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Stock assessment of brown seaweeds (Phaeophyceae) along the Bitung-Bentena Coast, North Sulawesi Province, Indonesia for alginate product using satellite remote sensing

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Abstract

Indonesia needs at least 1,100 tons of alginate per year for various food and non-food industries with a value of about 420,000 US Dollars. These needs are met through imports from abroad. The raw materials for alginate, namely brown seaweed (Phaeophyceae) are very abundant in Indonesian coastal zones, but its stock level is not yet known. This study aims: to explore the biomass of brown seaweeds along the coastal areas of Bitung-Bentena, North Sulawesi Province by mapping their habitat, distribution and density using the effective and efficient tool of satellite remote sensing; and to compile preliminary results on the quality of alginate extracted from brown seaweeds. Result show that based on the isocluster analysis of Landsat-7 ETM+ and field sampling, we successfully classified 6 different habitats in the reef flats of Bitung-Bentena with map which had accuracy of 73.6%. The total area of brown seaweeds was approximately 127.1 ha. Meanwhile, from 53 field transects, there were 6 species of brown seaweed with an average density for all species of 690.4 grams/m². Thus, the biomass of brown seaweed was 2,133.5 tons wet weight, equal to 29.9 tons of alginate. This study proves that satellite remote sensing is an effective and efficient tool for such kind of works, and must be continued along the entire of Indonesian coastal zones. In this study, the preliminary results on extracting alginate from brown seaweed are also presented.

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1. Introduction

Indonesia is the largest archipelagic country in the world with more than 17,000 islands and 81,000 km of coastline, the second longest coastline after Canada, so there is no doubt that Indonesia has extensive coastal region. The coastal zones of Indonesia have three unique ecosystems, namely mangroves, seagrass and coral reefs. Each of these ecosystems has productivity that is higher than the productivity of a tropical rain forest [1]. Thus, those ecosystems are abundant with unexplored biodiversity and living resources that provide diverse goods and environmental services for the benefit of local communities.

One of those abundant resources is brown seaweed (Phaeophyceae) that is distributed on the reef flats. Some genus of phaeophyceae are: *Padina*, *Sargassum* and *Turbinaria*, which potentially produce alginates [2, 3, 4]. Alginate is an organic polymer family of polysaccharides that are composed of two monomer units β -D guluronic acid (G) and α -L acid mannuronat (M) or alternating both (GGMM) [5, 6]. Alginate in brown seaweed is commonly fused with sodium, potassium, calcium and magnesium which are not soluble in water [7, 8, 9]. Alginate was first discovered by a British chemist ECC Stanford, which was extracted from brown seaweed in the form of alginic acid, then patented in 1881 [10, 7, 9].

Alginate is an important substance for the food and beverages industry, medical/pharmaceuticals (cosmetics), as well as for the non-food Industry, such as for textiles, paints and toothpastes, due to its ability as a thickening or emulsifier [4, 11]. Such kind of industries in Indonesia requires about 1,100 tons of alginate per year with a value of US \$ 420,000 [12]. All of this alginate is imported from abroad (European countries, USA, China, Japan, and the Philippines). There is no factory that produces alginate in Indonesia, although in fact, the brown seaweed used as raw materials are very abundant here.

Although the raw material for alginate is abundant in wild, but the standing stock of the brown seaweeds is still not yet known. Furthermore, the brown seaweed grows and blooms at certain seasons only, with different times and places. Our limited previous study on the stock of brown seaweeds was done only in the west part of Indonesia, mainly in Java Island, and even in a very narrow areas such as in Pari Island (Jakarta), Baron Beach, Yogyakarta (Central Java), and in some wider brown algae/seaweeds beds (*Sargassum* spp) on the south coast of Pamengpeuk and Cipatujah (West Java) [13, 14]. Little is known about their stocks in the eastern part of Indonesia.

Therefore, accurate assessment of the biomass or standing stock of brown algae is very important for self-sufficing the national needs on alginate. Thus, this study aims: 1) to explore the standing stock of brown seaweeds along the coastal areas of Bitung-Bentena, North Sulawesi Province by mapping their habitat, distribution and density using the effective and efficient tool of satellite remote sensing, and 2) to compile preliminary results on the quality of alginate extracted from brown seaweeds.

2. Methods

2.1. Study sites and time

This study was conducted along the coastal areas between Bitung and Bentena (approximately 31 km), North Sulawesi Province. However, based on initial field survey, the reef flat where the brown seaweed was abundant was only in a restricted areas about 2.5 to 3.0 km long that lay 22.2 km from Bitung and 5.6 km from Bentena (Fig. 1). The width of the reef flat ranged from 100 – 200 m. The study was carried out in July and September 2012, which coincided with the season for the growth of brown algae. During December to February (west monsoon) the sea becomes rough and most of the brown algae are damaged by big waves.

2.2. Satellite data and analysis

In this study we used Landsat 7 Enhanced Thematic Mapper Plus (ETM+) satellite image. However, since May 31, 2003, the scan line corrector (SLC) failed, causing the scanning pattern to exhibit wedge-shaped scan-to-scan gaps. The ETM+ has continued to acquire data with the SLC powered off (SLC-off), leading to images that are missing approximately 22% of the normal scene area. To improve the utility of the SLC-off data, the U.S. Geological Survey (USGS) developed new products that use the data from multiple ETM+ scenes to provide complete ground coverage

[15, 16]. Here, we used two Landsat-7 ETM+ images (Path: 111 and Row: 59) acquired in February 7, 2012 as an anchor image and in October 18, 2011 as a fill gap image. The software named “Frame_and_Fill_Software” was used for processing those images, the new filled gap image then was used for further analysis (Fig. 2).

Isocluster analysis module on IDRISI Andes (ver. 15) software was used to produce an unsupervised work map by utilizing the new filled gap image of blue, green, red and near infrared bands. This work map was printed, laminated and then verified in the field using sea truth data of 2 transect lines (150-300 m) taken every 10 m perpendicularly and parallel to the coast line using 0.5 x 0.5 m frames. Additional habitat observations outside the transect lines were also carried out. All positions of transect were measured using a GPS. After the field work was completed, the working map was verified by actual field conditions, resulting a new thematic map containing 6 classes of the reef flat habitats in the study sites as well as information on the area of each habitat (A, ha).



Fig. 1. Map of study site.

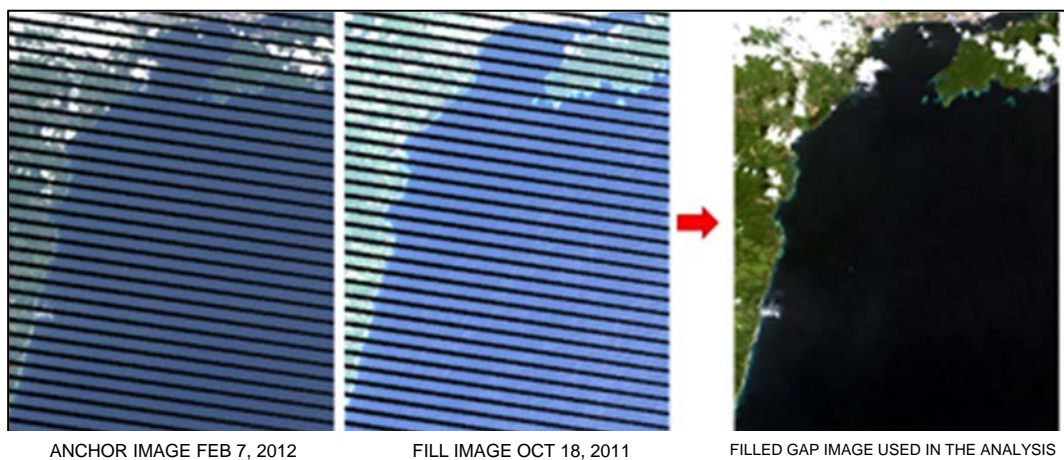


Fig. 2. Filled gap image of Landsat-7 ETM+ produced using anchor and fill images

2.3. Assessment of the stock of brown seaweeds

From the field sampling activities, all seaweeds (brown, red and green) inside each transect frame was collected and put in a plastic bag. On the beach, the brown seaweeds in the plastic bag were removed, rinsed in sea water and cleaned of sand and shells, then sorted according to their species, weighed, sun dried and packed for extracting their alginate in the laboratory. By this procedure, the density of each species of brown seaweed is known (D , gram/m²). Thus, the biomass or standing stock of brown seaweed (S , ton/ha) can be easily estimated by the equation: $S = A \times D$.

2.4. Extracting alginate

To extract alginate and do quality measurements, the packaged samples of brown seaweed were weighted, washed in freshwater and dried in the sun. Alginate extraction was done using the method of Chou and Chiang [17] and Draget, *et al.* [10]. Alginate yield percentage is calculated from the weight of alginate produced divided by the weight of dry raw materials before it is extracted, multiplied by one hundred. The viscosity was measured using a Brookfield viscometer LV type at a temperature of 25°C with a solution viscosity of 2% (w/v). Analysis of moisture and ash content was done at various accredited laboratories.

Observed Habitats



Transect, Taking Position using GPS, Collecting brown algae



Sorting, Weighing, Sun drying and Packing



Fig. 3. Field activity of collecting samples of brown seaweeds and verifying the working map.

3. Results and Discussion

3.1. In situ sampling and satellite mapping of brown seaweeds

Based on field sampling data of 53 transects (Table 1), we found at least 6 species of brown seaweeds, namely: *Sargassum crassifolium*, *S. polycystrum*, *Hormophysa* sp, *Turbinaria decurens*, *T. conoides*, and *Padina* sp. (Fig. 4). From these 6 species, the highest percentage of occurrence was *T. decurens* (50.9%) followed by *S. Crassifolium* (47.2%) and *S. polycystrum* (24.5%), while the other species were less than 10% with *T. conoides*, as the lowest occurrence (3.8%). Table 1 shows also the minimum, maximum, total density and the average density (D) per transect of each brown seaweed species. The highest average density per transect was for *T. decurens* (735.8 g/m²) followed by *S. Crassifolium* (408.8g/m²) and *S. polycystrum* (407.5 g/m²), while the other species were less than 100 g/m² with the lowest was *Padina* sp (3.9 g/m²).

Table 1. Stock assessment of brown seaweed from Bitung-Bentena coast. (Sc: *Sargassum crassifolium*; Sp: *S. polycystrum*; Hp: *Hormophysa* sp.; Td: *Turbinaria decurens*; Tc: *Turbinaria conoides*, and Pd: *Padina* sp).

Measured Parameter	Sc	Sp	Hp	Td	Tc	Pd	Total
No. of transects	-	-	-	-	-	-	53
Occurrences (%)	47.2	24.5	7.5	50.9	3.8	7.5	-
Minimum Density (g/m ²)	20	408	672	168	424	40	-
Maximum Density (g/m ²)	2,932	3,364	1,636	3,172	1,584	68	-
Total Density (g/m ²)	21,664	21,596	4,488	39,000	2,008	208	22,241
Average Density / transect (g/m ²)	408.8	407.5	84.7	735.8	37.9	3.9	-
Sargasum areas (ha) derived from filled gap Landsat-7 ETM+ image							127.1
Standing stock wet weight (tons)	519.5	517.9	107.6	935.3	48.2	5.0	2,133.5

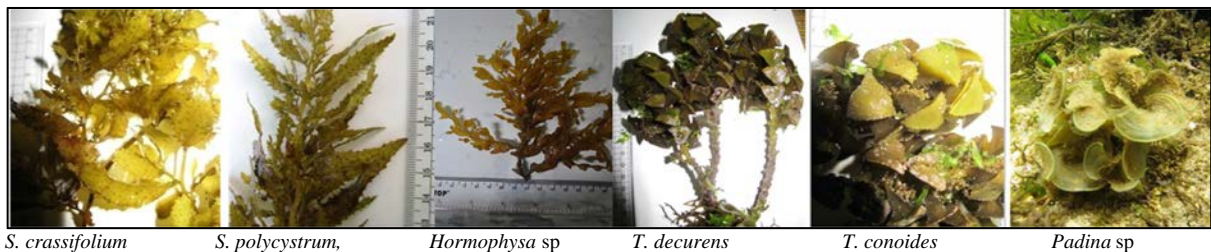


Fig. 4. Six species of brown seaweeds collected during the field sampling

Fig. 5 displays the thematic map of habitat in the reef flat along Bitung-Bentena coast produced using Landsat-7 ETM+ filled gap image (Fig. 2) based on isocluster analysis and after verification by field sampling (ground truth). This map contained 6 habitats, namely sea (in various depth), rocks, rock with brown seaweed attached, seagrass beds mix with brown seaweeds, seagrass-sand and land. However, the isocluster analysis can differentiate only 2 habitats of brown seaweed (rock-brown seaweeds that are mostly dominated by *Turbinaria* spp, and seagrass-brown seaweeds which dominated by *Sargassum* spp, *Hormophysa* sp and *Padina* sp). From 53 transects, 39 transects were laid in the habitats of rock-brown seaweeds and seagrass-brown seaweeds, while the rest of 14 transects were laid in the other habitats (seagrass-sand, and rocks). Thus, the accuracy of thematic map based on isocluster analysis was high enough (73.6%). The total pixels or the area (A) of rock-brown seaweeds and seagrass-brown seaweeds was 1,412 pixels or equal to 127.1 ha.

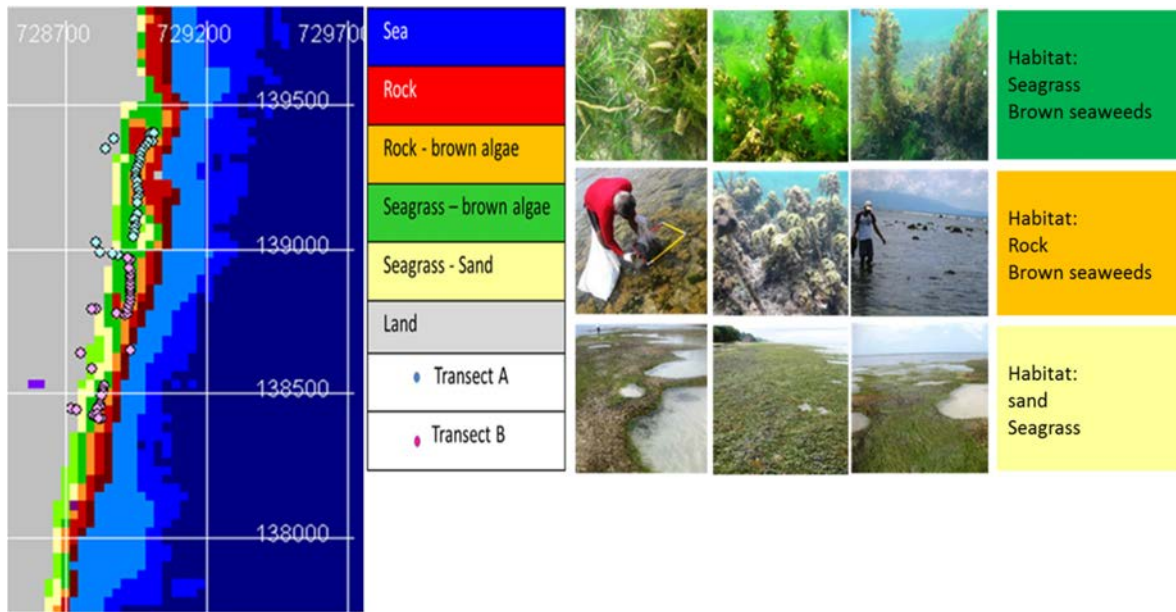


Fig. 5. Thematic map of reef flat habitat in Bitung-Bentena coast derived from Landsat-7 ETM+ filled gap image based on isocluster analysis and field works.

Similar study of *Sargassum* mapping using 7 multi-temporal Landsat-7 ETM+ before the scan line corrector failed (SLC-on) at different season and in different years between November 1999 and October 2002 was conducted by Mattio *et al.* [18] in the South West lagoon of New Caledonia (South Pacific). Their results showed that from 7 species of brown seaweed found in their study site, the Landsat-7 ETM could not differentiate the *Sargassum* at the species level. However, Landsat Images were able to recognize 11 *Sargassum* beds in the lagoon with a specific dominated species of *Sargassum* in each bed.

Noiraksar *et al.* [19] used the Japanese satellite ALOS AVNIR-2 (Advanced Visible Near Infrared) with a spatial resolution of 10 m by 10 m for mapping the brown seaweed beds, which dominated by *S. aquifolium*, *S. oligocystum* and small portion of *T. conoides* in the coastal area of the natural marine park reserve of Sattahip, Chon Buri Province, southeast of Bangkok, Thailand. Results showed that the mapping accuracy based on minimum distance method and maximum likelihood method applied to data from the red, green, and blue bands were 66.9% and 68.8%, respectively, but the accuracy increased to 75.0% using the minimum distance method applied to the depth invariant indices (DII) derived from the green and blue bands.

In the coastal zone of Rottnest Island, Western Australia, Hoang *et al.* [20] mapped the *Sargassum* spp. using high-spatial resolution 2 m by 2 m of WorldView-2 (WV-2) satellite data and by applying DII and then used four classifiers: the Minimum distance, Mahalanobis distance, K-means, and Parallelepiped classifiers. Results showed that the methods they used were able to classify 6 classes of habitats, Sandy substrate, Limestone substrate, Vegetated canopy of brown macro algae dominated by *Sargassum* and *Ecklonia* spp., Red macro algae (*Gracilaria* sp.) and coralline algae, Sea-grass and Algae turf. The accuracy of each classifier was, 98.3%, 98.3%, 42.5% and 93.5%, respectively. The K-means classification method gave the lowest accuracy.

Hennig *et al.* [21] monitored the intertidal zone which is covered by a variety of brown, red, and green seaweeds in the Helgoland Island of German North Sea using hyperspectral airborne remote sensing with 115 spectral bands from 430 nm in the visible light to 860 nm in the near infrared and with a spatial pixel resolution of 0.84 m. Their results indicated that the spectral classification corresponded well to the main vegetation types and discriminated the structures dominated by either red, green and brown seaweeds, sparsely vegetated areas of faunal habitats (mussel beds) as well as classes of water and sandy areas. However, differentiation of individual species had limited success and some mixed vegetation types were not confidentially classified. The overall accuracy was 75.9%.

Although in general, all the sensors used that are reported here were unable to differentiate well the species of brown seaweed with the mapping accuracies only around 70-80% [this study, 19, 20, 21], except [20], but overall, all the sensors could differentiate between the habitats dominated by brown seaweeds and the structures of other benthic habitats.

3.2. Assessment of brown seaweeds standing stocks

Based on the total areas of brown seaweeds habitats (A) derived from Landsat-7 ETM+ filled gap image and the average density of each species of brown seaweeds per transect from field sampling (D; Table 1), the standing stock of brown seaweeds (S) can be easily calculated with the equation of $S = A \times D$. Thus, the total standing stock of 6 species of brown seaweed along the coast of Bitung-Bentena was 2,133.5 tons of wet weight (WW). Three species of brown seaweed, *T. decurens*, *S. crassifolium*; and *S. Polycystrum* were the major contributors to the entire stocks, with each species having a weight of 935.3, 519.5 and 517.9 tons, respectively (see Table 1). The average ratio between wet and dry weight of brown seaweed was 10:1.4. Therefore, the dry weight (DW) biomass of the brown seaweeds in this area was about 298.7 tons DW.

As a comparison, in the lagoon of New Caledonia, the biomass of *S. Spinuligerum* reached its peak at 686 g DW. m⁻² during the warmer period (spring to summer), but the lowest during cool period (autumn to winter), 6 g DW. m⁻². *Hormophysa cuneiformis* also have the highest in biomass during winter (452 g DW. m⁻²), but the lowest in the same season, at the other areas of the lagoon (28 g DW. m⁻²) [18]. In the coastal areas of Sattahip, Chon Buri Province, Thailand, the biomass ranges of *S. aquifolium* and *S. oligocystum* were from 7.7 to 92.8 g DW. m⁻² and from 44.1 to 88.0 g DW. m⁻², respectively [19]. From this comparison, it seems that the brown algae biomass in the lagoon of New Caledonia was higher than in the coast of Bitung-Bentena. However, the biomass in our study sites was slightly higher than in the Sattahip, Thailand, although the species of brown seaweeds were different.

In our study, we found that the ratio between dry weight (DW) of brown seaweeds to alginate was approximately 10:1. Therefore, the total biomass for alginate from Bitung-Bentena coast can be estimated about 29.9 tons. Based on Geospatial Information Agency (BIG), the total coral reef areas in all districts within the North Sulawesi Province where brown seaweeds can grow well is 45,895 ha [22]. If brown seaweeds assume grow well only in a quarter (25%) of those coral reef areas, while the estimated alginate produced from 127. 1 ha (areas of Bitung-Bentena coast) was 29.9 ton, then the alginate production from the North Sulawesi Province can be estimated at least as 2,699.2 tons.

According to Anggadiredja et al. [12] Indonesia imported 1,100 tons of alginate per year for the food and non-food industry, while estimated in 2017 Indonesia needs about 2,800 tons per year [23]. Thus, Table 2 shows that the North Sulawesi Province alone would nearly be able to meet the Indonesian needs for alginate in 2017. There are still many provinces with huge of coral reef areas, such as Maluku (372,408 ha), South Sulawesi (224,172 ha), South East Sulawesi (206,052 ha), Central Sulawesi (178,296 ha), West Papua (130,081 ha), East Nusa Tenggara (104,320 ha), Riau Islands (93,316 ha) and many other provinces having wider coral reef areas than North Sulawesi Province [22].

3.3. Extracting alginate

From the 6 species of brown seaweeds collected in the field (Fig. 4), alginate was extracted only from the 3 species which had the highest stocks. The preliminary result of alginate extraction is shown in Table 3. The highest viscosity of alginate was obtained from *S. Polycystrum*. According to the Food Chemical Codex (FCC), the ranges of ash and moisture contents of alginate should be 18–27%, and less than 15% [13], while pH and viscosity should be in the ranges of 3.5-10 and 10-5000 cPs, respectively [20]. Based on the criteria [13, 24], the alginate produced from the Bitung-Tentena coast can be classified as good quality, except that the colour should be light brown or whitish for alginate used in food industry. Nevertheless, the alginate products obtained from this study can at least be used for supporting the non-food industry.

Table 2. The coral reef areas in the 7 districts of North Sulawesi Province with estimation of alginate potency [18].

Districts	Reef areas (ha)	Alginat Products (ton)
1 Bolaangmongodow	6,642.2	390.6
2 Manado City	1,375.9	80.9
3 Minahasa	2,247.3	132.2
4 South Mnahasa	6,872.8	404.2
5 North Minahasa	12,769.8	751.0
6 Sanghite Islands	13,171.0	774.6
7 Talaud Islands	2,815.9	165.6
Total →	45,894.9	2,699.2

Table 3. Quality of alginate product from different species of brown seaweeds collected from Bitung-Bentena Coast.

No.	Species of raw material	Moisture content (%)	Ash content (%)	pH	Viscosity (cPs)	Colour
1.	<i>Sargassum polycestrum</i>	12.87	23.24	9.09	3,222	dark brown
2.	<i>Sargassum crassifolium</i>	12.95	27.07	9.69	1,051	dark brown
3.	<i>Turbinaria decurens.</i>	12.88	22.99	9.30	760	dark brown

4. Concluding Remarks

This study demonstrates that remote sensing technology using various sensors is very effective and efficient for mapping and assessing the brown seaweeds stocks and for estimating the stock of alginates that can be produced from one coastal area. Despite most of the sensors could not separate the brown algae at species level, but they could clearly distinguish between habitats covered by brown seaweeds and by other habitats.

Although Landsat-7 ETM+ has continued to acquire data in the SLC powered off (SLC-off) condition, these images are still useful for coastal observation by applying fill gap image techniques such as shown in this study. Furthermore, with the availability of the Landsat-8 OLI (Operational Land Imager) which is much improved in its radiometric resolution (16 bits versus 8 bits in Landsat TM/ETM+) and/or if noncommercial satellite optical images with higher spatial resolutions are available (such as WV-2), then it will be possible to map the brown seaweed beds and estimate biomass with a greater degree of accuracy, especially when coupled with the depth invariant indices (DII) method as shown by the work of [20].

To be self-sufficient in supplying the national requirement for alginates, the continuation of mapping brown seaweeds in the entire coastal areas of Indonesia is essential. In addition, we can a plan to establish several alginate factories that, so far, have not existed in Indonesia.

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