The optimization of production and profit of Eucheuma cottonii cultivation in Kemojan Island, Indonesia

by Dian Wijayanto

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Abstract. This study aims to calculate the optimal time of cultivation of *Eucheuma cottonii* on Kemojan Island to produce maximum production and profit. Field experiments, observations, and interviews to get data on growth, costs, prices, and local ecological knowledge were conducted by the researchers. Mathematical modeling (based on polynomial models) was used to develop equations to estimate optimal biomass, optimal profit, and break-even points or BEP (bioeconomic approaches). The results showed that 86 days of cultivation time would produce the highest biomass growth, but the highest profit per cycle occurred at 73 days. BEP occurred at 8 and 137 days. Seaweed cultivation with a 40 days pattern was proven to produce higher aggregate profits, both compared to 86 days, 73 days, 60 days, 50 days, and 30 days.
Key Words: bioeconomic, *E. cottonii*, Kemojan Island, polynomial growth.

Introduction. Seaweed production has been one of the key sources of income for local communities on Kemojan Island (Wijayanto et al 2019). Minister of Forestry Decree No. 123 / Kpts-II / 1986 named the Karimunjawa Islands as a conservation area. Kemojan Islands is part of the Karimunjawa Islands, which have been designated as a conservation area since 1986. Therefore, the development of seaweed cultivation in Kemojan Island has a strategic value. First, it can minimize destructive behavior towards protected coastal resources in conservation areas, including coral reefs and mangroves. Without adequate livelihoods, local people can behave destructively towards coastal resources, including cutting mangrove trees, mining coral reefs, and catching fish with bombs and poisons (Zamroni 2018). Secondly, it can improve the welfare of the coastal communities of Kemojan Island. In most of the world, the poor live in rural areas and rely on livelihoods from agriculture, fisheries, and forestry. Agriculture (including seaweed cultivation) is also able to attract female workers in Indonesia (the female worker proportion of 39.3% in 2010), so the development of seaweed cultivation is important for empowering women in coastal areas (FAO 2017). Welfare issues are also a crucial issue for coastal communities and small islands. Poverty and limited natural resources are common problems in small islands in developing states (SIDs). Employment in small islands is relatively limited, and vulnerable to economic shocks, so livelihood diversification is needed (UNEP 2014). Seaweed cultivation can be an alternative livelihood for coastal communities which can simultaneously reduce the pressure of fish resources that have experienced overfishing in various regions in Southeast Asia, including Indonesia (McManus 1995; Angeles & Mendoza-Dreisbach 2020; Zairion et al 2020). Some fishermen also turn to become seaweed farmers and diversify their professions (fishermen and seaweed farmers) to better fulfill their living needs (Zamroni & Yamao 2011; Aslan et al 2018). Seaweed cultivation is also more certain in providing income to meet family needs than being a fisherman (Zamroni et al 2011; Rahatiningtyas 2019). Third, seaweed is needed for various human needs, both for food and non-food (fertilizer, cosmetics, medicine, and biofuels). Global seaweed production reached 14.7 million tons in 2005, with the contribution of aquaculture at around 13.4 million tons (Buschmann et al 2017; FAO 2018). Therefore, it is important to study the seaweed cultivation in Kemojan Island to optimize the welfare of seaweed farmers, support the Karimunjawa and supply raw material of seaweed processing industry.

Eucheuma cottonii is the type of seaweed that is grown on Kemojan Island. E *cottonii* is the same species as *Kappaphycus alvarezii,* also known as 'cottonii' (McHugh 2003; Valderrama 2012). Indonesia and the Philippines are the world's top producers of *K. alvarezii*. Meanwhile, Canada was once the world leading producer of *Eucheuma* sp. However, the Philippines was able to replace Canada as the main producer of *Eucheuma* sp. in the world due to lower labor costs. Success in the Philippines encouraged the growth of seaweed cultivation in Indonesia, which then became the largest producer of *Eucheuma* sp. since 2008 (Valderrama 2012). Seaweed farmers on Kemojan Island plant seaweed with a simple longline method with a cultivation time of 30 days to 65 days (Wijayanto et al 2019). They develop methods of seaweed cultivation based on experiences (learning by doing). Therefore, research is needed to optimize the seaweed cultivation in Kemojan Island, including the optimal seaweed cultivation time using a bioeconomic approach. Therefore, the researchers studied the growth of E. *cottonii* in the coastal waters of Kemojan Island with several models. Our results show that the polynomial growth function is the best model (Wijayanto et al 2020). The results of growth modeling can be developed as a basis in the study of bioeconomics of seaweed cultivation. Studies on the cultivation time optimization have also been carried out by several researchers, including Kazmierczak & Caffey (1996), Shamshak & Anderson (2009), Wijayanto et al (2017a, b). The purpose of this research was to calculate the optimal cultivation time of *E. cottonii* on Kemojan Island to produce maximum production and profit.

Material and Method

Material research. The material used in this study was *E. cottonii* that was cultivated in basket-longline for 40 days on the northwest coast of Kemojan Island to determine its growth patterns. The seaweed was put in the basket to control the growth of seaweed. Thus, it would not be affected by the predation of herbivorous animals, including *Siganus* sp., which is a type of fish that mostly preys on seaweed, especially young thallus (McManus 1995; McHugh 2003; De San 2012; Muthalib et al 2017). The growth rate of seaweed decreases significantly if herbivorous fish are abundant in seaweed farming locations (Kasim et al 2016).

Research location. The study was conducted in Kemojan Island in June to August 2019. Seaweed farmers on Kemojan Island plant seaweed on the northwest coast of Kemojan Island. There are several locations of seaweed farmers living on Kemojan Island, including sub-villages of Telaga, Gelaman, Mrican, Jelamun, and Batulawang (see Figure 1), and there are also living on Karimunjawa Island.

Respondents. Ninety (90) seaweed farmers on Kemojan Island were involved as the respondents to collect data of price, cost, and production data. The respondents were also interviewed related to local ecological knowledge (LEK), including pests and diseases in seaweed cultivation on Kemojan Island. LEK method has weaknesses related to the accuracy of information. However, LEK can provide essential information especially in research with limited data. The accuracy of the LEK method can reach almost 60%, and a combination with other methods is needed to increase understanding of the research object (Ruddle & Davis 2013; Cook et al 2014).

Research model. This study employed the polynomial growth model as the basis of the bioeconomic model. The polynomial growth model in this research follows equation 1.

$$Y = a + b.t - c.t^2 \quad (1)$$

Notation of Y is cultivated seaweed biomass (g per meter of planting media) and t is cultivation time (days). Notations of a, b, and c are constants. Revenue, cost, and profit follow the equations:

$TR = p.Y$ (2)

$TC = s + d.t$ (3)

$\Pi = TR - TC$ (4)

$\Pi = p.Y - s - d.t$ (5)

TR is total revenue (IDR per m of longline at time of t). Notation of p is the selling price of seaweed (IDR per g). TC is the total cost (IDR per m of longline at time of t). Π is profit (IDR per m of longline at time of t). Notation of s is the cost of seaweed seed procurement (IDR per g). Notation of d is depreciation of assets used in the seaweed cultivation business (IDR per day). The optimization of production follows the derivative procedure for equation (1), i.e. $dY/dt = 0$ as the first-order condition and d^2Y/dt^2 = negative as the second-order condition, then generate equation (6) that can be used to estimate the optimal time that generates the maximum production of seaweed cultivation in Kemojan Island (g per m of longline).

$t_{Ymax} = b/2c$ (6)

The profit optimization follows the derivative procedure for equation (5), i.e. $d\Pi/dt = 0$ as the first-order condition and $d^2\Pi/dt^2$ = negative as the secondorder condition. In that way, equation (7) is obtained that can be used to estimate the optimal time for maximum profit of seaweed cultivation in Kemojan Island (IDR per m of longline):

$t\pi_{max} = [b.p - d] / [2.c.p]$ (7)

To estimate the break-even point (BEP), the value of Π in equation (5) is conditioned that is equal to zero. The resulting equation can be seen in equation (8):

$$t_{BEP(1,2)} = \frac{-(bp - d) \pm \sqrt{(bp - d)^2 - 4.(-cp).(a.p - s)}}{2.(-c.p)} \quad (8)$$

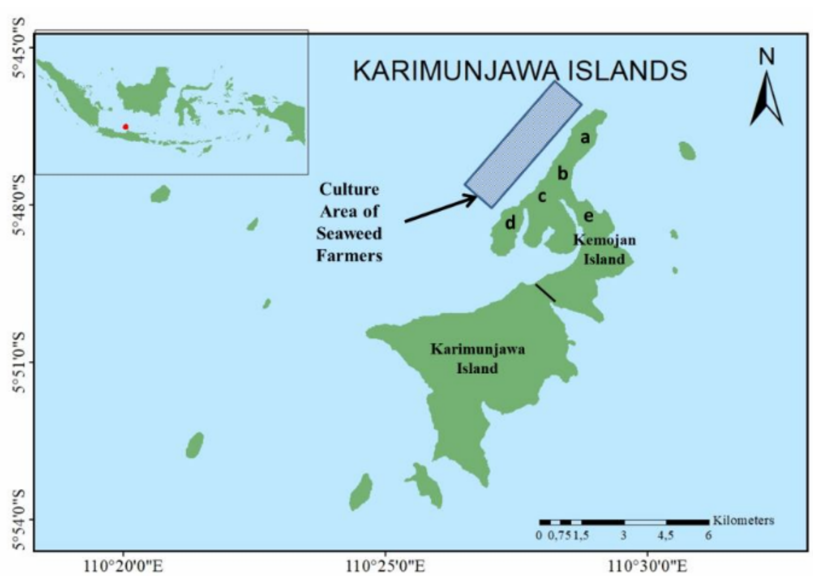

Figure 1. The research location (a. Sub-Village of Batulawang, b. Sub-Village of Telaga, c. Sub-Village of Gelaman, d. Sub-Village of Mrican, e. Sub-Village of Jelamun).

Results and Discussion. Seaweed has been used by humans since the Neolithic period. Coastal people usually grow seaweed in the coastal area for feed and food. Seaweed will be used for raw material in factories in the future. Seaweed cultivation includes pharmaceuticals, nutraceuticals, organic or sustainable food, health and beauty products, aquaculture or animal feeds, biofuels, and fertilizers (Winberg et al 2009; Buschmann et al 2017). The supply of seaweed from cultivation is significantly greater than seaweed capture in nature (FAO 2018). According to Winberg et al (2009), the type of seaweed that had the highest economic value was pharmaceuticals, while the lowest value was fertilizers. The type of seaweed planted by farmers on the coast of Kemojan Island is *E. cottonii* that can be processed for carrageenan (Wijayanto et al 2019). Carrageenan is commonly used for a variety of food needs, including ice creams, cakes, gel desserts, beer, and macaroni, as well as non-food purposes, including toothpaste, mineral oils, and paints (McManus 1995). The demand for carrageenan in the world has increased since post World War II (Valderrama 2012).

The optimal biomass harvested. The location of seaweed cultivation in the northwest coastal waters of Kemojan Island following the zone determined by the Karimunjawa National Park Office, i.e. marine cultivation zone. Seaweed farmers of Kemojan Island use un-motorized boats with a length of 3 m. Seaweed farmers cultivate seaweed using a long line with an average number of 19 units and an average length of 129 m per longline. Most seaweed farmers of Kemojan Island cultivate seaweed for 10 months per year. From January to February, seaweed farmers usually do not plant seaweed due to the big sea wave.

In this study, the researchers employed the polynomial growth function $Y = 983 + 49.73\ t - 0.29\ t^2$ that was obtained from field experiments, where the average initial weight of seaweed was 983 g per m. By using equation (6), it was obtained the time that produces the largest seaweed biomass, i.e. 86 days, that produces 3,114.7 g per m of longline. The results of the simulation of seaweed growth progress can be seen in Figure 2. The growth pattern of seaweed is in line with the findings of Parsons & Hunt (1981) and Paine et al (2011) who analyzed plant growth. The growth rate of plants decreases with plant age increasing. This growth pattern has indeed become a common pattern of plant and animal growth.

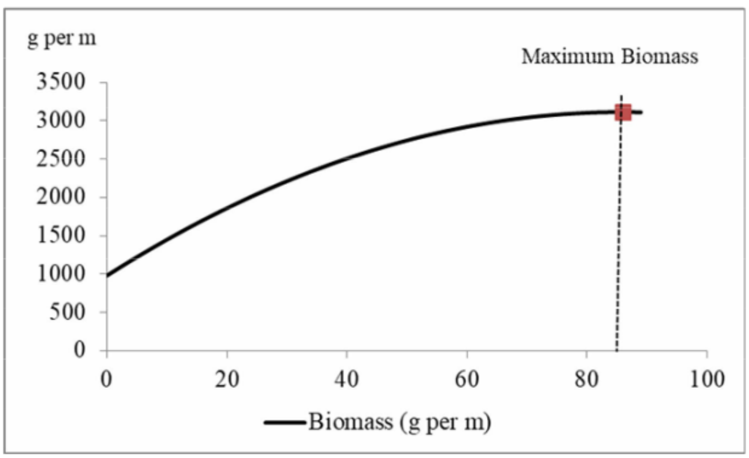

Figure 2. The biomass progress of seaweed.

Chen et al (1992) investigated the polynomial growth function for several types of fish, which can be used to predict the fish's growth. The growth function of the third-order polynomial growth and von Bertalanffy's growth function did not vary significantly in that analysis. Zhang et al (2016) have also developed a seaweed growth model for *Saccharina japonica* by making a concept that seaweed growth is a function of temperature, light, nutrient content in seaweed (internal nutrients), and also the content of nitrogen (N) and phosphorus (P) in the sea. Simulation results showed that nutrients, temperature, and light are the determining factors for seaweed growth. According to Kasim et al (2016), differences in cultivation methods could affect differences in the growth rate of seaweed.

Seaweed cultivated using a simple longline method allows herbivorous fish to prey on seaweed and it can cause slower growth rates compared to using the floating cage. Based on the results of interviews with seaweed farmers, obstacles experienced in seaweed cultivation on Kemojan Island include ice-ice disease, epiphytic plants, the presence of herbivorous fish and turtles, big waves around January to February. Seaweed farmers on Kemojan Island also have weak bargaining power in determining the seaweed selling price. According to Chung et al (2007), Hasyim et al (2012), and Irfan et al (2016), seaweed growth was influenced by depth, temperature, salinity, density, number of workers, sea currents, and seasons. Therefore, seaweed growth is influenced by various variables. The growth rate of seaweed on the coastal of Kemojan Island will be different from other locations.

The profit and BEP. The simulation results by using equations (7) and (8) showed that the maximum profit of seaweed cultivation on Kemojan Island occurred on the 73rd day, while the BEP occurred on the 8th and 137th days. The data were presented in Table 1, Figure 3, and Figure 4.

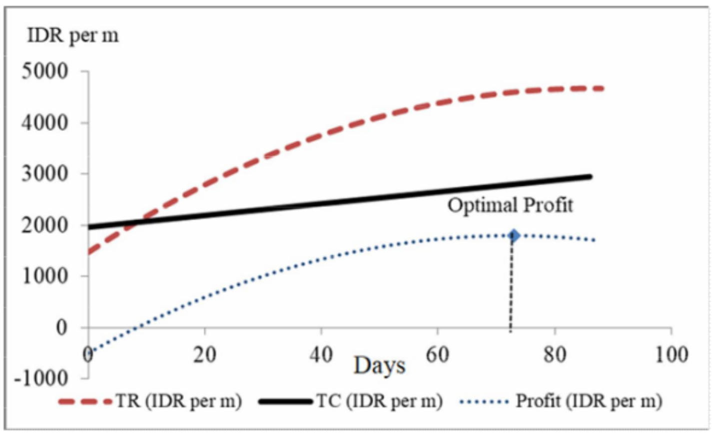

Figure 3. The Progress of TR, TC, and profit.

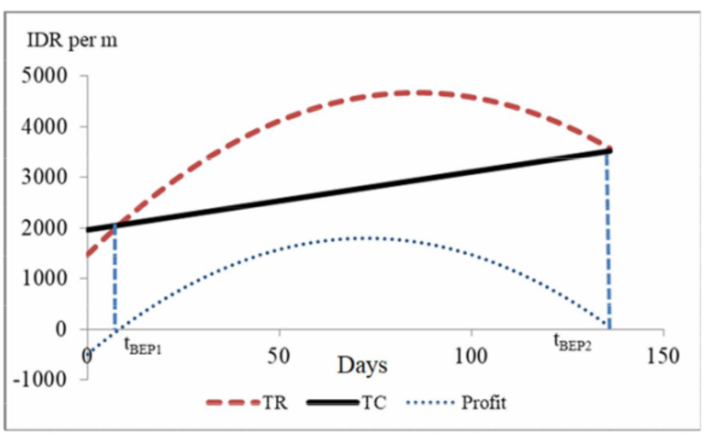

Figure 4. Break even point.

Table 1

The maximal profit and BEP

Cost and profit	*Values*	*Units*
Biomass of seed	2948.3	g per m per culture cycle
Seed price	2	IDR per g
Seed procurement cost (s)	1966	IDR per m per culture cycle
Assets depreciation (d)	11	IDR per day
Seaweed selling price (p)	1.5	IDR per g
Harvest time at a maximal profit ($t\pi_{max}$)	73	day
Maximal profit (π_{max}),	1800.6	IDR per m per culture cycle
Harvest time at BEP ($t\pi_{BEP}$),	8 and 137	day

Several researchers have examined BEP of seaweed cultivation, i.e. BEP production and or BEP price, including Alin et al (2015), van den Burg et al (2016), Alin & Eranza (2018), Ladner et al (2018) and Tawakkal et al (2019). Seaweed sale price and production costs differ by locations and cultivation process, influencing BEP based on price and production. The price of seaweed on Kemojan Island is more determined by the buyer. Seaweed farmers have low bargaining power in setting the price. Seaweed products on Kemojan Island are bought by collectors and then sold to Java Island, both big traders and seaweed processing companies. The seaweed selling price at the time of this research was IDR 1,500 per kg wet and IDR15,000 per kg dry. According to Sutinah et al (2018), the seaweed distribution chain in Sulawesi Island is also involved seaweed farmers, collectors, big traders, and seaweed processing companies with a selling price of *E. cottonii* dry at the farm level is IDR 7,000 per kg, while the marketing margin gained by traders is IDR 500 per kg, and marketing margins from large traders is IDR 2,500 per kg.

Sobari (1993) investigated the profit maximization of seaweed cultivation in Nusa Penida, Bali (Indonesia), with seed prices, rope prices, and labor wages influencing the profit model. As a result, the price of seeds has the greatest impact on earnings. Furthermore, farmers' seaweed cultivation can still be scaled to maximize profitability. However, the research of Sobari (1993) has not yet explained the optimal cultivation time.

The number of seeds planted is the most determining factor in the success of seaweed cultivation production. Meanwhile, the proportion of the cost of procuring seaweed seeds on Kemojan Island can reach more than 90% of the cost per cycle if farmers buy seeds. To save money, seaweed farmers on Kemojan Island use vegetative methods to obtain seedlings, namely cutting young thallus from their harvest as seaweed seeds for the next planting period (Irmayani et al 2015; Wijayanto et al 2019).

Several variables have to be considered when deciding the time of cultivation. The first factor is market demand. *E. cottonii* users are industries, that seaweed is used as raw material for making carrageenan and its derivative products. During this time, seaweed farmers on Kemojan Island set seaweed cultivation time at in an average of 42 days (Wijayanto et al 2019). The content of carrageenan from seaweed can differ between different locations. The content of carrageenan in seaweed is influenced by the supply of nutrients, temperature, the intensity of sunlight during cultivation, and the post-harvest drying process. Younger thallus tends to have a lower carrageenan content compared to older thallus (Budiyanto et al 2019). Hayashi et al (2007) showed that the best carrageenan conditions could be achieved if *K. alvarezii* was cultivated for 45 days. The second is cash flow interest. Although the simulation results show 73 days will generate maximum profits, 73 days is not necessarily an option for seaweed farmers on Kemojan Island. That is because the availability of capital from seaweed farmers is relatively limited. They prefer fast money turnover to meet family needs. Thus, 73 harvest days are considered too long by most seaweed farmers. Third, it is opportunity cost. Every business actor will try to make profit optimization. If it is assumed that the average length of seaweed culture time is 300 days per year and seaweed farmers use the 73 days pattern, then only get 4 full culture cycles. Then, if seaweed farmers use 40 days of culture pattern, so seaweed farmer can make 7 times of full culture cycle. The results of profit simulations with several scenarios can be seen in Table 2. The pattern of 40 days cultivation produces the highest aggregate profits, namely IDR 12,163 per m per year.

Table 2

Several profit on different time cultivation

Cultivation pattern (days per cycle)	*Harvest time (days)*	*Production (g per m per cycle)*	*Profit (IDR per m per cycle)*	*Cycle number per year*	*Profit accumulation (IDR per m)*	*Aggregate profit (IDR per m per year)*
a	b	c	d	e	f = d x e	g
86	86	3,115	1,722	3	5,167	6,561
	42	2,560	1,394	1	1,394	
73	73	3,068	1,801	4	7,202	7,188
	8	1,362	-14	1	-14	
60	60	2,923	1,732	5	8,659	8,659
50	50	2,744	1,579	6	9,472	9,472
40	40	2,508	1,339	7	9,371	12,163
	20	1,861	2,792	1	2,792	
30	30	2,214	1,012	10	10,117	10,117

Seaweed cultivation in the Karimunjawa Islands has been proven to generate positive social and economic impacts. Seaweed cultivation is proven to push increase the diversification of livelihoods for local people in Karimunjawa Islands, especially in Kemojan Island (Wijayanto et al 2019). The next impact is that it can reduce the pressure of fish resources because several traditional fishermen turn into seaweed farmers. Welfare improvement is also able to reduce the destructive behavior of the local people of Karimunjawa Islands, including the behavior of cutting down mangroves, and damaging coral reefs. Although seaweed cultivation in the Karimunjawa Islands has a positive impact related to social, economic, and environmental aspects, seaweed cultivation in the Karimunjawa Islands conservation area still needs to be controlled. According to Giddy (2016), seaweed cultivation can reduce the abundance of seagrass beds that in turn affects the life of organisms associated with seagrasses, including dugongs and turtles. In addition, ropes for seaweed farming can also trap dugongs, as is the case in the Philippines. Therefore, further research is needed regarding the environment carrying capacity for seaweed cultivation in Karimunjawa Islands, including on Kemojan Island, with a multi-dimensional approach, both social, economic, and environmental. However, according to Blankenhorn (2007) in the case of seaweed cultivation in Takalar Regency-Indonesia, it was proven that seaweed cultivation does not affect the existence of seagrass ecosystems, although the development of seaweed cultivation still needs to take into account the environment carrying capacity. It is recommended that seaweed cultivation be carried out in deeper waters and not in seagrass ecosystem areas. Thus seaweed cultivation does not affect seagrass beds, it might have a positive impact on traditional fisheries, where seaweed can become a fish nursery ground.

Conclusions. The results of this study showed that 86 days of culture produced the highest biomass increase, but 73 days produced the highest benefit per cycle. On 8 days and 137 days, BEP occurs. Whereas if seaweed farmers take into account the opportunity cost, seaweed cultivation with a 40 days pattern is proven it would generate higher aggregate profits compared to the pattern of 86 days (t_{Ymax}), 73 days ($t\pi_{max}$), 60 days, 50 days, and 30 days.

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