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Estimating the carrying capacity of green mussel cultivation by using net nutrient removal model

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ABSTRACT

This study aims to evaluate the nutrient removal potential and carrying capacity of green mussel cultivation by using the mass balance model. The developed model takes into consideration the green mussel growth rate, density and chlorophyll *a* concentration. The data employed in this study were based on culture conditions at Sriracha Fisheries Research Station, Thailand. Results show that net nutrient removal by green mussel is 3302, 380, and 124 mg/year/indv for carbon, nitrogen, and phosphorus respectively. The carrying capacity of green mussel cultivation was found to be 300 indv/m^2 based on chlorophyll *a* concentration which will not release phosphorus in the water environment beyond the standard (45 μg-PO_4^{-3}-P/L). Higher chlorophyll *a* concentration results in lowered green mussel carrying capacity. This model can assist farm operators with possible management strategies for a sustainable mussel cultivation and protection of the marine environment.

1. Introduction

Green mussel (*Perna viridis*) cultivation can be used to treat wastewater generated from intensive aquaculture, especially commercial fish and shrimp farms. Gao et al. (2008) found that green mussels have the potential to accumulate the waste from fish farm. They improved water quality by decreasing dissolved inorganic nitrogen (DIN) (Haamer, 1996) and the biological oxygen demand (BOD) (Chaiyakum and Tanwilai, 1992) and, thus, can be used as biofilter in estuarine and coastal areas to improve seawater quality, especially in Southeast Asia.

They are non-selective filter feeders. Free-floating microscopic creatures, especially phytoplankton, are their main food source. It has been found that they can remove large quantities of sestons from a seawater column (Chaiyakum and Tanwilai, 1992; Haamer, 1996; Gao et al., 2008; Wong et al., 2008); consequently, can control phytoplankton abundance through their filtration mechanism. However, green mussels not only uptake nutrient but also release waste through their excretion process. Both solid and soluble nutrients are released in their excretion, resulting in enrichment of nutrients in marine environment (Callier et al., 2006; McKindsey et al., 2009; Nizzoli et al., 2011; Srisunont and Babel, 2015). These enrichments can cause increased microorganism activity that subsequently causes depletion in dissolved oxygen (Slater and Carton, 2009; Jansen et al., 2012). Hence, the nutrient removal efficiency should consider nutrient uptake and release through excretion process. Thus, in order to culture green mussels without causing deterioration of the water quality in marine ecosystems, the carrying capacity of mussel cultivation must be estimated.

The carrying capacity of green mussel cultivation can be defined as the maximum number of green mussels in a farming area that will not affect seawater quality (Inglis et al., 2000; McKindsey et al., 2006). Many researchers have reported on carrying capacity models for bivalve cultures (van der Veer et al., 2006; Grant et al., 2007; Guyondet et al., 2010; Handa et al., 2011; Rosland et al., 2011; Dabrowski et al., 2013). Scope for growth (SFG) is one of the popular models to estimate nutrient removal by bivalves. The model shows assimilation rates of nutrient elements; carbon, nitrogen, and phosphorus into the bivalves through physiological processes such as filtration, excretion, and faeces production (Smaal and Widdows, 1994). However, the limitation of the model is that the source of the food cannot be identified. Unlike SFG, dynamic energy budget (DEB) shows the energy budget required for bivalves. The DEB model traces in individual organisms, the energy flow starting from the assimilation of food to the utilization of energy for processes like maintenance, growth, development, and reproduction (van der Veer et al., 2006; Dabrowski et al., 2013). The model's parameters have to be specifically calculated for each bivalve species, but not much study is done on green mussels. Another limitation is that the model does not include farm conditions, such as current speed, food concentration, and maximum bivalve density in the cultivation area.

The box model or mass balance model takes into consideration the amount of nutrients accumulated in the mussel based on input and

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output of nutrients in the environment. The research on the carrying capacity for blue mussel (*Mytilus edulis*) cultivation by Grant et al. (2007) used model parameters such as stock density, mussel growth rate, phytoplankton concentration, zooplankton concentration, and variations in the calculation of nitrate and ammonia concentrations in the seawater. However, their limitation was that they did not consider farm scale as a parameter, which may affect stock density and phytoplankton concentration. Later, Rosland et al. (2011) included more parameters in the box model such as farm conditions (spacing between longlines, farm length, and stock density) and background environmental conditions (current speed, seston concentration, and temperature). The box model is useful for mussel farm operation. However, the study concluded that the model is difficult to be used by local farmers (non-expert) as it is too broad. Moreover, the studies were focused on blue mussel (*Mytilus edulis*) which is mainly cultivated in temperate zones. None of these have been used to study green mussel cultivation in Southeast Asia. Even though there are plenty of researches on green mussel nutrient removal (Gao et al., 2008; Srisunont and Babel, 2015; Wong et al., 2008), these studies did not show the maximum green mussel stock density that could be maintained without causing unacceptable ecological damage.

The current research provides a nutrient removal model which can estimate the carrying capacity of mussel cultivation. The model developed can be used easily by non-expert users. The model's parameters (for this study) were a combination of green mussel physiology (filtration rate, assimilation rate, faeces production), environmental parameters (chlorophyll *a* concentration, total suspended solid concentration), and farming conditions (seawater velocity and stock density). The flow of carbon, nitrogen, and phosphorus present in phytoplankton and green mussel faeces, were considered. Understanding the mechanism of green mussel filtration and excretion can help in calculating the "net" nutrient removal by green mussels. Moreover, the study can also assist in finding optimum conditions required for the growth and survival of green mussels under cultivation, which can help to determine the maximum possible mussel yield that does not have a negative effect on the marine environment. This will ultimately lead to sustainable mariculture practices.

2. Materials and methods

2.1. Study area

The study area was a green mussel farm at the Sriracha Fisheries Research Station (SRI), Chon buri, Thailand. The parameters at SRI were collected in-situ and were employed for analyzing a cross section of the area (m^2), seawater water volumes (m^3), surface area (m^2), and contour depth by using a mapping program, Surfer (version 8). The speed of currents in the study area is influenced by tidal currents in the north-south direction and the seawater velocity was 0.4 m/s (average of high and low tide) (Tharapan and Anongponyoskun, 2010).

Green mussel densities were calculated in terms of the seawater surrounding per individual mussel (L/indv). Green mussel density in the mussel farm was calculated based on number of mussels divided by the total volume of seawater inside the farm.

2.2. Nutrient removal by green mussels

Nutrient removal by green mussels was calculated using a combination of the green mussel filtration model and the green mussel excretion model.

The filtration model evaluates nutrient uptake by green mussels. As shown in Table 1, different models have been employed in different mussel cultivation conditions (Tantanasarit et al., 2013a). The calculation was based on the amount of food consumed through mussel filtration. This study considered nutrient uptake as the content of carbon, nitrogen, and phosphorus in a phytoplankton cell, *Chaetoceros calcitrans,* as representative of marine phytoplankton which is the main food source for green mussels. Chlorophyll *a* concentration (μg/L) can be converted to *C. calcitrans* cell density (cells/mL) by using Eq. (1) (Tantanasarit et al., 2013a).

Table 1
Filtration model based on different culture conditions.

Culture condition	FR model	Equation
Laboratory	First order (1 h)	$FR = (26.95)(1 - e^{-0.23(x/0.0071(SL)^{\wedge}2.7454)})$
Field	First order (6 h)	$FR = (10.37)(1 - e^{-0.028(x/0.0071(SL)^{\wedge}2.7454)})$
Close system	Composite exponential (K_1)	$FR = (153.42)(1 - e^{-0.016(x/0.0071(SL)^{\wedge}2.7454)})$

Note: FR is filtration rate (L/h/g DW tissue); x is the volume of seawater (L/indv); and SL is green mussel shell length (cm) (Tantanasarit et al., 2013a).

$$\text{C.calcitrans cell density} = 0.0008 \times \text{Chl a} \quad (1)$$

Carbon, nitrogen, and phosphorus content in mussel faeces, and the corresponding release rate, were considered to evaluate nutrients released by mussels. The mussels released faeces 16.45% of the total mass dry weight of the food they consumed (Srisunont and Babel, 2015). The model ignores soluble excretion because it varies with the nutrient content in the surrounding seawater. Finally, by subtracting the nutrient released from the nutrient uptake, the net nutrient removal by green mussels was estimated using Eqs. (2) to (4).

$$N_p = FR \times \text{Chl a}\left(\frac{10^6}{0.08}\right) \times 0.0071(SL)^{2.7454} \times CNP_{pl} \times 10^{-9} \quad (2)$$

$$N_r = FR \times \text{Chl a}\left(\frac{10^6}{0.08}\right) \times 0.0071(SL)^{2.7454} \times 131 \times 10^{-9} \times 0.1645 \times CNP_f \times 10^{-3} \quad (3)$$

$$N_m = N_p - N_r \quad (4)$$

where; N_p is the nutrient uptake by the green mussel (mg/h/indv); N_r is the nutrients released by the green mussel (mg/h/indv); N_m is nutrient removal by the green mussel (mg/h/inv); FR is the filtration rate (L/h/g DW tissue) (Table 1); Chl *a* is chlorophyll *a* concentration in the seawater (μg/L); SL is the green mussel's shell length (cm); CNP_{pl} is carbon, nitrogen, and phosphorus content in *C. calcitrans* (pg/cell) which was employed as a representative of marine phytoplankton. *C. calcitrans* contains 36.24 pg C/cell, 4.76 pg N/cell, 1.27 pg P/cell, and the mass is 131 pg DW/cell (Tantanasarit et al., 2013b). CNP_f stands for the carbon, nitrogen, and phosphorus content in green mussel faeces, which are 266.07, 58.04, and 5.63 mg/g DW faeces, respectively (Srisunont and Babel, 2015).

In this study, the nutrient turn-over time from the faeces is calculated from Srisunont and Babel (2015). This can help us in understanding the amount of nutrient added into the water column due to green mussel excretions that are deposited as sediment. Although, the sedimentation rate was not evaluated in the study but the amount of nutrient release from the sediment (green mussel excreta) into the water column was estimated and represented as nutrient turn-over time.

2.3. Mass balance model

In this study, the mass balance model was employed to evaluate nutrient removal potential in an actual green mussel farming area using Eqs. (5) to (7).

$$CNP_{in}Q_{in} = N_m M + CNP_{out}Q_{out} \quad (5)$$

where, N_m is nutrient removal by the green mussel (mg/h/inv); CNP_{in} is carbon, nitrogen, and phosphorus at inflow (mg/L); CNP_{out} is carbon,