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Physiological responses of the pectinate Venus clam, *Gafrarium pectinatum* (Bivalvia: Veneridae) to increasing turbidity concentrations

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Abstract
This study is a first step in evaluating the potential of the filter-feeding clam *Gafrarium pectinatum* as an aquaculture species in northern Philippines. Effect of increasing turbidity concentrations on the filtration and pseudofaeces production of small-sized (25.52 ±1.24 mm shell length) and large-sized (36.36 ±1.42 mm shell length) clams were quantified under laboratory conditions. Filtration rates and pseudofaeces production significantly increased (p<0.05) with increasing turbidity concentrations. Shell size was not a factor that influenced the feeding physiology of the clams. Strong linear relationship (r^2=0.71) was observed between the filtration rate and pseudofaeces production of *G. pectinatum*. The result of the study showed the *G. pectinatum* is a sturdy bivalve and could be a potential species for aquaculture.

Keywords: *Gafrarium pectinatum*, filtration, pseudofaeces, turbidity, Santiago Island

1. Introduction
The coastal environment of Santiago Island, Philippines is exposed to both natural and anthropogenic threats. Intensified weather disturbances due to the changing climate may modify the natural structure of its aquatic ecosystem. The sediments discharge into the coastal zone during heavy rainfall may result in changes in the general water quality, bottom topography and water levels of the area. External pollution loads including silt, nutrients and heavy metals are carried by flood from the upland to the coastal area. This will influence the natural structure in the intertidal and subtidal zones of the island. Siltation and eutrophication affect the marine biota in various ways. The major impacts include variations in the substrate composition, fluctuations in nutrient concentrations and increased turbidity due to increased amount of suspended solids.

Human-induced threats in the coastal zone of the island include oil and coal spills and those arising from mariculture activities like harmful algal blooms and fish kills [1]. Mariculture activities such as fish cages and fish pens have been operating in the coastal waters since 1995 [2]. In 2002, the worst fish kills in the history of the Philippines hit the aquaculture sites in Bolinao causing huge damage valued at Php 600 million [3].

Other human perturbations in the area include recreational activities such as boating, snorkeling and scuba diving which are part of island's tourism industry. Capture fisheries for finfish and invertebrate species have been practiced in the area [4].

Bivalves are the commonly gleaned invertebrates in the coastal waters of Santiago Island. These filter-feeders are ecologically significant in the aquatic ecosystem. They may comprise a significant conduit of energy and nutrients from the water column to the benthos and control materials cycling between these compartments in shallow areas. Bivalve mollusks have also emerged as important regulators of community structure and ecosystem processes. Filter-feeding by bivalves reduces plankton biomass, increases water quality and may shape plankton communities [5].

The pectinate Venus clam, *Gafrarium pectinatum*, is an economically important bivalve harvested in the coastal waters of Santiago Island. It is a dioecious marine bivalve commonly found in the intertidal and shallow waters of the island, buried in muddy gravels and sands. It has a creamy white external coloration with occasional spots on the radial ribs and with brown lunule stained with purple underneath the breaks. Maximum shell length reported was 50 mm [6].

G. pectinatum is a significant source of food and livelihood in various regions. This clam is a traditional food for most coastal populations in the tropics [7]. In central Philippines, *G. pectinatum* is consumed as food and the empty shells are utilized for shellcraft [8]. Furthermore, this bivalve is harvested and sold in the coastal towns of Western Pangasinan, northern Philippines.

In the coastal waters of Santiago Island, natural population of *G. pectinatum* may experience high turbidity condition due to unregulated anthropogenic activities and erratic weather disturbances. Currently, it is not yet known up to what extent *G. pectinatum* can tolerate high turbidity conditions that are normally encountered in natural as well as in disturbed coastal environments. There are evidences that variations in body size and concentration of suspended particles influenced the physiological responses of bivalves [9]. Thus, a laboratory experiment was conducted to determine the effect of turbidity concentration and shell size on the filtration and pseudofaeces production of *G. pectinatum.*

At the moment, the *G. pectinatum* population in Santiago Island is commercially harvested. This study will aid in the development of culture techniques for this species in the island. Results may also be used to facilitate adequate stock management in the area.

2. Materials and Methods

A total of 70 clams were collected by hand at Santiago Island in Bolinao, Pangasinan (119°26'47'' E, 16°13'45'' N) and used in the range finding and definitive experiments. Laboratory experiments were done at the PSU-BC Aquaculture Laboratory. Two size classes of *G. pectinatum*, smaller-sized (23-28 mm; 25.52 mm mean shell length) and larger-sized (33-38 mm; 36.36 mm mean shell length) were used in the experiment.

The study used silt to control turbidity. Sediment samples from the collection sites were used for the preparation of silt. Silt was prepared by dry sieving using test sieves with 0.0063 mm mesh aperture. The silt was air-dried, pounded, and oven-dried to constant dry weight.

The experimental units used in this study were adopted from the work of Argente *et al*. [10] on *Polymesoda erosa*. This include a clam that was glued on a bamboo stick using elastomeric sealant and placed in a plastic container with 1L filtered seawater (34 ppt) treated with the desired concentration of silt.

Range finding test was conducted prior to the definitive test to determine the concentrations used. Four increasing turbidity concentrations (300, 600, 900, and 1200 mg L^{-1}) were used and a control treatment (37 mg L^{-1}) which corresponds to the prevailing TSS condition in the collection site. Each treatment has six replicates.

Prior to the start of the experiment, the clams were placed in the experimental units and a wait-period of two minutes was observed to ensure clam's stable condition. The experiment was done for 120 minutes (2 hours). After two hours, the clams were removed from the experimental units. Pseudofaeces clinging from the bamboo sticks, clam shells, and from the walls of the container were collected, oven-dried (70ºC) to constant dry weight and recorded accordingly. The seawater was filtered using pre-weighed (constant dry weight) Double Rings™ No. 102 filters. The filters with residue were air-dried and oven-dried (70ºC) to constant dry weight.

The filtration rate (FR; mg min^{-1} ind^{-1}) and pseudofaeces production (PP; mg min^{-1} ind^{-1}) of the *G. pectinatum* were determined based on the following equations [10]:

$$FR = [TSS_i - (Filter_r - Filter_i)] / \text{Time elapsed}$$
$$PP = \text{Wt of Pseudofaeces} / \text{Time elapsed}$$

Where:
TSS_i = initial quantity (mg) of total silt in the experimental unit
$Filter_i$ = initial weight (mg) of the filter
$Filter_r$ = weight (mg) of filter with residue
Time elapsed = 120 min

Results were statistically treated using 2-way ANOVA to determine the effects of body size and turbidity concentrations on the filtration rate and pseudofaeces production of the experimental animal. In cases of significant differences, Tukey HSD test was used as post hoc test. A linear regression analysis was also used to establish the relationship between filtration rate and pseudofaeces production of *G. pectinatum*.

Prevailing water salinity and temperature were determined *in situ.* Three replicates of 1 L water samples were collected in the collection site for three consecutive days with no rainfall to determine the TSS condition using the technique of Argente and Estacion [11]. Five replicates of substrate samples were collected in the area to determine the TOM using the chromic acid method [12].

3. Results and discussion

The results (Fig. 1) of the experiment showed that turbidity concentration influenced the feeding physiology of *G. pectinatum*. It appeared that filtration rates significantly increased (p<0.05) with the increasing silt concentration. However, results showed that shell size was not a factor that affects the filtration rates (p>0.05). Mean filtration rates at 1,200 mg L^{-1} turbidity concentration for both small (9.26 mg L^{-1} ind^{-1}) and large (9.28 mg L^{-1} ind^{-1}) clams were significantly higher among all treatments.

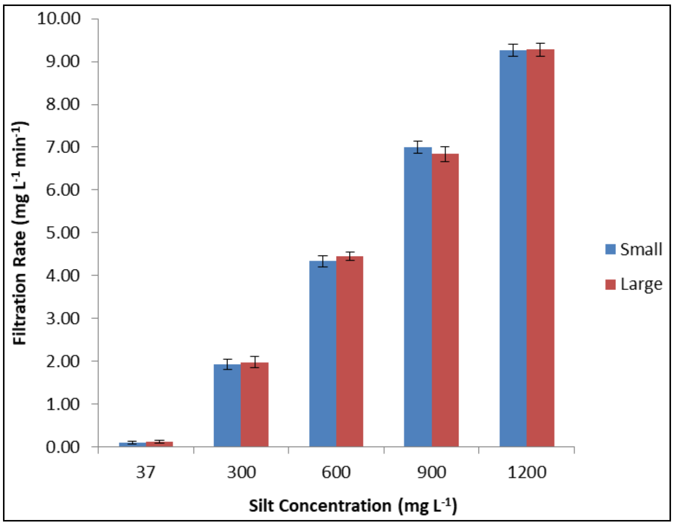

Fig 1: Filtration rate of small and large sized *G. pectinatum* at increasing turbidity concentrations. Bars indicate SD of the mean.

The filtration rate of *G. pectinatum* increased with increasing silt concentration up to 1,200 mg/L. The result suggests that *G. pectinatum* can thrive in highly turbid waters. Moreover, it appeared that *G. pectinatum* is more resilient to such condition as compared with other bivalves which can only tolerate water turbidity of 10 to 750 mg L^{-1} [10, 13, 14, 15].

The present study reported that the variation in shell size did not seem to be a strong modulator of filtration rates. This

result is also true with other bivalve such as *Paphia malabarica*, *Limnoperna fortunei* and *Polymesoda erosa* [9, 10, 16].
According to Riisgard *et al.* [17], high concentrations of suspended particles (silt) may in many situations reduce the overall food value of suspended phytoplankton cells by a diluting effect. With the intensification of weather phenomena due to climate change, this condition also intensifies and poses a threat to the bivalve community. This may affect the overall physiology of the bivalves since they are filter-feeders. However, this study revealed that *G. pectinatum* can still function normally at 1,200 mg L^{-1} turbidity concentration. This indicates that *G. pectinatum* is resilient to high turbid waters and could be a potential aquaculture species amidst climate change.
Similar results were observed in the pseudofaeces production of *G. pectinatum*. It appeared that production of pseudofaeces significantly increased (p<0.05) with the increasing silt concentration (Fig. 2). Likewise, the shell size did not considerably influence (p>0.05) the pseudofaeces production of the clams. The mean pseudofaeces production at 1,200 (small = 5.19 mg L^{-1} ind^{-1}; large = 5.38 mg L^{-1} ind^{-1}) and 900 (small = 4.13 mg L^{-1} ind^{-1}; large = 3.36 mg L^{-1} ind^{-1}) mg L^{-1} turbidity concentrations were significantly higher than that of the 600, 300 and 37 mg L^{-1} turbidity concentrations.
The production of pseudofaeces of *G. pectinatum* exhibited increasing rate at higher silt concentration. Pseudofaeces production by bivalves suggests optimum energy gain during feeding [18]. *G. pectinatum* produced more pseudofaeces in higher silt concentration to maximized energy gain instead of utilizing more to digest excess particles. This is also a process to regulate ingestion rate as well as preventing gill saturation. Iglesias *et al.* [19] equated filtration rate to ingestion rate, when all filtered material is ingested with no pseudofaeces production. Other bivalves such as *Dresseina polymorpha*, *Spisula subtruncata* and *Paphia undulata* were observed to experience similar condition [13, 15, 18].

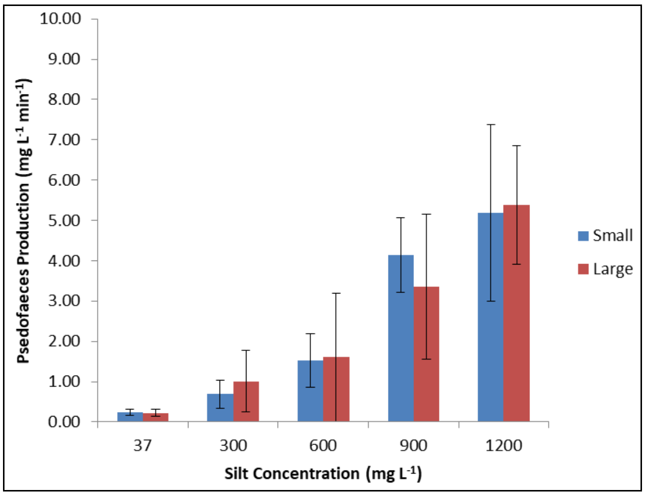

Fig 2: Pseudofaeces production of small and large size *G. pectinatum* at increasing turbidity concentrations. Bars indicate SD of the mean.

Results (Fig. 3) also showed that there was a strong linear relationship (r^2=0.7092) between the filtration rate and pseudofaeces production of *G. pectinatum.* Pseudofaeces production tends to increase as the filtration rate increases. This relationship indicates that pseudofaeces production of *G. pectinatum* is highly dependent on its filtering activities. Similar result was reported on the bivalve *Cerastoderma edule* which exhibited increasing proportion of rejected matter in association with high filtration rates [20].
The prevailing environmental conditions of the *G. pectinatum* clam bed in Santiago Island were shown in Table 1. Mean water temperature was 30.78 ˚C while the mean water salinity was 34 ppt. Mean TSS and TOM in the clam bed were 36.58 mg L^{-1} and 10.82%, respectively.

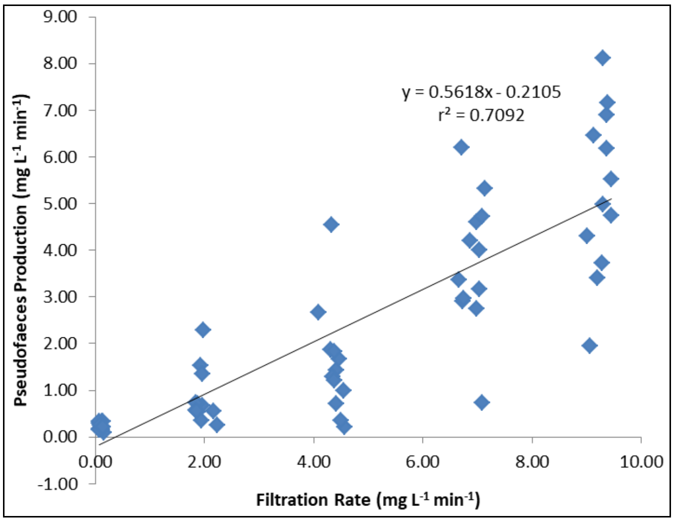

Fig 3: Relationship between the filtration rate and pseudofaeces production of *G. pectinatum.*

Table 1: Prevailing environmental conditions of the *G. pectinatum* clam bed in Santiago Island

Environmental Parameter	Range	Mean	Standard Deviation
Temperature (ºC)	29.67-31.67	30.78	3.43
Salinity (ppt)	33.67-36.00	34.00	0.44
TSS (mg/l)	28.53-45.73	36.58	2.77
TOM (%)	10.39-11.27	10.82	0.37

It appeared that *G. pectinatum* has higher threshold of water temperature as compared with other *Gafrarium* species such as *G. divaricatum* and *G. tumidum* which can only tolerate temperature ranges of 24-29 ˚C [21, 22]. This indicates that *G. pectinatum* is more resilient in high temperature environment which is a characteristic of a potential aquaculture species in this era of changing climate. Salinity was comparable with other *Gafrarium* species [21, 22], suggesting that these clams are strictly marine bivalves. TSS result suggests that turbidity on the clam bed was low during fine weather. TOM result indicates availability of nutrients in the substrate which can be resuspended, and in turn, could be a potential source of food for the clams.

4. Conclusion
G. pectinatum can survive at highly turbid waters. Filtration rate and pseudofaeces production significantly increased with increasing turbidity concentrations up to 1,200 mg L^{-1}. Moreover, shell size did not influence filtration and pseudofaces production of the clam suggesting resiliency of juvenile and adult individuals. *G. pectinatum* can be a candidate species for aquaculture.

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