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CARBON POTENTIAL OF MACROALGAE IN THE COAST OF KAUR REGENCY, BENGKULU PROVINCE

Potensi Karbon Makroalga di Pesisir Kabupaten Kaur, Provinsi Bengkulu

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ABSTRACT

Macroalgae as one of the productive tropical coastal ecosystems have the potential as primary producers in fixing marine organic carbon, as carbon absorbers, and carbon biosequesters. Kaur Regency has complete macroalgae biodiversity including the Chlorophyta, Rhodophyta and Phaeophyta groups estimated to have potential blue carbon reserves. Research related to macroalgae in Kaur Regency is still limited to the distribution of macroalgae biodiversity and density, so, it is necessary to study the above ground carbon stock of macroalgae as a baseline for coastal blue carbon management in the future. This study aims to examine the carbon content of macroalgae species found in the coastal of Kaur Regency. Field surveys were conducted to collect shoot density and harvesting data of macroalgae species. Macroalgae data were collected using the quadrat transect method measuring 1 x 1 m. Macroalgae samples were tested in the laboratory to calculate the bound carbon value of macroalgae types. The result showed that macroalgae lived on the coast of Kaur Regency have carbon potential vary among the species. Carbon potential is dominated by *Padina minor* with 585.26 gC/m^2, while *Tricleocarpa fragilis* has the lowest carbon value with 0.86 gC/m^2.

Keywords: Carbon, Kaur, Macroalgae, *Padina minor*

ABSTRAK

Makroalga sebagai salah satu ekosistem pesisir tropis yang produktif memiliki potensi sebagai produsen primer dalam mengikat karbon organik laut, sebagai penyerap karbon, dan biosekuester karbon. Kabupaten Kaur memiliki keanekaragaman hayati makroalga yang lengkap meliputi kelompok Chlorophyta, Rhodophyta dan Ocrhophyta yang diperkirakan memiliki potensi cadangan karbon biru. Penelitian terkait makroalga di Kabupaten Kaur masih terbatas pada distribusi keanekaragaman hayati dan kepadatan makroalga, sehingga, perlu dilakukan kajian stok karbon di atas permukaan tanah makroalga sebagai dasar pengelolaan karbon biru pesisir di masa mendatang. Kajian ini bertujuan untuk mengkaji kandungan karbon spesies makroalga yang terdapat di pesisir Kabupaten Kaur. Survei lapangan dilakukan untuk mengumpulkan data kepadatan tunas dan pemanenan spesies makroalga. Data makroalga dikumpulkan menggunakan metode transek kuadrat berukuran 1 x 1 m. Sampel makroalga diuji di laboratorium untuk menghitung nilai karbon terikat jenis makroalga. Hasil penelitian menunjukkan bahwa makroalga yang hidup di pesisir Kabupaten Kaur memiliki potensi karbon yang bervariasi antar spesies. Potensi karbon didomonasi oleh jenis *Padina minor* sebesar 585,26 gC/m^2, sedangkan terendah adalah jenis *Tricleocarpa fragilis* sebesar 0,86 gC/m^2.

Kata Kunci: Makroalga, Karbon, Kaur, *Padina minor*

INTRODUCTION

Macroalgae are marine algae that belong to the group of plants that live in the intertidal zone. Macroalgae have chlorophyll that plays an important role in the process of photosynthesis. Based on the absorption of sunlight, macroalgae are distinguished into three characteristics of pigment content, namely green, brown, and red algae that function in the process of photosynthesis (Siddiqui & Zaidi, 2016). Macroalgae play an important role in marine ecosystems, namely as one of the active primary producers that absorb carbon dioxide (CO_2) and produce oxygen (O_2) thereby reducing the impact of global climate warming and the greenhouse effect (Duarte et al., 2017). Macroalgae contribute up to 50% of carbon fixation on earth and cover as much as 71% of carbon storage in marine sediments. As primary producers in the sea, macroalgae have the potential for carbon absorption and storage (Pribadi & Ihsan, 2019). The existence of primary producers as coastal carbon biosequestrators capable of trapping and burying carbon in sediments (Laffoley & Grimsditch, 2009) over long periods (Fourqurean et al., 2019) warrants exploration of their potential as productive blue carbon sources (Macreadie et al., 2014).

Coastal plant ecosystems store carbon much longer than terrestrial plants because they can trap carbon in sediments and organic carbon soil associations during tidal processes. The carbon stored in macroalgae consists of aboveground carbon (AGC), a carbon reserve that can be stored for relatively long periods (Fourqurean et al., 2019). Despite their limited environmental conditions, macroalgae have very high potential as carbon stores.

Although macroalgae possess active blue carbon potential, they can be degraded due to the impacts of anthropogenic coastal development, cultivation activities, overharvesting, and climate change (Prathep et al., 2010). The presence of macroalgae serves as an indicator of sensitivity to environmental changes caused by human activities and climate change (da Silva et al., 2017). Therefore, monitoring the distribution, diversity, density, and carbon potential of macroalgae is necessary as a basis for sustainable management of habitat distribution and the potential for macroalgae carbon sinks.

Research on macroalgae along the coast of Kaur Regency is still limited to macroalgae biodiversity, which indicates that the macroalgae found in Kaur Regency have significant potential, including Chlorophyta, Rhodophyta, and Phaeophyta species with an average density of 4,231.11 g m^{-2} (Herliany et al., 2014).

Seaweed, along with other aquatic plants, plays a crucial role in climate change mitigation (Macreadie et al., 2021). Seaweed is known to absorb and store organic carbon for long periods, thus acting as blue carbon (Nelleman et al., 2009; Duarte et al., 2013). Estimating carbon sequestration in seaweed is more difficult than in seagrass or mangroves. Unlike mangroves and seagrasses, which store carbon in the underlying sediment, macroalgal communities dominate the rocky seafloor, and their contribution to carbon sequestration occurs largely through export to carbon pools outside their habitats and continental shelves, and in the deep ocean, making them difficult to measure (Krause-Jensen & Duarte, 2016; Pedersen et al., 2020). Consequently, data and information on carbon sequestration in macroalgae are very limited. Given the important role of macroalgae as a coastal carbon biosequestrator, research on the carbon potential of macroalgae in the coastal areas of Kaur Regency is necessary to generate information for estimating macroalgal carbon reserves.

RESEARCH METHODS

Field surveys were conducted in September 2024 at several sampling locations: Batu Lungun, Tebing Rambutan, and Laguna (Figure 1). The sampling transects were perpendicular from the shoreline to the shoreline at each macroalgae variety in 1 x 1 m quadrat plots placed above the macroalgae cover. Water quality parameters such as seawater temperature, pH, dissolved O_2 levels, and salinity were measured by taking water samples for analysis at the Fisheries Laboratory, Marine Science Study Program, University of Bengkulu.

A second field survey was conducted to collect data on macroalgae species. Macroalgae thallus harvesting was carried out to measure macroalgal carbon values. The harvested macroalgae samples were then cleaned or washed with fresh water to remove epiphytes and debris attached to the samples. They were then analyzed at the Fisheries Laboratory, Marine Science Study Program, University of Bengkulu.

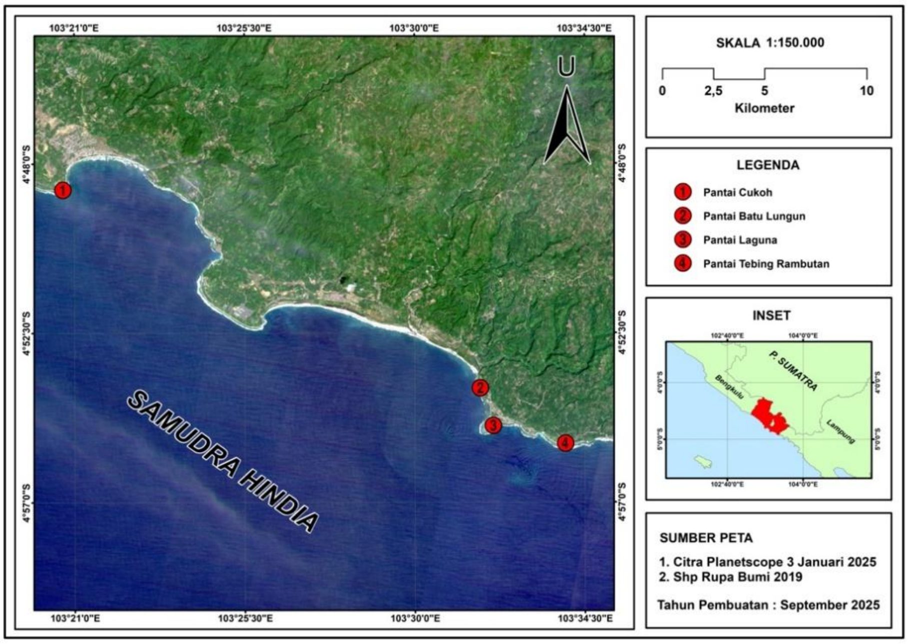

Figure 1. Field Survey Locations at Batu Lungun, Tebing Rambutan, and Laguna

Carbon content was analyzed using the Gravimetric method (Sahir et al., 2023), namely:

a. Water Content Measurement

Macroalgae samples were weighed, cleaned, and oven-heated at 105°C for 3 hours. The samples were then cooled in an exciter and weighed. The moisture content was calculated using the formula:

$$\text{Water Content} = a - b / a \times 100\%$$

Where:

a = sample weight before heating (g)

b = weight after drying (g).

b. Volatile Content Measurement

Macroalgae samples, heated at 105°C, were placed in porcelain bowls and tightly sealed. The samples were placed in an oven at 900°C for 6 minutes. Volatile content is calculated using the formula:

$$\text{Volatile content} = a - b / a \times 100\%$$

Where:
a = dry weight of the sample at 105ºC
b = dry weight at 900ºC

c. Macroalgae Biomass Measurement

Biomass is the weight of the sample calculated after heating in an oven for 2-4 days at 80-90ºC. Biomass is calculated using the formula:

$$\text{Biomass (\%)} = a / b \times 100\%$$

Where:
a = wet weight of the sample (g),
b = weight of the sample after heating at 90ºC (g)

d. Ash Content Testing

The sample is heated at 550ºC until ashing is complete. The sample is cooled in an exciter and weighed. Ash content is determined using the formula:

$$\text{Ash content} = b/a \times 100\%$$

Where:
a = sample weight (g)
b = ash weight (g)

e. Bound carbon testing

$$\text{Carbon content} = 100\% - \text{water content} - \text{volatile matter content} - \text{ash content}$$

The carbon content of each species was calculated based on the macroalgae thallus for each dominant species within a 1m x 1m quadrat transect, where the carbon value was obtained in units of gC/m^2.

RESULT

A total of 12 macroalgae species were found along the coast of Kaur Regency, including 10 species at Batu Lungun Beach and 9 species at Laguna Beach and Tebing Rambutan. Three species of Chlorophyta were found: *Ulva lactuca, Chaetomorpha crassa*, and *Boergesenia forbesii*. The Ochrophyta group of the Kaur coast consisted of *Padina minor* and *Sargassum polycystum*. The Rhodophyta group dominated the macroalgae cover on the Kaur coast, with 7 species: *Tricleocarpa fragilis, Chondracantus acicularis, Acanthophora spicifera, Gelidiela aceros, Palisada intermedia, Glacilaria edulis*, and *Endocladia muricata*. In general, the macroalgal substrate type ranged from rocky sand to sandy coral.

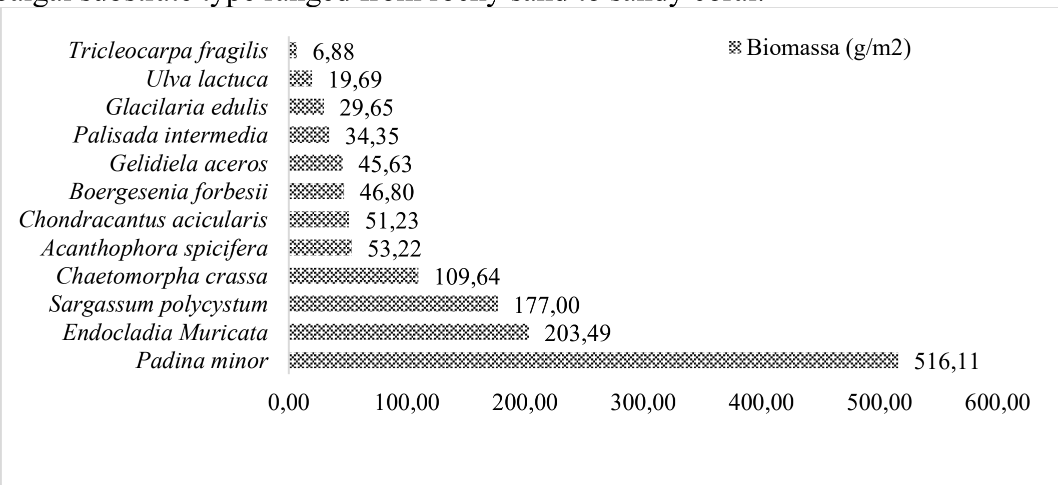

Figure 2. Average Biomass Content of Each Macroalgae Species Found on the Coast of Kaur Regency

The average biomass content of each macroalgae species was dominated by *Padina minor* (516.11 g/m^2), *Endocladia muricata* (203.49 g/m^2), *Sargassum polycystum* (177 g/m^2), and *Chaetomorpha crassa* (109.64 g/m^2). Eight other macroalgae species had lower biomass contents: *Acanthophora spicifera* (53.22 g/m^2), *Chondracantus acicularis* (51.23 g/m^2), *Boergesenia forbessi* (46.8 g/m^2), *Gelidiela aceros* (45.63 g/m^2), *Palisada intermedi* (34.35 g/m^2), *Glacilaria edulis* (29.65 g/m^2), *Ulva lactuca* (19.69 g/m^2), and *Tricleocarpa fragilis* (100 g/m^2) (Figure 2).

Table 1. Biomass Content of Each Macroalgae Species on the Coast of Kaur Regency

Species	**Biomass (g/m^2)**		
	Batu Lungun	**Laguna**	**Tebing Rambutan**
Ulva lactuca	32.07	0.26	26.73
Padina minor	451.94	234.04	862.37
Chaetomorpha crassa	98.50	150.73	79.70
Boergesenia forbesii	26.58	37.88	75.95
Tricleocarpa fragilis	20.63	0.00	0.00
Chondracantus acicularis	133.72	19.95	0.00
Sargassum polycystum	23.30	0.00	507.70
Acanthophora spicifera	41.40	116.31	1.95
Gelidiela aceros	106.98	29.90	0.00
Palisada intermedia	80.11	0.99	21.96
Glacilaria edulis	0.00	18.11	70.82
Endocladia muricata	0.00	0.00	610.47
Average	**84.60**	**50.68**	**188.14**

The biomass content of each macroalgae species showed different results at each observation location. The total carbon content of macroalgae in Tebing Rambutan reached 188.14 g/m^2, while in Batu Lungun it only reached 84.6 g/m^2 and Laguna reached 50.68 g/m^2. The *Padina minor* species contributed the highest biomass in Batu Lungun which reached 451.94 g/m^2, while *Tricleocarpa fragilis* had the lowest biomass reaching 20.63 g/m^2. The *Glacilaria edulis* and *Endocladia muricata* species were not found in Batu Lungun. The biomass in Laguna was dominated by the *Padina minor* species which reached 234.04 g/m^2, while the lowest biomass came from the *Glacilaria edulis* species at 18.11 g/m^2. *Endocladia muricata* was not found in Laguna. The biomass content at Rambutan Cliff is dominated by *Padina minor, Sargassum polycystum*, and *Endocladia muricata*, reaching 862.37 g/m^2, 507.70 g/m^2, and 610.47 g/m^2, respectively. *Acanthophora spicifera* has the smallest biomass content, reaching only 1.95 g/m^2. *Tricleocarpa fragilis, Chondracantus acicularis*, and *Gelidiela aceros* were not found at Rambutan Cliff (Table 1).

The average carbon content of each macroalgae species was dominated by the *Padina minor* group at 585.26 gC/m^2, while the lowest carbon potential came from *Tricleocarpa fragilis*, reaching 0.86 gC/m^2. Other potential carbon sources of macroalgae found were *Chaetomorpha crassa* (133.48 gC/m^2), *Boergesenia forbesii* (120.26 gC/m^2), *Acanthophora spicifera* (96.86 gC/m^2), *Sargassum polycystum* (67.09 gC/m^2), *Gelidiela aceros* (61.65 gC/m^2), *Chondracantus acicularis* (53.29 gC/m^2), *Palisada intermedia* (42.07 gC/m^2), *Glacilaria edulis* (34.51 gC/m^2), *Ulva lactuca* (31.92 gC/m^2), and *Endocladia muricata* (26.33 gC/m^2) (Figure 3).

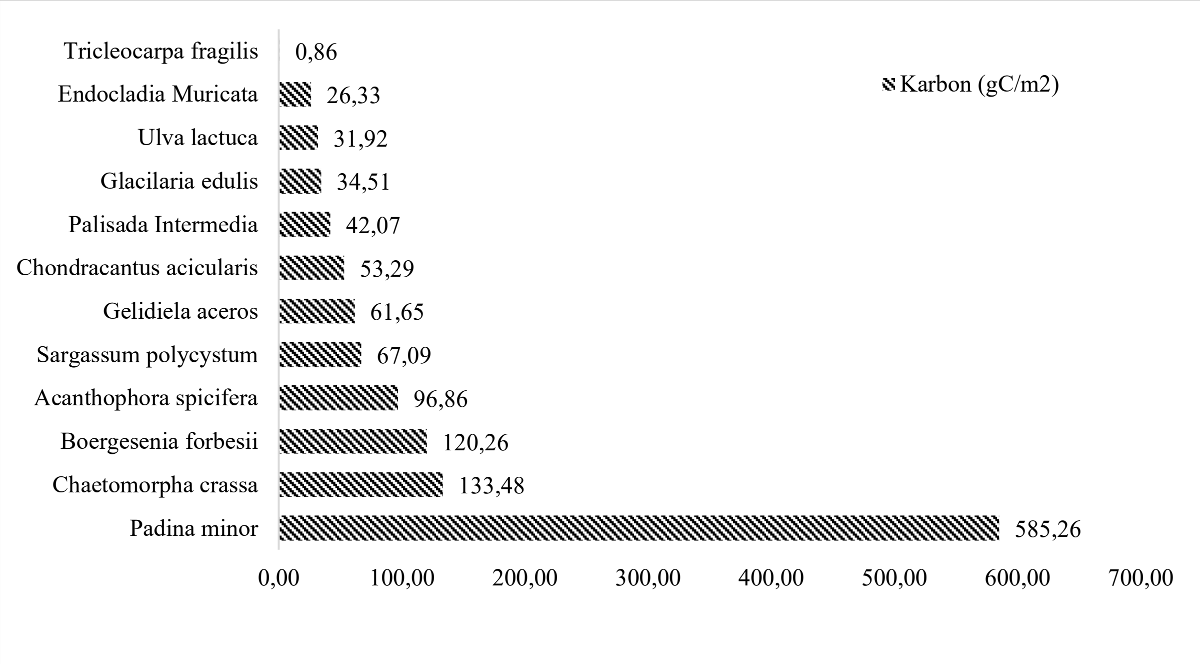

Figure 3. Average Carbon Content of Each Macroalgae Species Found on the Coast of Kaur Regency

The average carbon content of each macroalgae species was dominated by Tebing Rambutan, reaching 98.18 gC/m^2. The lowest carbon content was found in Batu Lungun and Laguna, reaching 56.66 gC/m^2 and 54.09 gC/m^2, respectively. The highest carbon content in Batu Lungun came from the *Padina minor* species, reaching 199.96 gC/m^2, while the lowest was found in the *Tricleocarpa fragilis* group, at 1.71 gC/m^2. The *Padina minor* group also dominated the carbon content in Laguna, reaching 220.50 gC/m^2, while *Ulva lactuca* had the lowest carbon content, at 0.91 gC/m^2. The carbon potential at Rambutan Cliff is also dominated by the *Padina minor* group, at 750.07 gC/m^2, while the lowest is from *Acanthophora spicifera*, at 2.38 gC/m^2 (Table 2).

Table 2. Carbon Stock Content of Each Macroalgae Species Found on the Coast of Kaur Regency

Species	**Carbon (gC/m^2)**		
	Batu Lungun	**Laguna**	**Tebing Rambutan**
Ulva lactuca	24.68	0.91	38.24
Padina minor	199.96	220.50	750.07
Chaetomorpha crassa	93.06	114.63	59.27
Boergesenia forbesii	75.80	107.21	57.51
Tricleocarpa fragilis	1.71	0.00	0.00
Chondracantus acicularis	93.75	12.83	0.00
Sargassum polycystum	11.13	0.00	123.05
Acanthophora spicifera	51.51	139.83	2.38
Gelidiela aceros	95.26	28.04	0.00
Palisada intermedia	33.12	0.97	84.13
Glacilaria edulis	0.00	24.13	44.89
Endocladia muricata	0.00	0.00	52.67
Average	**56.66**	**54.09**	**98.18**

DISCUSSION

The total average macroalgae biomass content on the coast of Kaur Regency was 323.42 g/m^2, dominated by the biomass of *Padina minor* (516.11 g/m^2), *Endocladia muricata* (203.49 g/m^2), and *Sargassum polycystum* (177 g/m^2). The smallest average biomass content came from the *Tricleocarpa fragilis* species (6.88 g/m^2) (Figure 2). The biomass of the Padina genus is relatively large compared to other macroalgae because this species is found in quite large quantities. Macroalgae biomass is influenced by the size and morphology of the macroalgae; the larger and thicker a species is, the higher its biomass content (Handayani, 2017; Silaban et al., 2024).

Tebing Rambutan Beach has the highest potential macroalgae biomass (188.14 g/m^2), while Laguna Beach has the lowest, at only 50.68 g/m^2 (Table 1). Kaur coastal waters have a sparse to moderate biomass, with Tebing Rambutan Beach categorized as moderate, while Batu Lungun and Laguna Beaches are categorized as sparse. Batu Lungun, Laguna, and Tebing Rambutan beaches have sandy to sandy coral substrates that are abundant with macroalgae. In addition to the biophysical factors of each species, macroalgae biomass is also influenced by external factors such as substrate type, water conditions, and season (Arfah & Patty, 2016).

The carbon content of macroalgae in Kaur Regency varies depending on the location and species studied, ranging from 0.86 to 585.26 gC/m^2. The highest carbon content is found in *Padina minor*, and the lowest in *Tricleocarpa fragilis* (Figure 3). The Padina genus is reported to have a carbon storage potential of 52.79 tons C/ha in Sumbawa, West Nusa Tenggara (Erlania et al., 2015). Variation in macroalgae carbon content is influenced by several factors, such as macroalgae type, morphological structure, climate/season, and coastal area characteristics (Mitra et al., 2014).

The average macroalgal carbon content in the Kaur Regency coast is 208.93 g C/m^2. Tebing Rambutan Beach has the highest macroalgal carbon storage, at 98.18 g C/m^2, while Laguna Beach only has a carbon storage of 54.09 g C/m^2 (Table 2). *Padina* sp. has great potential as a blue carbon source, having the highest carbon storage of approximately 52.79 tons C/ha in the waters of Labuhanbua, Sumbawa Regency (Erlania et al., 2015).

Red and brown seaweeds generally have a higher carbon content than green seaweeds (Erlania et al., 2015; Pribadi & Ihsan, 2019). According to Erlania et al. (2015), red and brown seaweeds have additional pigments in the form of phycoerythrin and phycocyanin and carotenoids which play an important role in absorbing light for photosynthesis, so that these two types of seaweed can still carry out photosynthesis in conditions with low light intensity and deeper waters. Based on research results, in general, brown seaweed has a higher carbon content than other types.

Morphology also influences the carbon content of macroalgae. In general, calcareous macroalgae have a lower carbon content than non-calcareous ones. Erlania et al. (2015) reported that calcareous species such as Halimeda, Actinotria, and Jania have a carbon content of 3.56–4.53%, lower than Gracilaria and Laminaria (35.02% and 36%, respectively) (Sondak & Chung, 2015). Calcareous macroalgae use their carbon reserves to form calcareous structures beneficial to the surrounding ecosystem, resulting in low carbon content in their thallus.

Geographic variations influence water conditions, which in turn impact the carbon content of macroalgae. Water depth, turbidity, and current movement are parameters that influence the carbon content of marine plants, including seaweed (Lavery et al., 2013; Ricart et al., 2020; Veenstra et al., 2021). These three parameters will affect the ability of the seaweed thallus to absorb carbon from the environment which has an impact on its carbon content. In addition, aquatic nutrients also play an important role in seaweed carbon absorption. Hurd et al. (2014) stated that water temperature and nutrients can affect the absorption and storage of macroalgal carbon. Pribadi & Ihsan (2019) added that the lack of inorganic carbon ions, mineral ions and light will inhibit macroalgal metabolism, especially in carbon absorption. The carbon stored in macroalgae is aboveground carbon and contributes as a carbon donor in the surrounding habitat because macroalgae live on rocky substrates which reduce the potential for long-term carbon storage in macroalgal habitats. Macroalgae have the potential to contribute to global blue carbon storage as a carbon donor (Hill et al., 2015).

CONCLUSION

Twelve species of macroalgae were found on the coast of Kaur Regency, including *Ulva lactuca, Padina minor, Boergesenia forbesii, Chaetomorpha crassa, Tricleocarpa fragilis, Sargassum polycystum, Chondracantus acicularis, Acanthophora spicifera, Gelidiela aceros, Palisada intermedia, Glacilaria edulis*, and *Endocladia muricata*. Carbon content varied between macroalgae species, with the highest carbon content being found in *Padina minor* at 585.26 gC/m^2, while the lowest was found in *Tricleocarpa fragilis* at 0.86 gC/m^2.

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