019. Seagrass were categorized into three classes, i.e., 0–29.9% (low), 30–59.9% (medium) and 60–100% (high)

2.3 Field Data

2.3.1 In Situ SPC and Biomass Sampling

Based on the unsupervised SPC image classification, 60 stations were designated on each island as the sampling points (20 for each SPC categories i.e., low, medium, and high). In situ measurements of SPC and seagrass density were carried out using a 50 cm × 50 cm plot (McKenzie et al. 2001). Seagrass species were also identified in every plot. A smaller plot (20 cm × 20 cm plot) was placed within the bigger plot to measure seagrass biomass. The plot was placed based on the types of seagrasses that exist within the bigger plot so that all types of seagrasses in the plot could be extracted. Seagrass biomass samples were collected with roots up to 40 cm long. Vined rhizomes were chopped using a machete before picking out any sample. Seagrass samples consisting of roots, rhizomes, leaves, and midribs were collected from each station. Substrate and dirt were cleaned away from the samples and then each of them was put into a labeled plastic bag for further laboratory analysis.

2.3.2 Biomass Analysis

In the laboratory, samples were cut into two parts, the biomass above the sediment or above ground biomass (AGB) which consists of leaves and leaf midribs, and the below-ground biomass (BGB) which consists of rhizomes and roots (Rohr et al. 2018). The samples were then oven-dried (60 °C) until a constant weight was achieved (Lyimo 2016). Samples were then weighed using a 0.01-g precision level digital scale. Seagrass biomass per shoot was calculated by dividing the total weight of each sample by the total number of its shoots. The mean biomass per area (g/m^2) for each seagrass percent cover category was determined by multiplying the number of biomass per shoots with each type of seagrass density. The result value was then multiplied by the area of each of the percent cover categories to get the total biomass per category.

2.3.3 Regression Analysis

The correlation between biomass (AGB, BGB, and total biomass) and the SPC results on every island was determined using regression linear analysis. Regression analysis was also performed to find the correlation between field survey data (in situ percent cover and biomass) with spatial data (percent cover and NDVI value).

3 Result and Discussion

3.1 SPC Based on Image Classification

The seagrass maps were generated using a pixel-based classification method (unsupervised classification). 3 highly populated islands in the Spermonde Archipelago were analyzed in this study. Based on the results, SPC in KL was mainly in the range between 30 and 59.9% (medium), which accounts for 60.38% of the total seagrass area on this island. Similarly, SPC on BC and BL islands were also mainly characterized by the medium SPC category, which accounts for 62.71% and 63.74%, respectively, of the total seagrass areas that were

Table 1 Percent cover of seagrass area from Sentinel-2 imagery classification

Seagrass percent cover (%)	Area (ha)
0–29.9 (low)	13.1
30–59.9 (medium)	78.38
60–100 (high)	34.89
Grand total	126.37

Table 2 Total seagrass area by Landsat 8 and Sentinel-2

Island	Area by Landsat		Area by Sentinel-2	
	Area (ha)	Years	Area (ha)	Years
BL	37.66	2019	53.18	2019
BC	9.61	2019	12.12	2019
KL	46.30	2019	61.07	2019

identified on each island. Overall, medium SPC category accounts for 62.02% of the total seagrass area identified on these three islands (Fig. 3; Table 1). Spermonde Archipelago has 683.70 ha of seagrass, so it can be said that these three islands contribute around 18.48% of the total seagrass in the Spermonde Archipelago.

Pixel-based analysis was also applied on L8 images to generate seagrass distribution maps on each island (Fig. 4). Due to its lower spatial resolution (30 m), seagrass mapping using L8 was only up to the aquatic habitat condition or seagrass distribution that was able to be classified using L8 (Fig. 4; Table 2). Nevertheless, the results between L8 and S2 show similar seagrass spatial distribution. As can be seen in Figs. 3 and 4, seagrass is dominantly grown in the western area of the islands, while the eastern part remained barren.

There were differences in total seagrass areas calculated with L8 and S2 image processing. Calculation with S2 resulted in a larger seagrass area by 24.2% on KL Island, 20.7% on BC Island, and 60.9% on BL Island compared with L8. Seagrass maps of KL and BC islands show that each island has several dominant and sparse seagrass distribution spots (Table 1). The seagrass-dominant areas at KL and BC islands were mostly on the west, southwest, to the south of the island, while on the north to the east side of the islands, the seagrass distribution was mostly sparse. Identification from the survey and aerial images indicate that lack of seagrasses on the east sides of the islands were due to water depth and human activities mostly centered on the east side of the island (the side that faces the mainland). This side was the main channel for local passenger ships (Fig. 5: A1, B1, C1) and the port area of each island.

The south side of BC and KL islands were mostly covered with white sands which were exposed during low tide and, therefore, not suitable for seagrass to grow. Seagrass distribution on BL Island was almost evenly distributed on each side of the island, except at the areas around the main port. BL is a highly populated island and packed with house settlements. People often dispose their household organic waste on the west side of the island, with the waste entering straight into the sea and the same thing occurs on the other islands. Hence, due to this activity, disposed organic materials on this side of the island has resulted in increasing organic nutrients inputs which support seagrass growth. As can be seen in the Fig. 5A2, 5B2, and 5C2 there are

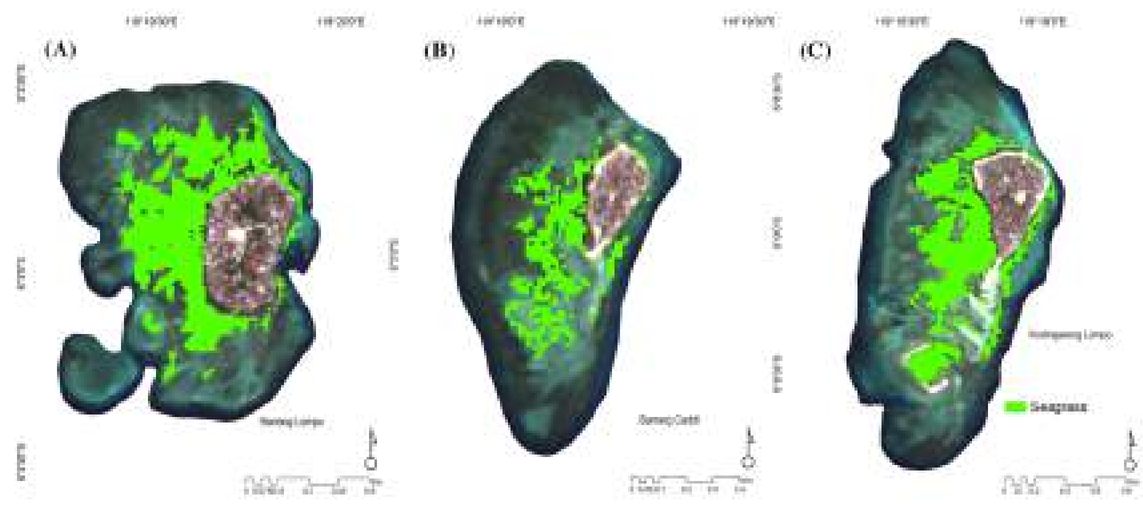

Fig. 4 Seagrass distribution maps of **A** Barrang Lompo, **B** Barrang Caddi, and **C** Kodingareng Lompo using 30 m^2 spatial resolution Landsat 8 OLI Imagery acquired on January 6th 2019

Fig. 5 Aerial photographs showing the shallow water condition on the east and the west side of Kodingareng Kompo (**A1–A2**), Barrang Caddi (**B1–B2**) and Barrang Lompo (**C1–C2**) islands. The east sides of the islands (**A1**, **B1** and **C1**) showed less seagrass beds than the west sides of the islands (**A2**, **B2**, **C2**)

more seagrass beds that can be observed on the west sides of these islands due to the disposal of richer organic materials compared to the east sides (Fig. 5A1, 5B1, 5C1). Nutrient enrichment enhanced seagrass biomass density, particularly in increasing the shoot biomass (Cabaco et al. 2013).

3.2 Accuracy Test

The accuracy test of the S2 image classification results was obtained using field data. Field data used was [illegible] sample of seagrass cover photos that have coordinates. Based on the image analysis results, the overall accuracy of the kappa value of each image was: KL Island 75%, BC Island 82.69%, and BL Island 80.60%.

3.3 Seagrass Percent Cover (SPC) and Density from In Situ Measurement

The result from in situ measurement shows that seagrass density and SPC have a synched pattern, from low to high density, and low, medium, and high categories, respectively (Table 3). In some cases, the seagrass density value may be higher in the percent cover high category than in the medium or low category. The consistent pattern of seagrass density in all three islands is more likely due to the relatively similar composition of seagrass species in the three percent cover category.

Six species of seagrass were found on the three islands, i.e., *Enhalus acoroides*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Halodule uninervis*, *Halophila ovalis* dan *Syringodium isoetifolium*. Seagrass composition was dominated by *T. hemprichii* in all categories. An exception was found on KL Island where *C. rotundata* dominated the low category (Fig. 6).

3.4 Correlation Between Density of Seagrass Using NDVI Algorithm and Percent Cover of Seagrass Using In situ Data

NDVI has been widely used in several studies in Indonesia to estimate vegetation biomass, greenness level, primary production, and dominant species in vegetation. The NDVI index value

Table 3 Seagrass density and percent cover from in situ measurement

Plot Category	Density (shoots/m^2)			Percent cover (%)		
	BL	BC	KL	BL	BC	KL
High	418.2	447	310.733	78.25	76.9	77.867
Medium	367.6	411.8	229.6	45.45	38.95	46.267
Low	239.6	178.2	268.235	23.9	18.6	20

BL Barrang Lompo, *BC* Barrang Caddi, *KL* Kodingareng Lompo

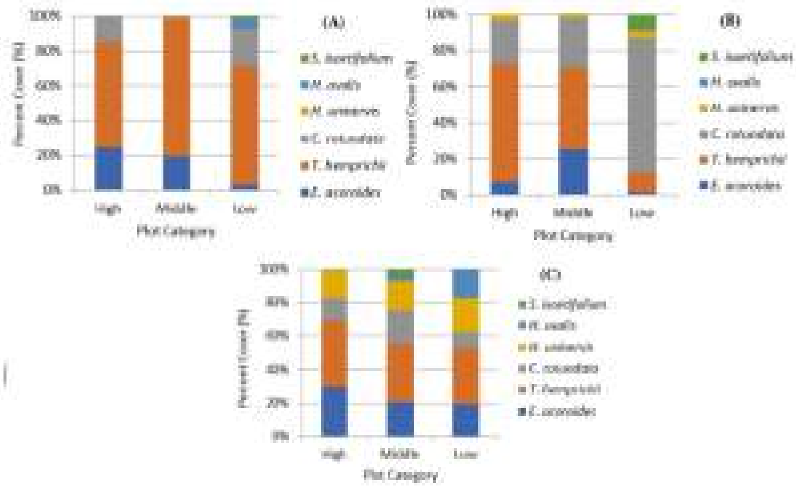

Fig. 6 Percent cover of each seagrass 'species' based on plot categories in **A** Barrang Lompo, **B** Kodingareng Lompo, and **C** Barrang Caddi

ranges from -1.00 to 1.00. The principle of NDVI is to measure level of greenness intensity. The intensity of greenness in Sentinel-2 (Fig. 7) and Landsat 8 (Fig. 8) images correlates with the level of density of the vegetation canopy.

The relationship between SPC from field measurements and NDVI values was analyzed using algorithmic modeling with linear regression. The regression equation was obtained from the relationship between the NDVI value of S2 images and the value of in situ SPC. The algorithm obtained was $y = 0.0053x - 0.785$. Regression analysis shows a linear correlation between NDVI and in situ data with R^2 value of 0.8255. The R value indicates a strong relationship between the in situ SPC and the NDVI values of satellite images (Fig. 9).

3.5 Seagrass Biomass

3.5.1 Total Biomass

Results from laboratory analysis showed seagrass BGB in all islands and in each seagrass cover category were higher than AGB. Seagrass BGB value on BL island on average was four times higher than AGB. Meanwhile, the ratio was smaller on the other two islands, which was about three to three and a half times higher (Table 3). Biomass stored under the substrate is one of the forms of seagrass adaptation. Seagrass grows in shallow waters, which makes it very vulnerable to the influence of waves. Without specific adaptation, seagrass can be easily uprooted by the waves. Seagrass adapts by storing more photosynthetic products under the ground than above, therefore, it can stay still under the impact of waves.

Among the three islands, the highest average biomass was found on BC Island, either for BGB, AGB, or the total biomass (Table 4). This is more likely due to the large composition of *E. acoroides*, especially in the high-percent cover category. The percent cover of *E. acoroides* reached 23.2% or about 30% of the total seagrass cover in the high category of the island. *E. acoroides* is a large seagrass species (Waycott et al. 2004) and the largest seagrass species that can be found in Indonesia.

Seagrass BGB was generally weighted higher than ABG in the seagrass categories on the three islands. High categories dominated seagrasses on the three different islands. There was a total of 8.62 ton dry weight/ha seagrass biomass on BL Island, 3.83 ton dry weight/ha on KL Island, and 10.99 ton dry weight/ha on BC Island (Fig. 10).

3.5.2 Correlation Between Biomass In Situ and NDVI

The correlation between the total biomass and the NDVI values of the three islands was analyzed. R^2 values acquired from regression analysis were 0.40 for Landsat 8, and 0.43

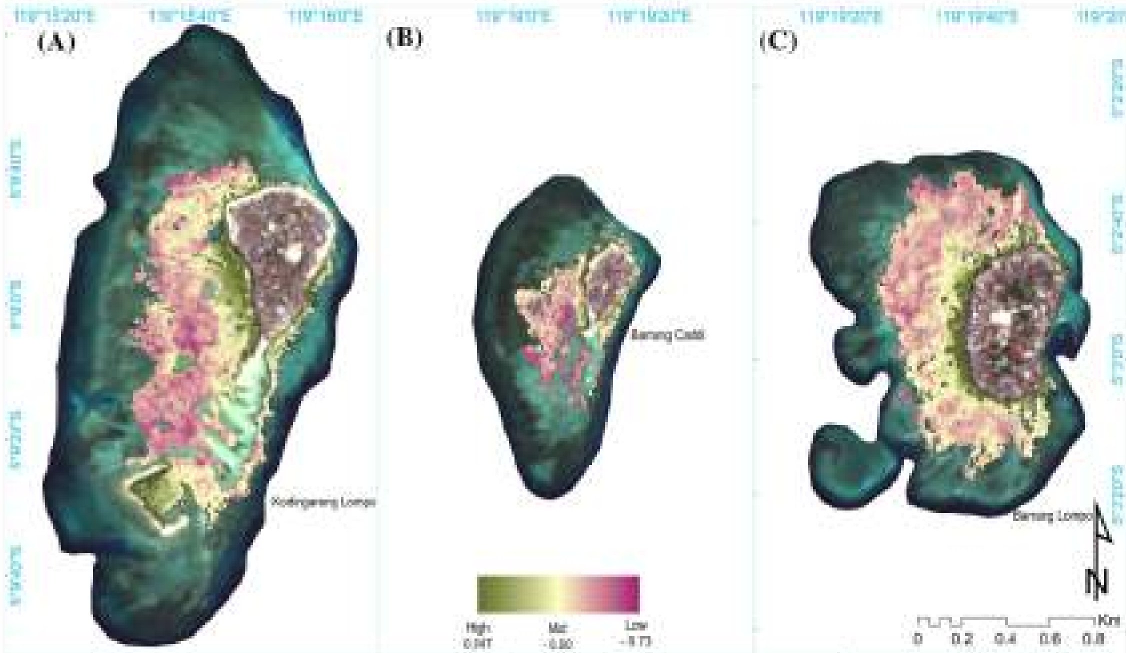

Fig. 7 NDVI values derived from Sentinel-2 on Kodingareng Lompo (A), Barrang Caddi (B) and Barrang Lompo (C)

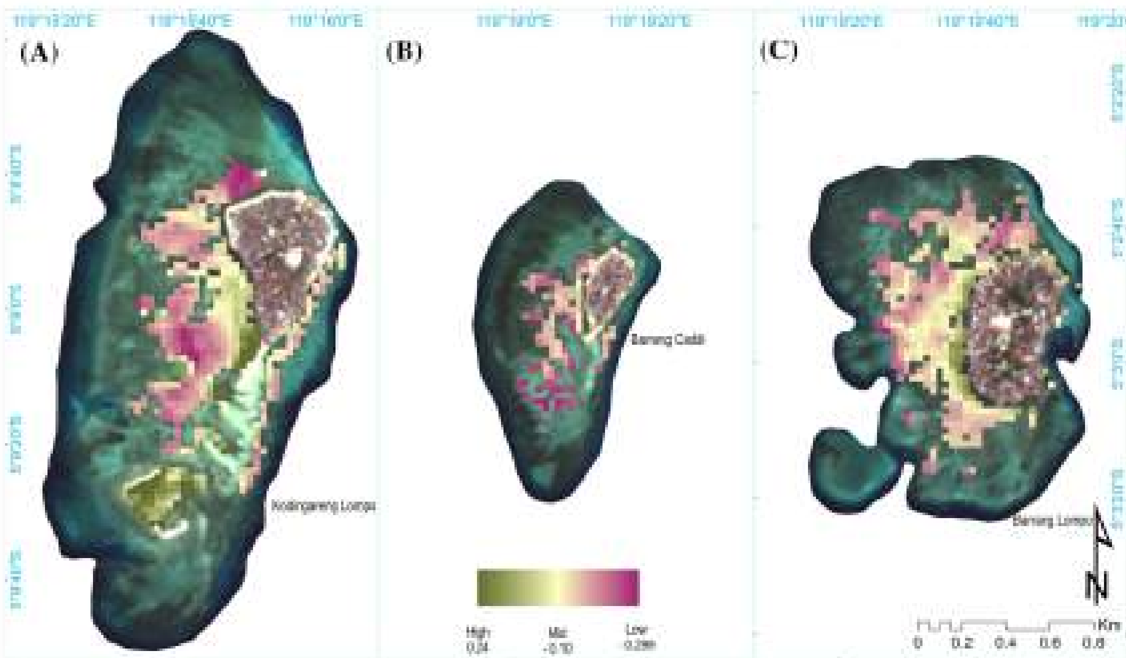

Fig. 8 NDVI derived from Landsat 8 on Kodingareng Lompo (A), Barrang Caddi (B) and Barrang Lompo (C)

Fig. 9 Correlation analysis of SPC between in situ measurement and NDVI values on the three islands: **A** Sentinel-2 imagery, **B** Landsat-8 imagery

Table 4 Seagrass biomass in the study locations based on high, medium, and low categories

Location	Category	Biomass (dry weight ton /ha)		
		Above ground	Below ground	Total
Barrang Lompo	High	1.05	3.49	4.55
	Medium	0.58	2.33	2.9
	Low	0.2	0.96	1.17
Kodingareng Lompo	High	0.48	1.28	1.76
	Medium	0.46	1.01	1.47
	Low	0.11	0.49	0.6
Barrang Caddi	High	1.33	4.83	6.16
	Medium	0.75	2.75	3.5
	Low	0.3	1.03	1.33

for Sentinel-2. These R^2-values indicate a low correlation between the total biomass value and the NDVI value. Overall, NDVI and carbon biomass of seagrass showed a linear relation (Fig. 11). The higher the total biomass value, the closer the NDVI value will be to 0 (solid seagrass cover condition), while the lower the total biomass value, the closer the NDVI value will be to −1 (low seagrass cover condition).

Moreover, on BL Island, the biomass value has more variation in the high seagrass cover category than in the low and medium categories (Table 4). This is due to the various species composition. Some plots were *T. hemprichii* dominant, while other plots were more *E. acoroides* dominant. Morphologically, the two seagrasses have different sizes, therefore, at the same cover percentage, they have very different biomass values. In the low and medium seagrass cover categories, *T. hemprichii* was consistently the dominant species.

Furthermore, in the high seagrass cover category, there was quite a lot of overlap between leaves, especially with the *T. hemprichii* species. In some plots (Fig. 10), a large addition of seagrass cover value can only cause a small increase in biomass value. Meanwhile, in other plots, the addition of the same amount of seagrass cover value can add a substantial biomass value. However, in the high and medium seagrass cover categories, the overlap between leaves was less. According to Mallombassi, et al (2020), the high slope value of *T. hemprichii* seagrass regression equation at high percent cover was because of the overlapping leaf canopy, resulting in a high increase of biomass value despite the small addition of the percent cover.

E. acoroides and *C. rotundata* significantly contributed to the medium to sparse percent cover category on KL and BC islands. This causes the biomass values of those two

Fig. 10 Field photographs of the low, medium, and high seagrass categories on Kodingareng Lompo and Barrang Lompo

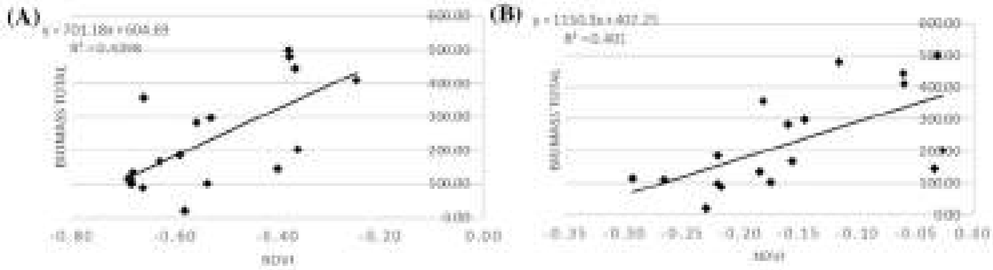

Fig. 11 Regression analysis of seagrass biomass and NDVI on Barrang Lompo, Barrang Caddi, and Kodingareng Lompo islands; A Sentinel-2 imagery, B Landsat 8 imagery

categories to vary largely. The contribution of the two seagrasses was about half of the dominant species *T. hemprichii*, while on BL Island, it can reach a quarter in the same category.

4 Conclusions

The result of this study showed that there is a strong correlation between in situ seagrass percent cover and NDVI values derived from the two satellite images. However, the correlation between in situ seagrass total biomass and the NDVI values showed a relatively weak correlation. Image classification showed that seagrass was distributed mostly on the west side of the islands, and there were six seagrass species identified on the sites, i.e., *E. acoroides*, *T. hemprichii*, *C. rotundata*, *H. uninervis*, *H. ovalis* and *S. isoetifolium*. In this study, we also discovered that there was a disparity of seagrass total cover area between Sentinel-2 and Landsat 8, due to spatial resolution diferrences. Sentinel-2 images were able to classify seagrass distribution up to the seagrass density category, however, they cannot be applied to differentiate seagrass density based on species. Nevertheless, both Sentinel-2 and Landsat 8 are useful for seagrass condition monitoring purposes.

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References

Cabaço S, Apostolaki ET, García-Marín P, Gruber R, Hernández I, Martínez-Crego B, Mascaró O, Pérez M, Prathep A, Robinson C, Romero J, Schmidt AL, Short FT, Van Tussenbroek BI, Santos R (2013) Effects of nutrient enrichment on seagrass population dynamics: evidence and synthesis from the biomass-density relationships. J Ecol 101:1552–1562. https://doi.org/10.1111/1365-2745.12134

Chavez PS Jr (1988) An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. Remote Sens Environ 24(3):459–479. https://doi.org/10.1016/0034-4257(88)90019-3

Congalton R, Green K (2008) Assessing the accuracy of remotely sensed data, principles and practices, 2nd edn. CRC Press, Boca Raton, p 200

Duarte CM, Marbà N, Gacia E, Fourqurean JW, Beggins J, Barrón C, Apostolaki ET (2010) Seagrass community metabolism: assessing the carbon sink capacity of seagrass meadows. Glob Biogeochem CyCles 24(4):GB4032. https://doi.org/10.1029/2010GB003793

Hedley JD, Harborne AR, Mumby PJ (2005) Simple and robust removal of sun glint for mapping shallow-water benthos. Int J Remote Sens 26(10):2107–2112. https://doi.org/10.1080/01431160500034086

Hochberg EJ, Atkinson MJ (2003) Spectral reflectance of coral reef bottom-types worldwide and implications for coral reef remote sensing. Remote Sens Environ 85(2):159–173. https://doi.org/10.1016/S0034-4257(02)00201-8

Kennedy H, Beggins J, Duarte CM, Fourqurean JW, Holmer M, Marbà N, Middelburg JJ (2010) Seagrass sediments as a global carbon sink: Isotopic constraints. Glob Biogeochem Cycles 24(4):GB4026. https://doi.org/10.1029/2010GB003848

Krause-Jensen D, Duarte C (2016) Substantial role of macroalgae in marine carbon sequestration. Nat Geosci 9:737–742. https://doi.org/10.1038/ngeo2790

Lavery PS, Mateo MÁ, Serrano O, Rozaimi M (2013) Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PLoS ONE 8(9):e73748. https://doi.org/10.1371/journal.pone.0073748

Lyimo LD (2016) Carbon sequestration processes in tropical seagrass beds. Ph.D. Thesis, Stockholm University, p 49

Lyzenga D (1981) Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. Int J Remote Sens 2(1):71–82. https://doi.org/10.1080/01431168108948342

Mallombassi A, Mashoreng S, La Nafie YA (2020) The relationship between seagrass Thalassia hemprichii percentage cover and their biomass. Spermonde 6(1):7–10. https://doi.org/10.20956/jiks.v6i1.9922

McKenzie LJ, Finkbeiner MA, Kirkman H (2001) Methods for mapping seagrass distribution. In: Short FT, Coles RG (eds) Global seagrass research methods. Elsevier Science, pp 101–121. https://doi.org/10.1016/B978-044450891-1/50006-2

Pu R, Bell S, English D (2015) Developing hyperspectral vegetation indices for identifying seagrass species and cover classes. J Coast Res 31(3):595–615. https://doi.org/10.2112/JCOASTRES-D-12-00272.1
Roca G, Alcoverro T, Krause-Jensen D, Balsby TJS, van Katwijk MM, Marba N, Santos R, Arthur R, Mascaró O, Fernández-Torquemada Y, Pérez M (2016) Response of seagrass indicators to shifts in environmental stressors: a global review and management synthesis. Ecol Indic 63:310–323. https://doi.org/10.1016/j.ecolind.2015.12.007
Rohr ME, Bostrom C, Canal-Vergés P, Holmer M (2018) Blue carbon storage capacity of temperate Eeelgrass (*Zostera marina*) meadows. Glob Biogeochem Cy 32:1457–1475. https://doi.org/10.1029/2018GB005941
Waycott M, McMahon K, Mellors J, Calladine A, Kleine D (2004) A guide to tropical seagrass of the Indo-West Pacific. James Cook University, Townsville
Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT, William SL (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc Natl Acad Sci USA 106(30):12377–12381. https://doi.org/10.1073/pnas.0905620106
Zoffoli ML, Gernez P, Rosa P, Le Bris A, Brando VE, Barillé AL, Harin N, Peters S, Poser K, Spaias L, Peralta G (2020) Sentinel-2 remote sensing of Zostera noltei-dominated intertidal seagrass meadows. Remote Sens Environ 251:112020. https://doi.org/10.1016/j.rse.2020.112020

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---

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---

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