The growth model of *Eucheuma cottonii* cultivated in Karimunjawa Islands, Indonesia

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Abstract. Seaweed cultivation has a strategic role in fisheries development in Indonesia. Indonesia is the second largest seaweed producer in the world. Seaweed cultivation is relatively easy and low-cost. Therefore, there are many coastal communities in the small islands that culture it, including in Karimunjawa Islands. Thus, seaweed cultivation has a large contribution to the economy of coastal communities. The most cultivated species of seaweed in Indonesia is *Eucheuma cottonii*. The purpose of our research was to develop the growth model of *Eucheuma cottonii* cultivated in Karimunjawa Islands. We used 9 (nine) observation (basket) units that were measured the growth weekly for 42 days. Our research location was on the coastal waters of Kemojan Village, Karimunjawa Islands. This research has proven that the polynomial growth model has the largest R^2 compared to the exponential model and the linear model. Based on polynomial growth model, the growth of *E. cottonii* follows the equation: Y = -0.29t2 + 49.73t + 1969.3 (R^2 = 0.9967) that Y is the biomass of seaweed and t is the day of culture. This growth model can be used to estimate the seaweed biomass and profit related to the harvest time.
Key Words: *Eucheuma cottonii*, Karimunjawa Islands, growth, polynomial, linear, exponential.

Introduction. Aquaculture has a strategic role in development of Indonesia (including seaweed culture), that is related to food security, employment, economic growth and poverty reduction. Indonesia is one of the major contributors to growth in aquatic plant production in the world. Indonesia produces mainly *Eucheuma* sp. (FAO 2016; Buschmann et al 2017; Wijayanto et al 2020).

At the present, seaweed is used for multiple applications and a broad variety of products. Seaweed products are used for fresh food, food additives, nutraceuticals, fertilizers, biofuels, cosmetics and medicines (Sutharsan et al 2014; El-Din 2015; Hernández-Herrera 2018; Uthirapandi et al 2018). In food industry, seaweed is used for deserts, ice-creams, concentrated milk, pasta, processed meats, sauces and Chinese soups, beer, soy milk, animal feed, dietetic drinks, and jams. Seaweed is also used for toothpaste, shampoo, and skin-care creams. In pharmaceuticals industry, seaweed is used for pills and gels (De San 2012). The red algae can be used as raw materials for paper making (Machmud et al 2014). Seaweed can also be utilized as energy sources or biofuel, bioplastic and biochemical (Akhtar et al 2014; Sunadji et al 2014; Ismail et al 2015).

The seaweed farming can improve the welfare of coastal and small islands communities, including in Karimunjawa Islands-Indonesia (Wijayanto et al 2020). Karimunjawa Islands is one of the famous marine tourism destinations in Indonesia. Karimunjawa Islands is also a marine protected area since 1986 based on the Decree of the Minister of Forestry (No. 123/Kpts-II/1986). Therefore, the development of seaweed culture is important for livelihood of local people. Without adequate livelihoods, so local people will tend to damage the environment and do not support conservation in Karimunjawa Islands.

Commercial eucheumoid cultivation has become a main source of livelihood for the coastal communities in developing countries (Wakibia et al 2011). The development of seaweed farming has good prospect in Indonesia, because of several factors, i.e. extensive farming area, high demand, low cost, and jobs opportunity. Seaweed farmer is also as an alternative livelihood to replace coral-miner, and mangrove logger (Zamroni 2018). Women can also take part in seaweed farming. Seaweed farming has positive impact on the socio-economic status of women cultivators. Seaweed farming in developing countries is usually a small-scale business family (Hussin & Khoso 2011).

Seaweed is easy to be cultivated and use simple-inexpensive technology. So, it is suitable and easily adapted by coastal communities who have limited capital power (Rahim 2018). In developing countries, seaweed farming is usually located in the coastal and pond. Seaweed cultivation can also be done using the polyculture method, for example with shrimp and milkfish (Yala et al 2017). *Gracilaria* sp. can increase shrimp productivity (Izzati 2011).

It is important to develop the growth model of seaweeds. Seaweed growth models can be estimated using mathematical modeling to optimize the profit of seaweed culture. Mathematical modeling has been widely used for the production optimization including in aquaculture (Wijayanto et al 2017a, b; Wijayanto et al 2018). The purpose of our research was to develop the growth model of *E. cottonii* cultivated in Karimunjawa Islands. By understanding its growth function, therefore production and profit of seaweed cultivation can be projected.

Material and Method

Research location. Research location was on coastal waters of Kemojan village, Karimunjawa Islands (Figure 1) near the local seaweed farms. Local seaweed farmers use the longline method. Our research was conducted in June to July 2019.

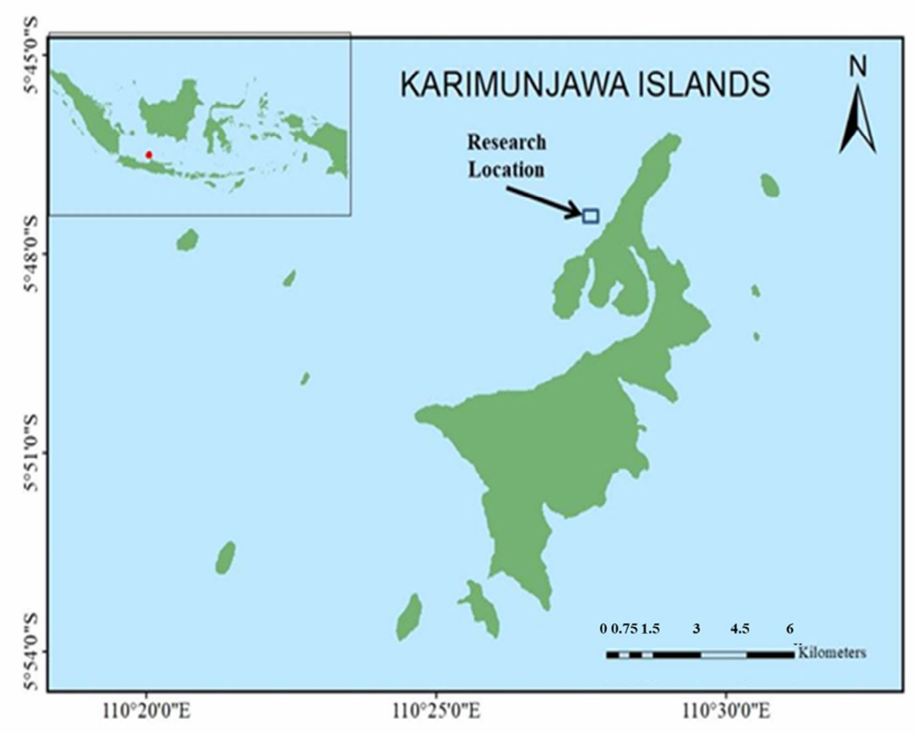

Figure 1. The research location.

Research material. In this research, we used *E. cottonii*. This seaweed was placed in basket-longline, so that it was not eaten by herbivore animals, including sea turtles and *Siganus* sp. We used 9 (nine) baskets (code of B1 to B9) and each basket was planted with seaweed weighing between 1625 and 1647 g with an average weight of 1637 g (Figure 2). The weight growth of seaweed on each observation unit was measured weekly for 42 days. We also measured water conditions weekly, including dissolved oxygen (DO), temperature, pH, and salinity using a portable multi-parameter water quality meter.

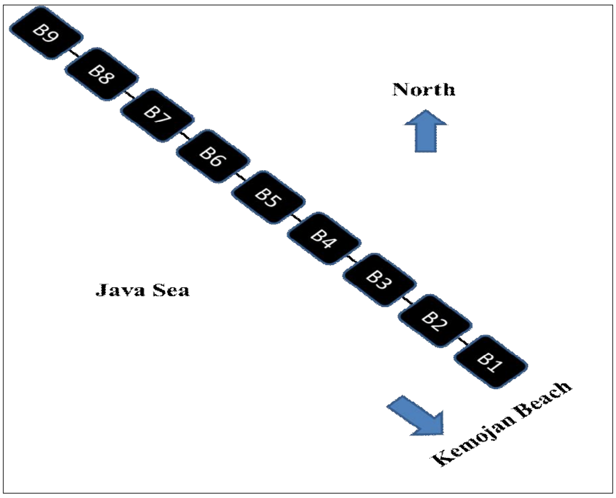

Figure 2. Basket of seaweed layout.

Growth model. Several studies have shown that the growth of seaweed is not linear. Surni (2014) has studied the growth of E. *cottonii* with linear and non-linear models (including exponential and polynomial models). Her research has proven that several non-linear models have a higher R^2 than linear models. Our research used several models, i.e. exponential, linear and polynomial growth model.

a) Exponential model: $Y = a. e^{b.t}$
b) Linear model: $Y = c + d.t$
c) Polinomial model: $Y = e + f.t + h.t^2$

where: Y is the weight of seaweed (g);
t is time of culture (day);
a, b, c, d, e, f and h are constants.

Result and Discussion. Karimunjawa Islands consist of 27 islands, including Karimunjawa Island and Kemojan Island as the biggest islands. In Kemojan Island, most people work as farmers (agriculture), fishermen and seaweed farmers. Tourism-based businesses have not developed on Kemojan Island and this is in contrast to Karimunjawa Island. Therefore, the development of seaweed culture is important for Kemojan Island people for their livelihood.

Water quality. Water quality affects the survival and growth of aquatic biota, including seaweed. At the site of research, DO was in the range of 6.9 to 7.8 ppm while the requirements of *E. cottonii* cultivation are more than 4 ppm (Supriyantini et al 2017). Water temperature was in the range of 28.0 to 31.5^{o}C while the requirements of *E. cottonii* cultivation are 24 to 32^{o}C (BSN 2011). Similarly, for pH of 7.0 to 8.5 that it was in accordance with the eligibility requirements for *E. cottonii* cultivation (BSN 2011; Limi et al 2018). Water salinity was in the range of 35 to 39 ‰ which is indeed natural.

According to Hasyim et al (2012), the best location for seaweed culture is coastal waters with suitable requirements for total suspended solid (TSS), sea surface temperature (SST), and area with calm water that is sheltered from waves, strong currents and predators. According to Zamroni (2018), seaweed farmer select the seaweed farm area with consideration of: (1) location protected from large waves, (2) nutrient-rich waters, (3) pollution-free waters, and (4) close to the beach to save costs. According to Nursidi et al (2017), environmental waters in the dry season are not ideal for seaweed cultivation because seaweed growth is not optimal. Climate change is also affecting the production of seaweed culture (Amri & Arifin 2016). High sedimentation can reduce seaweed farming production (Limi et al 2018). Karimunjawa Islands have high biodiversity, both in the mangrove, seagrass and coral reef ecosystems (BTNKJ 2019). Karimunjawa Islands is also far from sources of industrial pollution. So, seaweed cultivation in Karimunjawa has no problems related to water quality. The location of seaweed cultivation in Kemojan Island is also in accordance with the zonation of conservation in Karimunjawa Islands.

Growth model. Seaweed (*E. cottonii*) culture in Karimunjawa islands are harvested in 30-65 days with average of 42 days (Wijayanto et al 2020). According to Zamroni (2018), seaweeds in Serewe Bay (Lombok Island, Indonesia) are mostly harvested for 30 days due to the limited working capital of seaweed farmers. In this research, *E. cottonii* growth can be seen in Table 1. In 42 days, seaweed grew with an average weight gain of 1,871 g or 114% of the initial weight. According to Yala et al (2017), the growth increment of *E. cottonii* can reach 1,142% or 11 times from the initial weight in polyculture with *Penaeus vannamei* and *Chanos chanos*.

Table 1

The growth of *E. cottonii* (g)

Days	*B1*	*B2*	*B3*	*B4*	*B5*	*B6*	*B7*	*B8*	*B9*	*Average*
0	1632	1633	1644	1637	1640	1625	1647	1644	1634	1637
7	1867	1871	1814	1769	1903	1965	1911	1869	1867	1871
14	2119	2176	2055	1991	2204	2336	2287	2119	2160	2161
21	3121	2819	2896	2244	3295	3115	3192	2282	2722	2854
28	3524	3064	3287	2383	3550	3615	3644	2420	2860	3150
35	3623	3394	3386	2736	3850	3885	4090	2561	3079	3400
42	3694	3594	3454	2815	4033	3968	4218	2603	3200	3509
Y_{42}-Y_0	2062	1961	1810	1178	2393	2343	2571	959	1566	1871

Using the data in Table 1, the growth model simulation was performed. Simulation results show that the growth of *E. cottonii* that is cultivated in the Karimunjawa Islands has the following growth models:

a) Exponential model: $Y = 2080.6\ e^{0.0137\ t}$ (R^2 = 97.0%)

b) Linear model: $Y = 2040.9 + 37.45\ t$ (R^2 = 98.8%)

c) Polynomial model: $Y = 1969.3 + 49.73\ t – 0.29\ t^2$ (R^2 = 99.7%)

This research showed that the growth models produced can be used to predict the progress of seaweed weight, because R^2 is relatively high. Even so, the growth of seaweed is also influenced by sufficient space to grow. If there is enough space to grow, the growth of seaweed will be optimal. The polynomial model has a greater R^2 than the other two models. Thus, the polynomial model is the best model for predicting seaweed growth. Illustration of seaweed growth can be seen in Figure 2.

Seaweed growth models can be used to estimate production, revenue and profit. By using the equation: $Yt = Yo + 49.73\ t - 0.29\ t^2$, therefore the progress of seaweed biomass can be estimated. Notation of Yo is the initial weight of seaweed. Notation of t is the age (time) of cultivation (days). Notation of Yt is the weight of seaweed when t days. Seaweed growth models can be used for bioeconomic modeling. We have used the polynomial growth model as a basis for bioeconomic modeling in aquaculture, including for *Osphronemus goramy* (Wijayanto et al 2017a), *Litopenaeus vannamei* (Wijayanto et al 2017b) and *Oreochromis* sp. (Wijayanto et al 2018). Aquaculture bioeconomic modeling on the basis of a polynomial growth model has proven to be valid.

Seaweed growth is influenced by depth, temperature, salinity, pH, nitrate, phosphate, density of seaweed planted, and number of workers (BSN 2011; De San 2012). Depth and brightness of water influence the penetration of sunlight into the waters needed in the process of photosynthesis by seaweed. Therefore sea water temperature is influenced by water depth. The depth of the research site is around 2 meters and sunlight penetration can reach the bottom of the water. According to BSN (2011), the recommended waters location for *E. cottonii* cultivation has a depth of 2 meters. While a density of seaweed that is planted affects the adequacy of space for seaweed to grow. Workers are needed in the process of seaweed caring from weeds and pests. The well-maintained seaweed produces optimal growth. According to Chung et al (2007), the growth of seaweed is also influenced by the season. Season will affect temperature, precipitation, salinity, and NH_4^+. According to Hasyim et al (2012), water movement is also vital for seaweed growth relate to supplying nutrient, aiding in nutrient absorption, cleansing dirt, holding CO_2 and O_2 exchange.

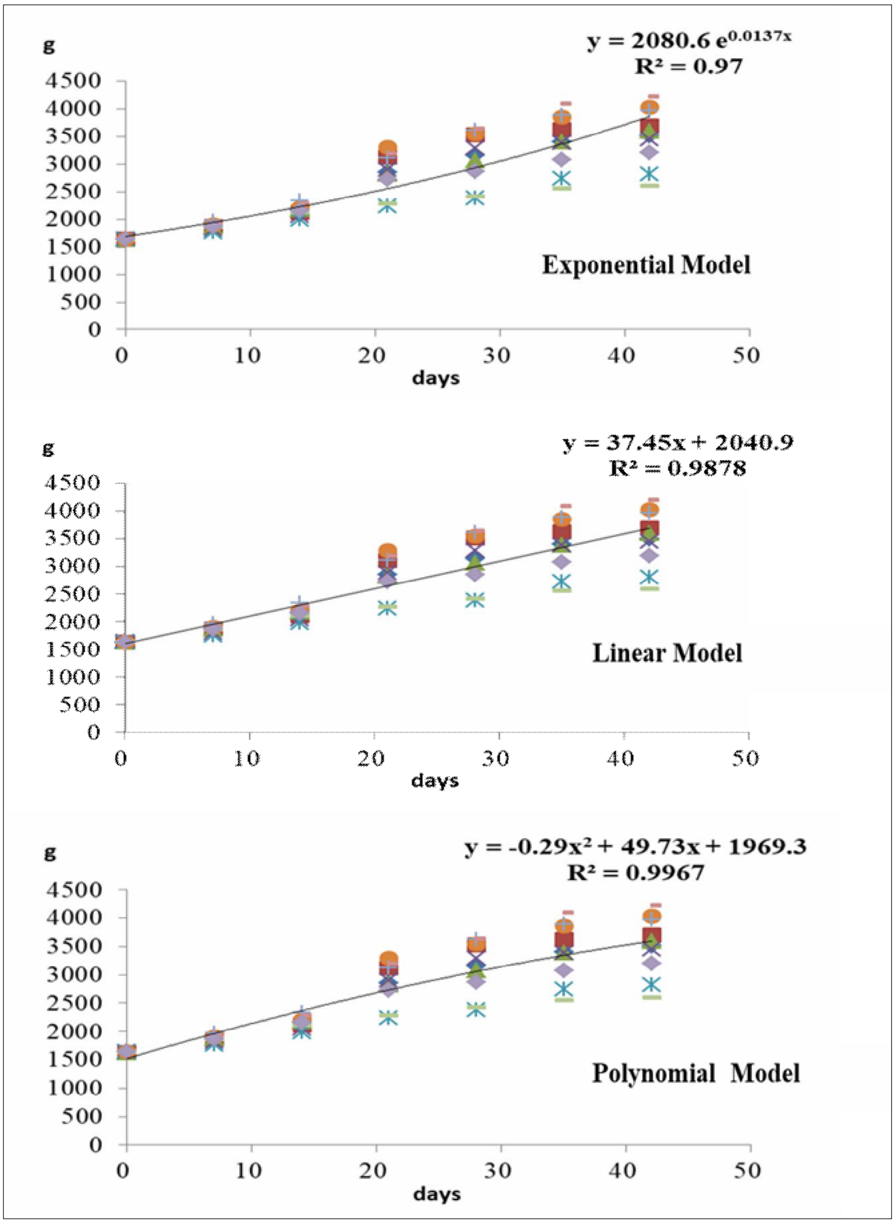

Figure 2. The growth progress of *E. cottonii*.

Conclusions. Our research showed that the best growth model of *E. cottonii* follows the equation: Y = Yo + 49.73 t – 0.29 t^2 (polynomial model) with R^2 of 99.7%. By using this growth model, seaweed farmers can estimate the progress of seaweed weight, and also production and profitability of *E. cottonii* cultivation. Seaweed growth models also can be used for bioeconomic modeling.

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