Simulation of "Net" Nutrients Removal by Green Mussel (*Perna viridis*) in Estuarine and Coastal Areas

Chayarat Tantanasarit, Sandhya Babel

***Abstract*—**Green mussels (*Perna viridis*) can effectively remove nutrients from seawater through their filtration process. This study aims to estimate "net" nutrient removal rate by green mussel through calculation of nutrient uptake and release. Nutrients (carbon, nitrogen and phosphorus) uptake was calculated based on the mussel filtration rate. Nutrient release was evaluated from carbon, nitrogen and phosphorus released as mussel faeces. By subtracting nutrient release from nutrient uptake, net nutrient removal by green mussel can be found as 3302, 380 and 124 mg/year/indv. Mass balance model was employed to simulate nutrient removal in actual green mussel farming conditions. Mussels farm area, seawater flow rate, and amount of mussels were considered in the model. Results show that although larger quantity of green mussel farms lead to higher nutrient removal rate, the maximum green mussel cultivation should be taken into consideration as nutrients released through mussel excretion can strongly affect marine ecosystem.

***Keywords*—**Carbon, Excretion, Filtration, Nitrogen, Phosphorus.

I. Introduction

MARINE bivalves can be used as biofilter in estuarine area to improve seawater quality due to the low cost operation and maintenance. The green mussel (*Perna viridis*) is a well-known biofilter in estuarine and coastal areas in Asia. It is a non-selective filter feeder. It feeds on plankton and other microscopic creatures which are free-floating in seawater. Thus, it removes large quantities of seston from seawater column [1], and can be used for controlling phytoplankton abundance in coastal water [2]. It has the potential to remove fish farm wastes at mariculture sites [3]. The mussel farming improved water quality by decreasing dissolved inorganic nitrogen (DIN) and biological oxygen demand (BOD) in an intensive shrimp farm's wastewater [4], [5]. Moreover, green mussel is a remarkable species in terms of its ability to reach very high biomass levels, to withstand environmental fluctuations, and to concentrate a variety of organic and inorganic environmental pollutants [6]. It is also harvested as commercial food around the world. Therefore, green mussels are enjoyed as food and also help in water treatment as they are biofilter.

Nevertheless, green mussels not only uptake nutrients, but also release nutrients through their excretion process. Both solid and soluble nutrients released from green mussel excretion result in enrichment of nutrient in marine environment [7]-[9]. Green mussels release their excretion in form of soluble ammonium, nitrite, nitrate and phosphate, and insoluble faeces which precipitate and deposit on sea bed. Faeces materials are biodegradable, and thus nutrients can be released back into seawater. These nutrients can promote phytoplankton growth again. Therefore, to understand net nutrient removal by green mussel, both nutrients uptake and release must be evaluated.

This study considers flow of carbon, nitrogen, and phosphorus present in phytoplankton and green mussel faeces. Understanding mechanism of green mussel filtration and excretion can help in calculating "net nutrient removal" by green mussels. Results from the study can help in understanding benefits of green mussels in terms of nutrient removal. Moreover, it also can assist in finding optimum conditions required for growth and survival of green mussels.

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II. Materials and Methodology

A. Study Area

The study area is Sriracha Fisheries Research Station, Chon buri, Thailand. The current in the study area is influenced by tidal current in North-South direction and the seawater velocity is 0.4m/sec (average of high and low tide) [10]. By using Surfer mapping program, the characteristics of seawater volume at the study area are found as shown Table I.

TABLE I
AREAS PARAMETERS OF SRIRACHA FISHERIES RESEARCH STATION COASTAL LINE AREA AND THE GREEN MUSSEL FARMING AREA

	Sriracha Fisheries Research Station Coastal Line Area	Farming Area
Cross Section Area* (m^2)	4402	938
Seawater Water Volumes (m^3)	3,281,256	729,856
Seawater Surface Area (m^2)	754,965	123,635

Note:*Cross section area was calculated for the south edge of the study area due to North-South seawater current direction

B. Nutrient Removal by Green Mussel

To find nutrient uptake, carbon, nitrogen and phosphorus content in phytoplankton cell are considered. Phytoplanktons are consumed through green mussels filtration. For nutrient release by green mussels, carbon, nitrogen and phosphorus content in mussel faeces, and the corresponding released rate are considered. These equations ignore soluble excretion because it can be vary based on nutrient content in surrounding seawater. Thus, by subtracting nutrient release from nutrient uptake, net nutrient removal by green mussel can be estimated using following equations:

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$$N_p = FR \times Chl\ a(10^6/0.08) \times 0.0071(SL)^{2.7454} \times CNP_{pl} \times 10^{-9} \quad (1)$$

$$N_r = FR \times Chl\ a(10^6/0.08) \times 0.0071(SL)^{2.7454} \times 131 \times 10^{-9} \times 0.1645 \times CNP_f \times 10^{-3} \quad (2)$$

$$N_m = N_p - N_r \quad (3)$$

where; N_p is nutrient uptake by green mussel (mg/hr/indv); N_r is nutrient release from green mussel (mg/hr/indv); N_m is nutrient removal by green mussel (mg/hr/inv); FR is filtration rate (L/hr/g DW tissue) as referred to (4); Chl*a* is chlorophyll *a* concentration in seawater (μg/L); SL is green mussel shell length (cm); CNP_{pl} is carbon, nitrogen and phosphorus content in *Chaetoceros calcitrans* (pg/cell) which was employed as representative of marine phytoplankton. It contains 36.24 pg C/cell, 4.76 pg N/cell, and 1.27 pg P/cell and mass is 131 pg DW/cell [11]; and, CNP_f is carbon, nitrogen and phosphorus content in green mussel faeces which are 266.07, 58.04 and 5.63 mg/g DW faeces, respectively [12].

$$FR = (26.95)\left(1 - e^{-0.23(x/0.0071(SL)^{\wedge}2.7454)}\right) \quad (4)$$

where, FR is filtration rate (L/hr/g DW tissue); x is volume of seawater (L/indv); and, SL is green mussel shell length (cm).

C. Mass Balance Model

In this study mass balance model was employed to describe nutrient restoration potential in actual green mussel farming area refer to (5), (6) and (7).

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

where; N_m is nutrient removal by green mussel (mg/hr/inv); CNP_{in} is carbon, nitrogen and phosphorus at inflow (mg/L); CNP_{out} is carbon, nitrogen and phosphorus at outflow (mg/L); Q_{in} is water inflow rate (L/hr); Q_{out} is water outflow rate (L/hr); M is no. of green mussel inside the farm.

$$CNP_{in} = Chl\ a(10^6/0.08) \times CNP_{pl} \times 10^{-9} \quad (6)$$

where; CNP_{in} is carbon, nitrogen and phosphorus at inflow (mg/L);Chl*a*is chlorophyll *a* concentration in seawater (μg/L); and, $CNP_{pl}$is carbon, nitrogen and phosphorus content in *C. calcitrans* (pg/cell) [11]. The term Chl*a* (10^6/0.08) comes from the calibration curve between chlorophyll *a* (μg/L) and *C. calcitrans* cell density (cells/ml) [13]. The calculation of CNP_{out} is same asCNP_{in}.

$$Q_{in} = v \times A \quad (7)$$

where; Q_{in} is water inflow rate (L/hr); *v* is seawater velocity (m/hr) at inflow; and, *A* is cross section area of the study area (m^2). The calculation of Q_{out} is done in a similar way as Q_{in}.

III. Results and Discussions

As shown in Table II nutrient uptake, release and removal by green mussels are calculated at chlorophyll *a* 4 μg/L and volume of seawater per individual mussel (5 L/indv) which represent green mussel density. This condition is found in this study, and also normally occurs in mussel farm at Sriracha Fisheries Research Station [14]. As research found by Tantanasarit et al. [13], the mussel size influences filtration rate due to difference in size and, difference in g DW tissue. Green mussel shell length increase by 1 cm/month and can be recognized as the mussel growth rate [15]. Thus, the calculation in Table II is recalculated every month as the mussels have been growing over the year. It can be seen that each month has different nutrient removal rate corresponding with the mussel growth or due to change in size. Thus, carbon, nitrogen and phosphorus removal rate by green mussel can be calculated as 3302, 380 and 124 mg/year/indv, respectively. This study evaluates nutrient uptake in the individual mussel. Results are applied to estimate the large scale uptake (the whole mussel farming area). Although most of the evaluations are from experimental finding under laboratory condition, the results can be well compared with the field observation. It can be also reasonably compared with previous researchers finding faeces release rate [16] and filtration rate [17].

Nutrient (carbon, nitrogen and phosphorus) removal potential by green mussels at the mussel farms area in Sriracha Fisheries Research Station can be evaluated by using (5), (6) and (7). Removal potential is based on actual green mussel farming condition; mussel production (17,627,945 mussels), farming area and seawater volumes as shown in Table I. Refer to (5), the chlorophyll *a* concentration at outflow is estimated by varying inflow chlorophyll *a* concentration: 5, 10, 15, 20 and 25 μg/L. Results of the simulation are shown in Table III.

It can be seen from Table III that total chlorophyll *a* removal is 3.27% (based on carbon removal). Even though the chlorophyll *a* concentration is varied, the percentage of nutrient removal is same. Hence, this range of chlorophyll *a* concentrations (5-25 μg/L) does not affect nutrient removal efficiency by green mussel. Results are in line with research by Rajesh et al. [18]. They reported that green mussels achieved high filtration and ingestion rate with an increase in algal concentrations, until a cell density of 10^5 cell/ml or chlorophyll *a* concentrations around 80 μg/L was reached.

Nutrient removal in Table III is calculated using only green mussel shell length 7cm. According to green mussel growth rate (shell length extended 1 cm/month), green mussel require at least 7 months cultivation period to reach the market size (shell length 6-7cm). This size can be harvested as commercial food [15]. Therefore, nutrient removals by different size of green mussel are calculated as shown in Table IV.

TABLE II
NUTRIENT UPTAKE, RELEASE AND REMOVAL BY GREEN MUSSEL AT CHLOROPHYLL *a* 4 μg/L AND GREEN MUSSEL DENSITY (SEAWATER 5 L/indv)

Shell Length (cm)	FR(L/hr/g DW tissue)	Nutrient Uptake (mg/mo/indv)			Nutrient Release (mg/mo/indv)			Nutrient Removal (mg/mo/indv)		
		C	N	P	C	N	P	C	N	P
1	26.95	24.96	3.28	0.87	3.95	0.86	0.08	21.01	2.42	0.79
2	24.54	152.45	20.02	5.34	24.12	5.26	0.51	128.33	14.76	4.83
3	14.76	279.11	36.66	9.78	44.16	9.63	0.93	234.95	27.03	8.85
4	8.15	339.53	44.60	11.90	53.72	11.72	1.14	285.81	32.88	10.76
5	4.78	367.32	48.25	12.87	58.12	12.68	1.23	309.21	35.57	11.64
6	3.01	381.33	50.09	13.36	60.33	13.16	1.28	321.00	36.93	12.09
7	2.01	389.07	51.10	13.63	61.56	13.43	1.30	327.51	37.68	12.33
8	1.41	393.67	51.71	13.80	62.28	13.59	1.32	331.39	38.12	12.48
9	1.03	396.58	52.09	13.90	62.74	13.69	1.33	333.84	38.40	12.57
10	0.77	398.51	52.34	13.97	63.05	13.75	1.33	335.46	38.59	12.63
11	0.60	399.84	52.52	14.01	63.26	13.80	1.34	336.58	38.72	12.67
12	0.47	400.79	52.64	14.05	63.41	13.83	1.34	337.38	38.81	12.70
SUM		3923	515	137	621	135	13	3302	380	124

Note: FR = filtration rate, mo = month, C = particulate carbon, N = particulate nitrogen, P = particulate phosphorus

TABLE III
CARBON (C), NITROGEN (N) AND PHOSPHORUS (P) REMOVAL POTENTIAL BY GREEN MUSSEL (SHELL LENGTH 7 CM) AND GREEN MUSSEL DENSITY (SEAWATER 5 L/indv) AT DIFFERENT CHLOROPHYLL *a* (CHL*a*) CONCENTRATION

	Inflow			Removal			% C Removal
Chl*a*	C	N	P	C	N	P	
(μg/L)	tons/day			tons/day			
5	7.34	0.96	0.26	0.24	0.03	0.01	3.27
10	14.69	1.93	0.51	0.48	0.06	0.02	3.27
15	22.03	2.89	0.77	0.72	0.08	0.03	3.27
20	29.37	3.86	1.03	0.96	0.11	0.04	3.27
25	36.71	4.82	1.29	1.20	0.14	0.05	3.27

TABLE IV
CARBON (C), NITROGEN (N) AND PHOSPHORUS (P) REMOVAL POTENTIAL BY GREEN MUSSEL AT DENSITY (SEAWATER 5 L/indv) AND CHLOROPHYLL *a* 4 μg/L

Shell	Inflow			Removal			% C Removal
Length	C	N	P	C	N	P	
(cm)	(tons/month)			(tons/month)			
1	176	23	6	0.37	0.04	0.01	
2	176	23	6	2.26	0.26	0.09	
3	176	23	6	4.14	0.48	0.16	
4	176	23	6	5.04	0.58	0.19	
5	176	23	6	5.45	0.63	0.21	
6	176	23	6	5.66	0.65	0.21	
7	176	23	6	5.77	0.66	0.22	
SUM	1232	161	42	29	3	1	2.35

As shown in Table IV, different size of green mussel can perform different nutrient removal. This is based on difference in filtration rate. Similar results were reported by other researchers [3], [13]. It can be found that through green mussel growth during 7 months period, the mussel can remove nutrient 2.35 % based on carbon removal.

In addition, results show that there is little nutrient removal by green mussel at Sriracha Fisheries Research Station mussel farming area. Chlorophyll *a* concentration at inflow is not much different as compared with chlorophyll *a* at outflows (Table III), and total nutrient removal is only 2.35% (Table IV). This shows that the Sriracha Fisheries Research Station costal line area still has more capacity to culture green mussels. However, the limitation of this simulation is that mussel size and density are fixed throughout the calculation. Even though, it can be seen from this calculation that more green mussels can be cultivated without effect on marine environment, there should be the maximum green mussel density. Too dense of green mussels can deplete their integrity, and also affect marine environment through their excretion [19]. Therefore, the carrying capacity of green mussel cultivation should be considered in future study in order to implement sustainable marine culture in estuarine and coastal areas.

IV. CONCLUSIONS

Combination of nutrient uptake and release can effectively demonstrate net nutrient removal by green mussel. These results provide basic information and, yet, can be applied for nutrient restoration by green mussel farming. By knowing amount of green mussel harvested from the farm, net nutrient removal by green mussel can be calculated. Finally, nutrient removal potential by green mussel based on farms at Sriracha Fishries Research Station costal line area can be estimated as 2.35 % using 7 months growth period. However, the carrying capacity of green mussel cultivation should be further validated to avoid effect of nutrient regeneration through the mussel excretions on marine environment.

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