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The Estimation of Environmental Carrying Capacity and Economic Value of Seaweed Cultivation in Kemojan Island

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Abstract: *Eucheuma cottonni* cultivation has been a major source of income among residents of Kemojan Island. Expansion of seaweed cultivation area in Kemojan Island waters needs to be anticipated by analyzing the carrying capacity of the aquatic environment. Studies on the environmental carrying capacity of seaweed (*E. cottonni*) cultivation on Kemojan Island has never been conducted. This study aims to estimate the carrying capacity of the aquatic environment on Kemojan Island for seaweed cultivation. We have combined BOD_5, tropic saprobic index (TSI), and regression to estimate the carrying capacity of the coastal environment for seaweed cultivation. There were 5 observation stations in this study. The measurement resulted in TSI values that ranged between 2.43 to 7.43 (slightly polluted to unpolluted categories) and BOD_5 values between 2.6 to 5.4 ppm (below the sea waters pollution threshold). The total estimated area capacity that can be developed for E. *cottonni* cultivation was approximately 86.2 ha (sea waters) with a potential production of 7,392 tons (wet weight) per year and economic value reaching IDR 11.09 billion.

Keywords: BOD_5, *Eucheuma cottonni*, tropic saprobic indexes, Kemojan island.

克莫詹岛海藻养殖环境承载力及经济价值估算

摘要：杜鹃花种植一直是 克莫扬 岛居民的主要收入来源。需要通过分析水生环境的承载能力来预测科莫扬岛水域海藻种植面积的扩大。从未对克莫让岛海藻（杜鹃花）种植的环境承载能力进行研究。本研究旨在估计克莫让岛水生环境对海藻种植的承载能力。我们结合 生物需氧量 $_5$、热带腐烂指数和回归来估计沿海环境对海藻种植的承载能力。本次研究共设 5 个观测站。测量得出的 热带腐烂指数 值介于 2.43 至 7.43 之间（轻度污染至未污染类别），生物需氧量 $_5$ 值介于 2.6 至 5.4 百万分之几 之间（低于海水污染阈值）。估计可用于种植 杜鹃花的总面积约为 86.2 公顷（海水），潜在产量为每年 7,392 吨（湿重），经济价值达到 110.9 亿印尼盾。

关键词：生物需氧量 $_5$, 杜鹃花, 热带腐生菌指数, 克莫扬 岛。

1. Introduction

Kemojan Island is a part of the Karimunjawa Islands. The Karimunjawa Islands is a protected marine area in Indonesia (111,625 ha). It is also a popular marine tourism destination for domestic and international tourists [1-3]. The Indonesian government has regulated the zonation of waters in Karimunjawa Islands; core zone, marine protection zone, marine tourism zone, traditional capture fisheries zone, and marine cultivation zone [2]. The community's welfare should be considered to support the conservation program.

Seaweed cultivation has developed as one of the main occupations among the local community in Kemojan Island. Wijayanto et al. [4] proved that seaweed farmers could fulfill their family needs by cultivating seaweed using at least 19 rope units with an average rope length of 129 m. Seaweed cultivation is considered low-risk farming with a guaranteed yield, attracting fishermen to switch professions as seaweed farmers [3, 4]. Various aspects of seaweed cultivation on Kemojan Island need to be measured, including the carrying capacity of the aquatic environment. This

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study estimated the aquatic environment carrying capacity and economic value of seaweed (*E. cottonni*) cultivation in Kemojan Island.

2. Materials and Methods

2.1. Location and Time of Research

This study was conducted in the Kemojan Island waters (northwest coast), particularly at the Karimunjawa waters conservation area [2]. Observations were administered in 5 observation stations (see Fig. 1) from September to October 2020. Measurements were carried out during high tides. Rizki et al. [5] stated that sea currents on the northwest coast of Kemojan Island flow from northeast to southwest during high tide and from the southwest to the northeast during low tide.

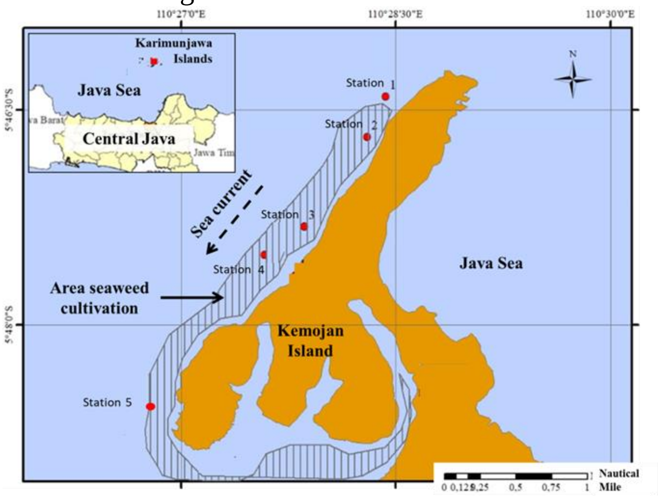

Fig.1 Research location

2.2. Measurement of BOD_5

BOD_5 was measured by performing titration based on SNI (Indonesian national standard) number 6989.72:2009 [6].

2.3. Plankton and Saprobity Analysis

Plankton samples were obtained through filtration of 100 liters of water samples collected from the site. Furthermore, the water sample was filtered through a plankton net. The filtered water was then put into a sample bottle and added 4% formalin solution. The formulas used in the analysis of plankton uniformity and diversity referred to [7-10]:

$$N = (T/L).(P/p).(V/v).(1/w) \quad (1)$$

$$H' = -\sum Pi \ln Pi \quad (2)$$

$$Pi = Ni/N \quad (3)$$

$$E = H'/Hmax \quad (4)$$

N is the number of plankton per liter. T is the area of the cover glass (mm^2). L is the field of view on a microscope (mm^2). P is the amount of plankton filtered. The notation p is the number of fields of view observed. V is the volume of the filtered plankton sample (ml). The notation v is the volume of the plankton sample under the cover glass (ml). While w is the volume of filtered plankton samples (liters). H' is the index of plankton diversity. Ni is the number of individuals of the plankton species (type i). N is the total number of individuals. E is the uniformity index. H'max is obtained from ln S, where S is the number of species found. Analysis of the saprobity water was carried out using the following formula [8, 9, 11]:

$$SI = \frac{1(nC)+3(nD)+1(nB)-3(nA)}{1(nA)+1(nB)+1(nC)+1(nD)} \quad (5)$$

$$TSI = \frac{1(nC)+3(nD)+1(nB)-3(nA)}{1(nA)+1(nB)+1(nC)+1(nD)} x \frac{nA+nB+nC+nD+nE}{nA+nB+nC+nD} \quad (6)$$

The notation n is the number of individual organisms in each saprobity group; The notation nA is the number of individual organisms in the polysaprobic group; The notation nB is the number of individual organisms as part of the mesosaprobic group; The notation nC is the number of individual organisms as part of the mesosaprobic group; The notation nD is the number of individual organisms as part of the oligosaprobic group; The notation nE is the number of individual constituents other than groups A, B, C, and D.

3. Result

3.1. Plankton Analysis

The results of uniformity and diversity analysis of phytoplankton and zooplankton are presented in Tables 1 and 2. In general, the level of plankton diversity index ranges from 1.53 to 2.22 for phytoplankton and 0.65 to 1.48 for zooplankton. The marine biota community is considered unstable if the diversity value is less than 1, moderate if the diversity value is between 1 and 3, and stable if the diversity value is more than 3 [9, 10].

Table 1 Plankton composition on site

No.	Species	Station 1	Station 2	Station 3	Station 4	Station 5
1	*Cerataulina sp*			178		
2	*Ceratium* sp.	14				
3	*Chaetoceros* sp.	50				
4	*Climacosphenia* sp.		14			
5	*Coscinodiscus* sp.	28	7	35	69	28
6	*Cyclotella* sp				4	
7	*Dictyocha* sp.	7				
8	*Diploneis* sp.				4	7
9	*Ditylum* sp.				7	
10	*Eucampia* sp.	7				23
11	*Fragilaria* sp			66	35	
12	*Glenodinium* sp.			7		

Continuation of Table 1

13	*Guinardia* sp.	40				
14	*Gymnodinium* sp.	7	107			
15	*Gyrosigma* sp.					7
16	*Hemiaulus* sp.				16	
17	*Leptocylindrus* sp.		50	30	54	
18	*Melosira* sp.				7	
19	*Navicula* sp.			7		
20	*Nitzschia* sp.	21		42	21	28
21	*Oscilatoria* sp	85	142	395	192	285
22	*Phyrophacus* sp.		16			
23	*Pleurosygma* sp.				45	16
24	*Protoperidinium sp*			180	152	59
25	*Rhizosolenia* sp.	64	26	14	54	178
26	*Thalassionema* sp.				16	
27	*Thallasiosira* sp	78				
28	*Thallasiothrix* sp.	57				
	Zooplankton					
1	*Brachyscelus* sp.					21
2	*Calanus* sp.	45	5		19	43
3	*Euterpina* sp.				12	
4	*Favella* sp.	14	5	7		
5	*Limacina* sp.	7		7		50
6	*Nauplius*	164	79	129	171	167
7	*Oithona* sp.	21	7	17	43	236
8	*Tintinnopsis* sp.			14	10	57

Table 2 Analysis of uniformity and diversity of phytoplankton

Station	Number of species	Diversity Index	Uniformity Index	Abundance (Cell per liter)
1	14	2.12	0.80	683
2	9	1.54	0.70	636
3	10	1.69	0.73	959
4	7	1.53	0.79	364
5	12	2.22	0.89	462

Table 3 Analysis of uniformity and diversity of zooplankton

Station	Number of Species	Diversity Index	Uniformity Index	Abundance (Cell per liter)
1	5	1.03	0.64	255
2	6	1.48	0.83	574
3	4	1.11	0.62	188
4	4	0.65	0.47	95
5	5	1.06	0.65	252

The uniformity levels of the five stations range from 0.70 to 0.89 for phytoplankton and 0.47 to 83 for zooplankton. Only station 4 shows low uniformity for zooplankton, while other stations have high uniformity. According to Ujianti et al. [10], a uniformity index close to 1 indicates an even distribution between species, while a uniformity value close to 0 indicates low species uniformity. The results of the probity analysis are shown in Table 3. In general, the TSI value ranges from 2.43 to 7.43, which is between light pollution to not polluted categories.

Table 4 Saprobity analysis

Station	SI	TSI
1	1.00	4.09
2	1.00	3.33
3	1.00	7.43
4	1.00	4.36
5	1.00	2.43

3.2. BOD_5 Analysis

The results of the BOD_5 analysis shown in Table 4 presents that, in general, the BOD_5 value ranges from 2.6 to 5.4 ppm (below 10 ppm) under the pollution threshold (Decree of the Minister of the Environment No. 51/2014). The results of this study match with [5, 12]. Yuliana et al. [12] conducted a study in Menjangan Island waters located approximately 10 km away from station 5 of this study. Whereas, Rizki et al. [5] conducted their study in Kemojan Island waters.

Table 5 BOD_5 (ppm) analysis

Station	BOD_5
1	3.2
2	2.7
3	3.7
4	2.6
5	5.4

2.3 Environmental Carrying Capacity and Economic Analysis

The regression analysis of BOD_5 to the length of the cultivated area (distance) and TSI to the length of the cultivated area (distance) can be seen in Fig. 2. The cultivated area's length and the TSI were found to share a negative correlation, indicating that more intensive cultivation activities tend to decrease TSI. At the same time, a smaller TSI value reflects a higher pollution level. On the other hand, a positive relationship was found between the length area of cultivation and BOD_5, implying that more intensive cultivation activities increase BOD_5 (indicating increasingly polluted area).

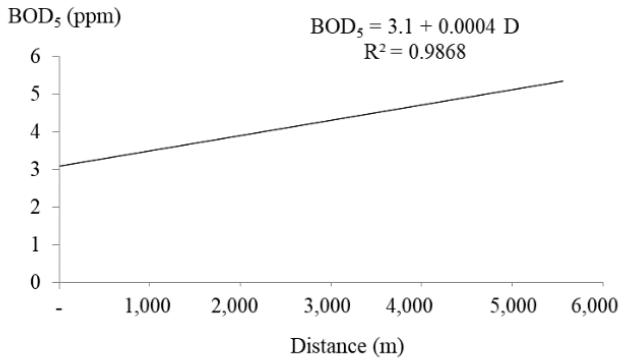

Fig.2 The relationship between BOD5 and TSI with length of cultivation area (distance was calculated from station 1 - zero-meter point)

The estimated production capacity and economic potential are shown in Table 5. We developed 2 scenarios using the BOD_5 and TSI approaches. According to the Decree of the Minister of the Environment No. 51/2014, the BOD_5 threshold for marine tourism is 10 ppm. Meanwhile, based on TSI reference, a value of 1.5 is classified as low waters [11]. There is a potential to expand the cultivation area from the current area in the capacity scenarios. The increase in the area can be obtained by expanding the cultivation area towards the sea (not towards the land).

Table 6 Estimated maximum capacity and economic potential

	Estimation of Existing Condition	**Scenario 1 (BOD = 10 ppm)**	**Scenario 2 (TSI = 1.5)**
Total area (m^2)	4,630,000	8,625,000	4,736,363
Maximum accumulative rope length (m)	1,322,857	2,464,286	1,353,247
Production potential (kg in wet/year)	3,968,571	7,392,857	4,059,740
Economic value production potential (IDR/year)	5,952,857,143	11,089,285,714	6,089,609,689

3. Discussions

Marine protected areas or MPAs (including Karimunjawa Islands) are determined to counter global marine environmental degradation and support local fishing businesses and create job opportunities through ecotourism at the same time. Several studies have confirmed the important role of MPAs in protecting coral reef ecosystems, seagrass beds, and fishery resources. The impact of MPAs will be more significant in the long term [13, 14].

Seaweed cultivation activities in Kemojan Island have positively impacted the local community's welfare. From an economic perspective, the development of tourism activities in the Karimunjawa Islands brings both positive and negative impacts on poverty alleviation. Tourism development opens up employment opportunities for tourism workers, such as hotel employees, restaurant employees, and tour boat rental service providers. Large-scale hotels are mostly owned by immigrants (not the local community). On the other side, land conversion reduces the income of local farmers [15]. Therefore, seaweed cultivation needs to be developed as an alternative livelihood for the community in Karimunjawa Islands. Seaweed cultivation in Indonesia is mostly done traditionally using a limited amount of capital. It is time for the Indonesian government to encourage the development of intensive seaweed cultivation in offshore waters, especially for industrial purposes [4]

Wijayanto et al. [16] also stated that for optimal profits, the cultivation of E. *cottonni* should employ a 40-day cultivation pattern per cycle. Meanwhile, the optimal distance between the ropes for the growth of E. *cottonni* and its revenue cost (RC) ratio is 25 cm [17]. However, seaweed cultivation activities might negatively affect the aquatic environment, where Kemojan Island is a part of the Karimunjawa waters conservation area. Water quality is an important factor in the sustainability of coral reefs and other aquatic biotas in the Karimunjawa Islands conservation area [12]. As stated by Sulardiono et al. [18], anthropogenic activities in the form of tourism and marine cultivation (in a cage) leave organic waste in Menjangan Island waters (Karimunjawa Islands), increasing the eutrophication process, which in turn decreases the water quality from the oligotrophic to mesotrophic category. Kennedy et al. [3] also highlighted that water pollution, tourism activities, and marine aquaculture are indeed a northern threat to the health of coral reefs in the Karimunjawa Islands.

Plankton population can be an indicator of water pollution. Phytoplankton holds a very important role in aquatic ecosystems and the food chain; Its population relates to the productivity of the waters. The greater amount of phytoplankton population indicates more fertile waters [19]. Some researchers have conducted plankton analysis to measure water saprobity as an indicator of pollution, including [8], [9], and [11]. Lower TSI value has also been an indicator of increasingly polluted waters.

Intensive seaweed cultivation in Kemojan Island can potentially bring biological waste, including dead seaweed. This condition increases the demand for oxygen in bacteria decomposition of organic waste. As a result, the competition for oxygen among biotas in these waters becomes tighter. Therefore, seaweed cultivation in Kemojan Island needs to be well-regulated. Environmental carrying capacity should be set as a guide in managing seaweed cultivation. Oxygen in the aquatic environment is produced through photosynthesis, both by phytoplankton and aquatic plants. Oxygen is used in the respiration process of marine biota, including plants, animals, and bacteria, and the decomposition of organic matter described by BOD [11, 19].

BOD is an indicator of the need for oxygen to decompose biological waste materials in the water by microorganisms. High BOD disrupts the oxygen balance in the waters. If the water's oxygen runs out, fish and aquatic plants might die. The excessive increase in organic matter in the waters can lead to the enrichment of inorganic matter and the growth of phytoplankton. Furthermore, phytoplankton blooms cause depletion of dissolved oxygen (DO) and death of aquatic biota [18, 20]. The distribution of BOD in the waters of Kemojan Island is influenced by tides [5]. BOD indicates the presence of organic matter in the waters, in which greater BOD reflects that the waters are increasingly polluted with organic matter [18]. The Indonesian government has set a BOD_5 limit of 10 ppm for marine tourism and 20 ppm for marine life [21].

The complexity of seaweed cultivation problems in Karimunjawa Islands demands a comprehensive approach regarding the protection of protected biota in conservation areas, environmental carrying capacity, and socio-economic interests of the local community. The development of seaweed cultivation in Kemojan Island should go hand in hand with marine conservation. Too large seaweed cultivation in coastal areas brings changes in coastal ecosystems, including seagrass beds. There is also a potential conflict of interest between seaweed farmers and sea turtle protection because sea turtles can be the pests of seaweed cultivation. These problems challenge the managers of the Karimunjawa Islands region to find the balance among tourism development, conservation (coral reefs and mangroves), coastal cultivation, marine aquaculture, and coastal fisheries. Wibawa et al. [22] argued that the gaps in the policies set by government agencies in the Karimunjawa Islands still occur. Involving academics, businessmen, government, and (local) communities (ABGC approach) is important to prevent policy overlap [1]. Community involvement is also an important factor in developing and managing marine resources in the Karimunjawa Islands, including in Kemojan Island [3].

4. Conclusion

The TSI values of the 5 observation stations ranged between 2.43 to 7.43 (light pollution category), and BOD_5 values were between 2.6 to 5.4 ppm (below the marine pollution threshold). It is estimated that the available land capacity for E. *cottonni* cultivation is 86.2 ha with a potential production of 7,392.9 tons (in wet) per year or equal to IDR 11.09 billion (scenario 1). This study proved that the combination of TSI, BOD_5, and linear regression could be used to estimate the carrying capacity of the aquatic environment for seaweed cultivation. Further research can be done by increasing the water quality variable and using a non-linear regression model to estimate the carrying capacity of the aquatic environment.

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