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Approach of Maximum Sustainable Yield (MSY) Concept to Design a Sustainable Phytoremediation System to Improve Shrimp Pond Water Quality

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Abstract: Maximum Sustainable Yield (MSY) concept was applied to investigate about its applicability in order to assess the potential ability of *Gracilaria edulis* as phytoremediation agent. Strategy to design a high efficiency of sustainable phytoremediation system is addressed in this paper. Tank cultivation of *G. edulis* was conducted in tank filled with shrimp pond water for six weeks. The active and inactive biomass for vegetative propagation was numerically partitioned and modified logistic model was consisted of active biomass for propagation. It was clearly confirmed the high applicability of modified logistic growth model (R^2=0.980) when 239.2g of biomass was defined as inactive for propagation. According to the result, MSY was 0.68g/day at 12.02g of active biomass under the experimental condition. The simulated logistic model for biomass growth pattern has well employed with the experimental data (R^2=0.986). According to these results, it is remarkable to consider propagative portion of biomass to assess the behaviour of phytoremediation agent and to consider MSY concept on *G. edulis*. The results revealed the significance to propose a sustainable phytoremediation system by this approach, which can be focused on the management strategy to retain maximum efficiency of the system. Thereby, it is suggested to consider three parameters, such as, active biomass ratio, intrinsic growth rate and self growth inhibition effect as strategies to design a sustainable phytoremediation system.

Key words: Biomass partitioning % Growth rate % Logistic model % Harvest % Surplus biomass

INTRODUCTION

In Southeast Asian countries, intensive shrimp farming has been rapidly increases to meet the demand of food production for human consumption [1]. The intensive shrimp cultivation potentially causes environmental impact such as eutrophication [2, 3] and consequently cultivated shrimps are susceptible to diseases [4]. In this perspective, integration of seaweed cultivation in aquaculture wastewater is considerable as an advanced approach, in which seaweed act as a biofilter to assimilate the excess nutrient from the wastewater [5, 6]. Besides that seaweed has potential to offer as an alternative source of raw material for phycocolloid agar, human food and animal feed [7-9] and its biomass resources has the potential to produce biofuel [10]. Accordingly, screening to find appropriate species has been conducted. Hence, *Gracilaria* is known as an appropriate species for its high propagation ability [5, 11, 12] and potential to produce economic valuable byproducts [13]. On this context, we have focused on phytoremediation system development by *Gracilaria* propagation to improve excess nutrient of shrimp pond water in this study.

The concept of phytoremediation in the integrated system is to absorb targeted pollutant by plants and harvest the surplus biomass or its tissue from the system. Here, the term surplus refers to excess recruitments and growth over natural mortality during a unit time [14]. Thereby, growth rate such as specific growth rate or relative growth rate were assessed in the prior studies and the capability for nutrient absorption has been discussed [5, 6, 12]. Considering the context of these researches, a hypothesis has been shared that the efficiency of a phytoremediation system is attained when the biomass performed higher growth rate which absorbs excess nutrient and generate hydrocarbon. Thus, nutrient uptake rate could be dependable on genetic property of the applied species.

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However, the harvesting rate is also being inevitable factor that affect the growth rate of a phytoremediation agent, as plant-itself is independent dynamic of living system. This definition for self dependability of phytoremediation agent has likely to be apart from the prior researches. Accordingly, maximum sustainable yield (MSY) concept [15] is highlighted in this study. Once a phytoremediation agent has been chosen, harvesting rate could be the most important controlling factor to design a phytoremediation system. Hence, the aims of this study were to investigate about the applicability of MSY concept and to assess the potential ability of *G. edulis* as a phytoremediation agent. Then strategy to design a high efficiency of sustainable phytoremediation system is addressed.

MATERIALS AND METHOD

Materials: Gracilaria edulis was selected as a phytoremediation agent, as this species naturally grows in canals around the shrimp cultivation pond in *Johor Bahru*, Malaysia. Besides that, this species has been widely cultivated around India for agar production [16]. Tank cultivation of *G. edulis* was performed under controlled conditions in environmental laboratory of Universiti Teknologi Malaysia. Healthy thalli of the *G. edulis* were collected at the Brackishwater Culture Research Centre, Gelang Patah, Johor (1°26' 21.5"N and 103°34' 55.2"E) in a canal of natural growth, downstream of shrimp cultivation pond. After collection, *G. edulis* was transported to the laboratory in a polystyrene box filled with brackish water. In laboratory, the *G. edulis* was washed under running water and cleaned of epiphytes. The water sample used in this experiment was brackish shrimp pond water. It was collected from the shrimp pond of the same research institute and transported to the laboratory. The experiments were conducted over a period of six weeks. Three tanks of 36 L volume were used for cultivation. The species were maintained in controlled conditions of light intensity (1000 lux), photoperiod (12:12 L: D cycle), temperature (28-30°C) and provide constant aeration. A total of 240g of *G. edulis* was hung by using 1 mm nylon lines and 20 cm submerged. The tanks were weeded twice a week. One fifth of the total volume of water in the tanks was exchanged with fresh shrimp pond water once per week. The seaweeds were blotted on paper towel to remove excess water, weighed (fresh weight) and restored back to the tanks [12].

Analytical Model: Gracilaria has a cylindrical and highly complex multiaxial thallus organization. In the body, apical cells are usually visible at the dense of tapered tip of branches [17-19], where the maldistribution of apical cells performs heterogeneous propagation of thallus biomass. Accordingly, the propagative and inpropagative thallus biomass was numerically partitioned in this research, as follows:

$$W_a = W_t - W_i, \quad (1)$$

Where W_t is total biomass, W_a is active biomass for propagation and W_i is inactive biomass for propagation. Hereby, it is assumed a negative effect of self growth inhibition of biomass for the propagative biomass as follows:

$$(dW_a/dt)|W_a = f(W_a), \quad (2)$$

Where the left side of equation is standardized growth rate on active biomass for propagation. Then the negative function of the existing biomass is simply written as logistic model [15] as follows:

$$f(W_a) = a - bW_a, \quad (3)$$

Where a and b are positive constant, respectively. From equation (2) and (3), growth rate is explained as multiple functions between active biomass itself and its negative effect of self growth inhibition, as follows:

$$dW_a/dt = W_a\,(a - bW_a). \quad (4)$$

This is concave down parabola formula of growth rate, which has maximum growth rate of $a^2/4b$ (g/day) at $b/2a$ (g) of active biomass. This equation can be solved by separation of variables, as follows:

$$W_t = \frac{a/b}{1+(a/X_0 - b)e^{-rt}} \quad (5)$$

Where W_0 is initial biomass for propagation at $t = t_0$.

This modified logistic model was investigated based on equation 3 by least square method for experimental data for W_a. Then the propagative portion of the biomass is chosen from the highest R^2 coefficient of determination. Average value from triplicates experimental data was used for the analysis. From this investigation, parameters such as growth rate (a), self growth inhibition effect (b) and maximum growth rate ($a^2/4b$) are extracted, respectively. Here, due to the continuous harvesting rate is negative effect for growth rate, the effect of the continuous harvesting is formulated from the equation 2 and 3, as follows,

$$(dW_a/dt)|W_a = (a - bW_a) - h, \quad (6)$$

Where h is harvesting rate (h>0). This can be rewritten as:

$$(dW_a/dt) = W_a\,(a - bW_a) - W_a h, \quad (7)$$

Where stable existing biomass represents the boundary condition of sustainable harvesting.

Then, next equation:

$$W_a h = W_a\,(a - bW_a) \quad (8)$$

explains production of surplus biomass as crop from the system at every one unit time. By this equation, MSY is $a^2/4b$ at $W_a = a/2b$.

RESULTS

Result of laboratory experiment showed that maximum biomass achieved was 260g, which accounted for 20.8g increase in biomass within six weeks and the growth pattern shows a sigmoid curve (Figure 1). Figure 2 shows the R^2 coefficient value of linear regression model with equation 3 along the numerically partitioned various data of inactive biomass (W_i) by equation 1. The trend of R^2 performed unimodal peak where inactive biomass was 239.2g where the highest R^2 coefficient of determination was 0.980. The 98.0% of difference in standardized growth rate on active biomass, such as $(dW_a/dt)|W_a$, was explained by logistic model (equation 3 and Figure 3). Simultaneously, parameters such as a and b were 0.113 g/day and 0.0047 g/day for a unit biomass, respectively.

Figure 4 shows the result of growth rate (dW_a/dt) against its active biomass (W_a). The trend of the growth rate had peak at intermediate active biomass and it was simulated by equation 4 and then the result was overwritten in figure 4 (R^2=0.922). The simulation explained the 92.2% of the difference in growth rate. From the result, the peak of the growth rate, *i.e.* MSY was 0.679 g/day at 12.02g of active biomass under the experimental condition. At this point, standardized growth rate was calculated by equation 3 as 0.056g/day for 1g of active biomass in the experimental condition. Thereby, growth rate was 0.0028g/day for 1g of total biomass (W_t). On the other hand, from the result of optimum a and b detected above, biomass growth pattern was simulated as shown in figure 1 by equation 5. The simulation has explained growth pattern of active biomass as 98.6%.

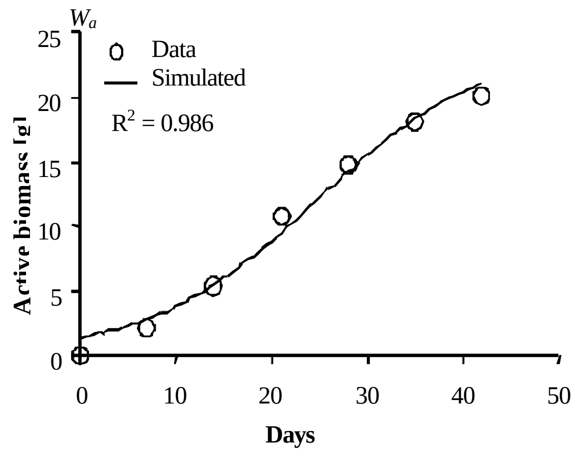

Fig. 1: Growth pattern of active portion of biomass for vegetative propagation, which was numerically partitioned by equation 1.

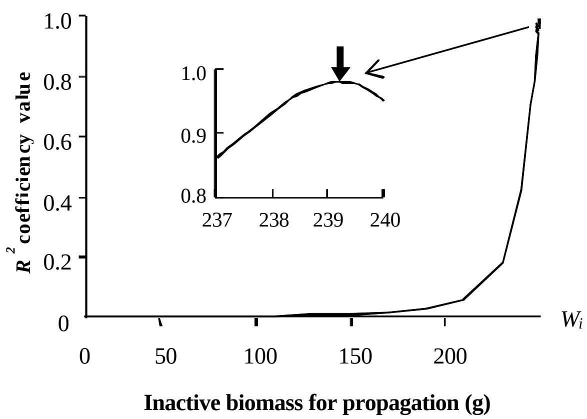

Fig. 2: Detection of optimum active biomass. R^2 coefficiency value was calculated by equation 3 for experimental data and the most optimum modified logistic model was selected, when the inactive biomass was 239.2g.

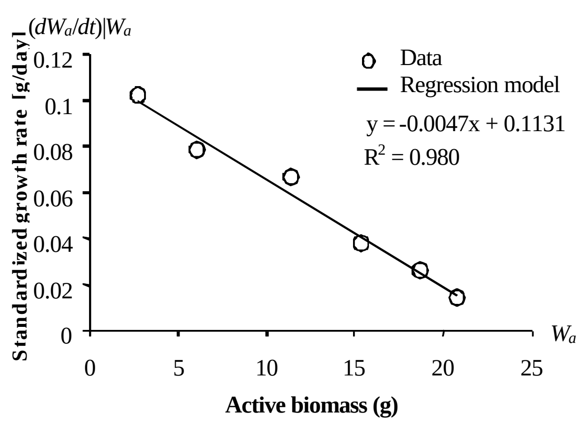

Fig. 3: The trade off relationship which caused by self growth inhibition of its biomass.

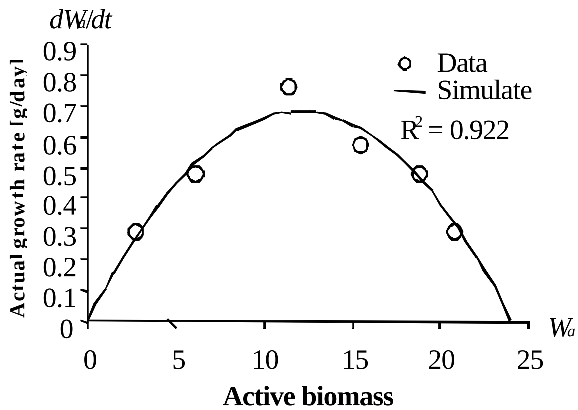

Fig. 4: The concave down parabola function of growth rate, which peak is MSY.

DISCUSSION

According to the prior empirical studies for *Gracilaria* species, efficiency and feasibility for nutrient removal have been assessed as potential phytoremediation agents. Buschmann *et al*. [20] depicts high efficiency for ammonium removal up to 90% in a tank cultivation of *Gracilaria chilensis* using fish effluents, that has permitted a biomass production of 49 kgm^{-2} year^{-1} and an agar production of 1.2 kg m^{-2} year $^{-1}$, with improved agar quality which is able to remove 50% and 90-95% of the dissolved ammonium, in winter and spring, respectively. Jones *et al*. [6] investigated the combined efficiency of a three-stage system for treating shrimp pond effluent, which consist of sedimentation, oyster filtration and finally absorption of nutrients by *G. edulis* in a controlled laboratory experiment.

This study has achieved 87% of its total NH_4 uptake within first hour. However, these studies do not consider the concept of MSY for harvesting of phytoremediation agent. Considering this gap, our experimental tank cultivation of *G edulis* has significantly pointed out a new perspective, because it has obviously exhibited concave down parabola function of growth rate (R^2=0.922). This result reveals that the most productive, *i.e.* the highest efficiency of nutrient uptake by seaweed biomass was performed by intermediate biomass of seaweed employing the MSY concept (R^2=0.980). These results clearly indicate the high applicability of logistic model and MSY concept to design a sustainable phytoremediation system.

The concept of MSY has been mainly introduced in fisheries based on an isolated fish population whose growth follows a logistic dynamics [21] in order to perform maximum sustainable harvest as the target reference points to sustain the resources [14, 22]. MSY is the equilibrium between surplus biomass production and harvested biomass, where the amount of seaweed biomass is stable, when surplus biomass is continuously removed [15]. According to this character, MSY could be one of management goals in order to facilitate the optimum harvest rate of a sustainable phytoremediation system. Our result indicates that this model can be employed to consider strategy of harvesting rate of phytoremediation agent that uptake the targeted pollutant, as it can represents the maximum potential of harvestable surplus agent during a unit time [14].

However, the significance of modification of logistic model was only elucidated by the optimum numerical partitioning for propagative portions of biomass (Figure 2). If this modification is not considered, logistic model is not applicable (R^2= 0.0003), but after taking into account the active biomass for propagation, the modified logistic model was highly applicable (R^2= 0.980). According to the significance, this study is remarkable to identify the needs to consider the propagative portion of biomass to assess the behaviour of phytoremediation agent that follows a logistic dynamics and MSY concept. In this study, the MSY was 0.68g/day at 12.02g of the active biomass under the experimental condition. At this point, 1g of active biomass produced 0.056g/day surplus biomass, *i.e.* 5.6% of maximum daily growth rate has evaluated for active biomass. However the growth rate was 0.0028g/day, *i.e.* 0.28% of daily growth for total biomass (W_t), in reality. This less growth is considered to be occurred by lack of treatment of *G. edulis* for seedlings to enhance their vegetative propagation. Thus, because the modified logistic growth pattern was highly significant (R^2= 0.980), it is clearly indicated as strategy to consider three parameters, such as, active biomass ratio (W_a/W_t), intrinsic growth rate (a) and self growth inhibition (b) to design phytoremediation system. By this point of view, it required to investigate about conditions and parameters that affect on these three parameters in future studies.

CONCLUSION

Experimental tank cultivation of *G. edulis* was conducted to investigate on applicability of logistic model and the concept of MSY to assess the potential ability of phytoremediation agent. The biomass data was numerically partitioned into active and inactive portion for vegetative propagation and then modified logistic model was consisted with propagative biomass. The result showed the high applicability of the modified logistic model (R^2=0.980) and MSY (R^2=0.922). MSY was clearly detected as 0.68g/day at 12.02g of active biomass under the experimental condition, which was 5.6% of daily maximum biomass growth rate. But it was 0.0028g/day and 0.28% for total biomass, respectively. Based on the results, MSY concept is highly significant for *G. edulis* and will be significant to produce sustainable high efficiency phytoremediation system by MSY. Thereby, as modified logistic model was highly applicable (R^2=0.980), it is clearly indicates the strategy to design a phytoremediation system is to consider the three parameters, such active biomass ratio (W_a/W_t), intrinsic growth rate (a) and self growth inhibition effect (b).

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REFERENCES

1. Xu, Y., J. Fang and W. Wei, 2008. Application of *Gracilaria lichenoides* (Rhodophyta) for alleviating excess nutrients in aquaculture. J. Applied Phycol., 20: 199-203.
2. Zhou, Y., H. Yang, H. Hu, Y. Liu, Y. Mao, H. Zhou, X. Xu and F. Zhang, 2006. Bioremediation potential of the macroalga *Gracilaria lemaneiformis* (Rhodophyta) integrated into fed fish culture in coastal waters of north China. Aquaculture, 252: 264-276.
3. Troell, M., C. Halling, A. Nilsson, A.H. Buschmann, N. Kautsky and L. Kautsky, 1997. Integrated marine cultivation of *Gracilaria chilensis* (Gracilariales, Rhodophyta) and salmon cages for reduced environmental impact and increased economic output. Aquaculture, 156: 45-61.
4. He, P., S. Xu, H. Zhang, S. Wen, Y. Dai, S. Lin and C. Yarish, 2008. Bioremediation efficiency in the removal of dissolved inorganic nutrients by the red seaweed, *Porphyra yezoensis*, cultivated in the open sea. Water Research, 42: 1281-1289.
5. Msuya, F.E. and A. Neori, 2002. *Ulva reticulata* and *Gracilaria crassa*: Macroalgae that can biofilter effluent from tidal fishponds in Tanzania. West Indian Ocean J. Marine Sciences, 1: 117-1126.
6. Jones, A.B., W.C. Dennison and N.P. Preston, 2001. Integrated treatment of shrimp effluent by sedimentation, oyster filtration and macroalgal absorption: a laboratory scale study. Aquaculture, 193: 155-178.
7. Besada, V., J.M. andrade, F. Schultze and J.J. González, 2009. Heavy metals in edible seaweeds commercialised for human consumption. J. Marine Systems, 75: 305-313.
8. Luning, K. and S. Pang, 2003. Mass cultivation of seaweeds: current aspects and approaches. J. Applied Phycology, 15: 115-119.
9. Capo, T., J. Jaramillo, A. Boyd, B. Lapointe and J. Serafy, 1999. Sustained high yields of *Gracilaria* (Rhodophyta) grown in intensive large-scale culture. J. Applied Phycol., 11: 143-147.
10. Ferrell, J. and V. Sarisky-Reed, 2010. National Algal Biofuels Technology Roadmap in A technology roadmap resulting from the National Algal Biofuels Workshop, Daniel Fishman, *et al*., US Department of Energy: US.
11. Jayasankar, R. and N. Ramamoorthy, 1997. Propagation of *Gracilaria edulis* (Gmelin) Silva by Reproductive Method. Indian J. Fisheries, 44: 353-360.
12. Marinho-Soriano, E., R.A. Panucci, M.A.A. Carneiro and D.C. Pereira, 2009. Evaluation of *Gracilaria caudata* J. Agardh for bioremediation of nutrients from shrimp farming wastewater. Bioresource Technol., 100: 6192-6198.
13. Schuenhoff, A., M. Shpigel, I. Lupatsch, A. Ashkenazib, F.E. Msuya and A. Neori, 2003. A semi-recirculating integrated system for the culture of fish and seaweed. Aquaculture, 221: 167-181.
14. Casas-Valdez, M., D. Lluch-Belda, S. Ortega-Garia, S. Hernandez-Vazquez, E. Serviere-Zaragoza and D. Lora-Sanchez, 2005. Estimation of maximum sustainable yield of *Gelidium robustam* seaweed fishery in Mexico. Journal of the Marine Biological Association of the United Kingdom, 85: 775-778.
15. Mahujchariyawong, J. and I.S., 2001. Modelling of environmental phytoremediation in eutrophic river-the case of water hyacinth harvest in Tha-chin River, Thailand. Ecological Modelling, 1: 121-134.
16. Kaladharan, P., K. Vijayakumaran and V.S.K. Chennubhotla, 1996. Optimization of certain physical parameters for the mariculture of *Gracilaria edulis* (Gmelin) Silva in Minicoy lagoon (Laccadive Archipelago). Aquaculture, 139: 265-270.

17. Lobban, S.C. and H. P.J. 1994. Seaweed ecology and physiology. UK: Cambridge University Press.
18. Lee, R.E., 1999. Phycology. 4th ed: Cambridge University Press.
19. Ohmi, H., 1958. The species of Gracilaria and Gracilariopsis from Japan and adjacent waters. Mem Fac Fish, Hokkaido Univ, 6: 1-66.
20. Buschmann, A.H., *et al*., 1996. Integrated tank cultivation of salmonids and *Gracilaria chilensis* (Gracilariales, Rhodophyta). Hydrobiologia, 326-327(1): 75-82.
21. Legovic, T., J. Klanjscek and G.S. 2010. Maximum sustainable yield and species extinction in ecosystems. Ecological Modelling, 221: 1569-1574.
22. Jensen, A.L., 2002. Maximum harvest of a fish population that has the smallest impact on population biomass. Fish Resources, 57: 89-91.
23. Reddy, C., B. Jha, Y. Fujita and M. Ohno, 2008. Seaweed micropropagation techniques and their potentials: an overview. J. Applied Phycol., 20: 609-617.
24. Glenn, E.P., D. Moore, J.J. Brown, R. Tanner, K. Fitzsimmons, M. Akutigawa and S. Napolean, 1998. A sustainable culture system for *Gracilaria parvispora* (Rhodophyta) using sporelings, reef growout and floating cages in Hawaii. Aquaculture, 165(3-4): 221-232.