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Original Paper

Physiological responses of the Asian green mussel (*Perna viridis*) in highly turbid waters

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Abstract

In order to simulate conditions induced by climate change, the filtration rates and pseudofaeces production of *Perna viridis* from two distinct size categories were investigated at progressively increasing total suspended solid concentrations. Filtration rates of smaller mussels increased with increasing total suspended solid concentration. For larger mussels, filtration rates increased with increased concentration up to 800 mg L^{-1}, after which filtration rate dropped sharply. Pseudofaeces production also increased with increasing total suspended solid concentration up to 600 mg L^{-1}, beyond which no further significant increase was observed for large mussels, and there was a considerable decline for small mussels. The results show that the mussels of different sizes have different filtration rates with smaller mussels ranging from 0.11 to 2.62 mg min^{-1} and in larger mussels from 0.21 to 4.83 mg min^{-1}. Pseudofaeces production ranged from 0.08 to 0.67 mg min^{-1} for small mussels and from 0.02 to 1.42 mg min^{-1} for larger mussels. These results may imply that smaller mussels are more vulnerable to siltation and high sediment load compared to larger individuals. In the natural environment, this situation can be caused by more frequent and severe typhoons resulting from climate change.

Key words: aquaculture, bivalves, filter-feeders, water quality.
Abbreviations: FR, filtration rate; PP, pseudofaeces production; TSS, total suspended solid.

Introduction

Centralized over warm tropical oceans, a typhoon or tropical cyclone is a violent circular storm distinguished by strong precipitation, high winds, and low atmospheric pressure. The Philippines rank among the countries most frequently affected by typhoons in Southeast Asia (Tran et al. 2022). The Philippine Area of Responsibility experiences annually an average of twenty typhoons (Santos 2021). Based on records, typhoons entering the region have intensified in the past two decades (Desquitado et al. 2020). Climate change, specifically increase in sea surface temperatures, is the primary cause of this typhoon intensification (Chen et al. 2021). The oceans absorb the increased temperature as the planet's climate warms due to the assimilation of greenhouse gases, such as carbon dioxide, into the atmosphere. The generation and intensification of typhoons are significantly aided by elevated sea surface temperatures (Kanada et al. 2021). Through the years, climate change has altered atmospheric circulation patterns, influencing the frequency and tracks of typhoons (Lee et al. 2020).

The frequency and intensity of typhoons can significantly impact the siltation and sediment load of water in aquatic environments. Sediment from seafloors and riverbeds may be stirred up by the intense winds associated with typhoons, resulting in an increase in water column turbidity (Lee et al. 2016; Sequeiros et al. 2019). Sediment, debris, and pollutants from the adjacent landscape may also be transferred into the water column during periods of heavy rainfall, thereby augmenting the suspended sediment load (Zhou et al. 2015; Andrade et al. 2021). Such conditions of extreme turbidity can be detrimental to aquatic organisms, particularly to sessile, filter-feeding bivalves.

The Asian green mussel, *Perna viridis* L., is an indigenous bivalve species found in the Indo-Pacific Region (Noor et al. 2019). This particular species is a member of the Mytilidae family, which is the sole family under the order Mytiloida. *P. viridis* is a large mussel with a rapid growth rate. Typically, they are found at depths of less than 10 m and have a lifespan of about three years (Soon, Ransangan 2014). *P. viridis* grows quickly, reaches maturity early, and is extremely resilient to a wide range of pollutants, salinity, and water temperature (McDonald 2012). Individuals have two similar smooth, elongated shell valves, a smooth, pear-shaped external surface with concentric development lines, and a ventral border that is slightly concave (Villaluz et al. 2016). *P. viridis* exhibits gonochorism, with fertilization taking place externally (Asaduzzaman et al. 2019).

In Philippine fisheries, *P. viridis* is an essential bivalve species. The country's green mussel aquaculture provides local fisherman with a sustainable source of income (Toralde et al. 2021). By means of estuarine and marine cultivation, this mussel species promotes the nation's food security and contributes to the aquaculture industry (Layugan et al. 2018). In addition, ecological benefits are associated with the cultivation of *P. viridis*, as these filter-feeding bivalves contribute to the enhancement of water quality through the elimination of organic particulates (Melendres, Largo 2021). Nevertheless, the physiological processes of this bivalve might be adversely affected if exposed to conditions of extremely high turbidity.

P. viridis, like other bivalves, is a suspension feeder that primarily feeds on plankton and organic matter (Wong, Cheung 1999; Tan, Ransangan 2016). Green mussels and other bivalves have a tendency to consume organic particles from the filtered matter while intentionally rejecting inorganic particles (Soon, Ransangan 2014). *P. viridis* obtains nourishment by propelling water through a series of gill filaments that strain and remove minute particles such as phytoplankton, zooplankton, and other organic substances from the water (Wong, Cheung 2001). Water and sediments are subsequently expelled through the excurrent siphon. The feeding activity of *P. viridis* is adversely impacted by a large amount of suspended particles (Luesiri et al. 2022). Extreme weather conditions could trigger this phenomenon in the natural environment (Priya et al. 2023).

Juvenile and adult *P. viridis* could potentially suffer as a result of the severe water turbidity caused by the intensified weather conditions resulting from climate change. As of now, the impact of exposing juvenile and adult Philippine green mussels to extremely turbid waters on their filtration and pseudofaeces production has not been quantified. Given the significant economic and ecological implications that this bivalve species holds for the country, it is imperative to generate such information in order to devise suitable interventions. For this reason, the influence of body size and total suspended solid (TSS) concentration on the filtration rate (FR) and pseudofaeces production (PP) of *P. viridis* was investigated in a controlled environment.

Materials and methods

Sixty green mussels (*Perna viridis*) were collected from a mussel aquaculture area in Bolinao, Pangasinan, Philippines. Water samples were taken from the collection site to determine the prevailing salinity (25 g kg^{-1}) and TSS (50 mg L^{-1}) conditions. Substrate samples were also collected for silt preparation, which was used as suspended particles during the experiment.

The green mussels were brought to the PSU-Binmaley Campus Fisheries Science Laboratory within 24 h upon collection for acclimatization. In the laboratory, *P. viridis* samples were acclimatized in a rectangular tank filled with filtered brackish water for 24 h prior to the experiment. The green mussels were not fed during the acclimatization period to ensure filtering activity throughout the experiment. Two size classes of *P. viridis*, 30 small mussels (48.34 ± 0.29 mm shell length) and 30 large mussels (65.33 ± 0.60 mm shell length) were used to observe the filtration rates and pseudofaeces production.

Substrate samples were wet sieved to separate the silt (39 μm diameter). The silt was air-dried, pounded and oven-dried to constant dry weight. Experimental concentrations of suspended silt were based on the prevailing TSS condition of the collection site. Five increasing turbidity concentrations (200, 400, 600, 800 and 1000 mg L^{-1}) and a control treatment (50 mg L^{-1}; prevailing TSS condition of the collection site) were used in the study.

The experiment employed a complete randomized design. An experimental unit, based on the work of Argente et al. (2014; 2018), included an individual mussel placed in a plastic container filled with 1 L of filtered brackish water (salinity 25 g kg^{-1}) and silt particles of the established experimental TSS concentrations. In order to attain the required salinity of 25 g kg^{-1}, brackish water for the study was prepared by mixing seawater (35 g kg^{-1}) and freshwater (0 g kg^{-1}) in a 5:2 (*v*/*v*) ratio. The container was aerated from the bottom to ensure silt particle suspension throughout the experiment. A piece of plastic was placed above the air source to avoid mussel distress which could affect filtration activity. A total of five replicates were used for each experimental TSS concentration.

Upon the placement of the mussels in each experimental unit, a wait-period of approximately two minutes was observed before the actual timing of the experiment. This was done to permit the stabilization of mussels in the experimental units. The experiment was run for 2 h. The experimental units were illuminated with a standard fluorescent lamp emitting light with an intensity of 1800 lumens. The water temperature was maintained at around 28 °C during the incubation period.

After two hours, the mussels were removed from the experimental units. The brackish water used was filtered using pre-weighed (constant dry weight) Whatmann™ GFC 47 mm filters. The filters with residues were air-dried for 24 h and oven-dried at 100 °C to constant dry weight. Similarly, the pseudofaeces that were sticking to the mussel shells and container walls were collected and placed on pre-labelled containers, air-dried for 24 h and oven-dried until they reached a constant dry weight.

This study defines FR as the amount of suspended particles that the mussel absorbs. The gills collect suspended particles, which are then carried to the stomach for processing (Penry 2000). Pseudofaeces are particles rejected by bivalves without making it through the digestive tract, because they are unsuited for consumption (Argente et al. 2024). The filtration rate (FR, mg min^{-1}) and psedofaeces production (PP, mg min^{-1}) of the *P. viridis* were calculated using the equations (Argente et al. 2014; Argente et al. 2018):

$$FR = [TSS_i - (Filter_r - Filter_i)] \ / \ Time\ elapsed, \text{ and}$$

$$PP = \ Wt\ of\ Pseudofaeces \ / \ Time\ elapsed,$$

where TSS_i is the beginning quantity (mg) of total silt in the experimental unit, $Filter_i$ is the initial weight (mg) of the filter, $Filter_r$ is the weight (mg) of the filter with residue. The time elapsed was 120 min.

Results were statistically treated using two-way ANOVA to determine the effects of body size and TSS concentrations on the FR and PP of the experimental animal. In cases of significant differences, Tukey HSD was used as a post hoc test.

Results

The filtration rate (FR) of small mussels varied between 0.11 and 2.62 mg min^{-1}, whereas those of larger size ranged between 0.21 and 4.83 mg min^{-1} (Fig. 1). The results demonstrated that FR increased significantly with increasing turbidity up to a TSS concentration of 800 mg L^{-1}. At a TSS concentration of 1000 mg L^{-1}, it appeared that the FR of smaller mussels remained unchanged, whereas a substantial decline in FR was observed in the larger individuals. FR of *P. viridis* also showed significant differences with body size. The FR of the larger mussels was found to be substantially greater than that of smaller mussels.

The pseudofaeces production (PP) in small mussels varied from 0.08 to 0.67 mg min^{-1}, while a wider range of PP was found in large mussels, ranging from 0.02 to 1.42 mg min^{-1} (Fig. 2). Like FR, PP rose as TSS increased. However, there was a notable rise in PP only until the concentration reached 600 mg L^{-1}. Beyond that point, there was no further significant increase in PP for large mussels, and there had been a considerable decrease in PP for small mussels. The results also indicated that the size variation significantly influenced the PP of *P. viridis* ($p < 0.05$).

Discussion

The increase in filtration rate (FR) of *P. viridis* seen in this study was similar to that of other experiments on this mussel and other bivalves. In other experiments, it was shown that *P. viridis* increases the FR when exposed to high levels of particulate matter until a certain limit, after which it decreases. (Wong, Cheung 1999; Rajesh et al 2001; Luesiri et al. 2022). Other bivalves, such as *Polymesoda erosa* and *Gafrarium pectinatum*, also exhibited such behavior (Argente et al. 2014; Argente et al. 2018). Filter feeding behavior of bivalves is observed to increase in response to elevated turbidity levels (Velasco, Navarro 2005). It was postulated that elevated concentrations of suspended particles, such as sediment, can frequently diminish the overall nutritional value of suspended phytoplankton cells through a process of dilution (Riisgard et al. 2001). As a consequence of climate change-induced weather phenomenon intensification, this condition also escalates and presents danger to the bivalve community. This may have impact on the bivalves' overall physiology, given that they consume substances through filtration. Mortality of *P. viridis* was observed after 15- and 20-day exposure to high concentration of suspended particles under laboratory conditions (Luesiri et al. 2022).

Filter feeders expend significant energy in filtration of suspended particles from waters that are extremely turbid (Montagnac et al. 2020). As a result, the filter feeding activity of bivalves exhibits distinct threshold limits (Argente et al. 2014; Argente et al. 2018; Luesiri et al. 2022). Beyond the threshold, the physiological response of these species to their environment could be adversely affected. An initial increase in filtration rate was observed in a study on the burrower bivalve *Paphia undulata*, which was subsequently followed by a decrease at higher concentration of suspended particles, attributed to the clam's intrinsic ability to induce valve opening and filtration activity when exposed to lower concentrations (Morillo-Manalo, Del Norte-Campos 2010). Subsequently, increased concentration of suspended particles may cause overloading of the ctenedia, the filter apparatus responsible for the valve closure and subsequent decrease in FR. Unpredictable weather fluctuations have

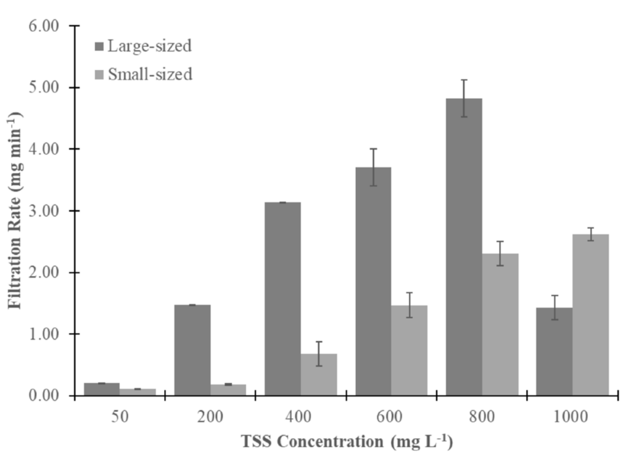

Fig. 1. Filtration rates of small- and large-sized *Perna viridis* at increasing TSS concentration. Bars indicate SE.

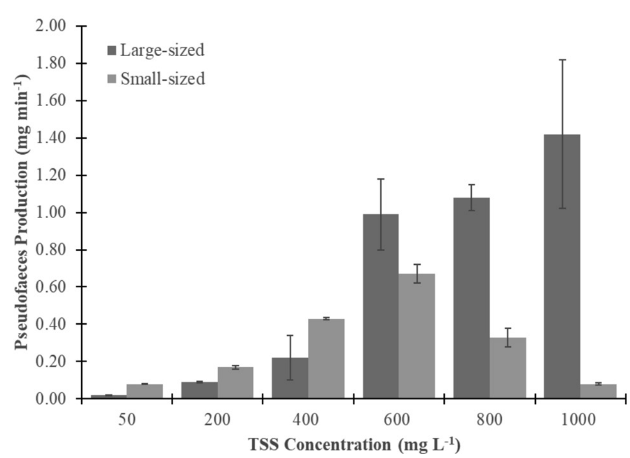

Fig. 2. Pseudofaeces production of small- and large-sized *Perna viridis* at increasing TSS concentration. Bars indicate SE.

the potential to cause turbidity in aquatic environments. In turbid waters, bivalves with a greater filtration threshold would be more resilient (Argente et al. 2014).

Bivalves generate pseudofaeces as a means of managing excessive accumulation of non-food particles in order to optimize their feeding process. PP necessitates energy expenditure as bivalves actively sort and eject undesirable particles. The feeding efficiency and energy expenditure of many bivalves were shown to be greatly impacted in environments with high turbidity (Barillé et al. 1997; Bacon et al. 1998). In this study, the production of pseudofaeces by *P. viridis* rose as the concentration of TSS increased, until it reached 600 mg L^{-1}. At this point, the PP plateaued in large mussels and significantly decreased in small mussels. Consistent patterns were noted in other experiments with *P. viridis* (Wong, Cheung 1999; Rajesh et al. 2001), and suggested in its natural habitat (Tan, Ransangan 2016). This indicates that elevated levels of TSS, potentially caused by intensified weather conditions, have a detrimental impact on the formation of pseudofaeces by *P. viridis*, possibly as a result of stress responses in the mussels.

The FR and PP of *P. viridis* vary considerably in relation to body size. In comparison to small (juvenile) mussels, larger (adult) individuals generally exhibit a greater FR and PP in highly turbid water. These physiological responses tend to increase in proportion to the size of the body, which is consistent with other bivalves (Rajesh et al. 2001). The viability of smaller individuals of these species may be significantly compromised in turbid waters caused by climate change.

The experiment was done in a controlled environment, which does not account for the ecological complexities in the natural habitat of *P. viridis*. Nevertheless, the results provided insights on the potential physiological behavior of green mussels in highly turbid water. *P. viridis* can withstand conditions of elevated turbidity, as exhibited in this study. However, similar to other bivalves, this mussel has a threshold beyond which it may experience stress that may ultimately be fatal. In its habitat, such a scenario might result from extreme weather disturbances due to climate change. These findings contribute biological information that may be useful for the management of natural and cultivated *P. viridis* populations in the Philippines. Appropriate interventions ought to be formulated in order to safeguard such populations.

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