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Filtration capabilities of freshwater mussel (*Lamellidens marginalis*) and apple snail (*Pila globosa*) and their potential impacts on freshwater integrated multitrophic aquaculture systems

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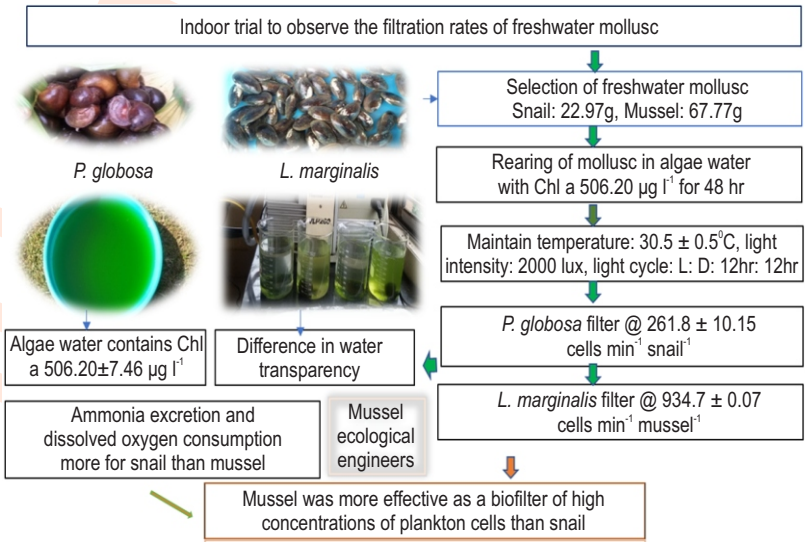
Abstract

Aim: The study aimed to assess the relative filtration rates of an indigenous freshwater mussel, *Lamellidens marginalis* and an indigenous freshwater snail, *Pila globosa*, and their suitability for incorporation into freshwater integrated multi-trophic aquaculture (FIMTA) systems.

Methodology: An indoor experimental trial was conducted in a wet laboratory (temperature: 30.5 ± 0.5, light intensity: 2000 lux, light cycle: L: D: 12hr: 12hr). The trial was performed in glass aquaria in triplicate filled with algae rich water to assess their filtration rate. Simultaneously, the impacts of these two molluscs on inorganic nitrogen and phosphorus were evaluated.



Results: *L. marginalis* exhibited filtration rates of 934.7± 0.07 cells min^{-1} mussel^{-1} and 13.79 ± 0.04 cells g^{-1} min^{-1}) against 261.8 ± 10.15 cells min^{-1} snail^{-1} and 9.74±0.15 cells g^{-1} min^{-1} for *P globosa*. Similarly, the mussel also exhibited markedly higher turbidity and chlorophyll clearance capacity ($p<0.05$) in comparison to snail, especially during initial 6-12 hr when initial concentrations of algal population, turbidity and Chl-a were high. Notably, the oxygen consumption and ammonia excretion rates were greater for snail than mussel after 24hr and at the end of the experiment.

Interpretation: The results provide quantitative information on the filtration capacity of two indigenous freshwater molluscs that have considerable local food as well as economic value and would pave the way for their utilization as ecological engineers, especially organic extractive in freshwater integrated multi-trophic aquaculture (FIMTA) system. It is concluded from the study that *L. marginalis* was more efficient in extracting almost four times algal cells than, *P. globosa*.

Key words: Eutrophication, Filtration, *Lamellidens marginalis*, *Pila globosa*

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Introduction

The demand for aquatic products is growing due to population growth and increased fish consumption per capita. By 2030, aquatic food production is forecast to increase by a further 15 percent, mainly by intensifying and expanding sustainable aquaculture production (FAO, 2022). Production has increased worldwide since 1980s, and uncontrolled intensification of production has led to environmental and social problems (Troell *et al.,* 2014). Intensification of production systems by introducing formulated feed promotes aquaculture expansion, but is associated with an increase in environmental damage. Hence, aquaculture faces environmental challenges in increasing both quantity and quality of production without increasing negative externalities like eutrophication. Filter feeding organisms like mussels are good component of aquatic ecosystems to protect the water bodies from eutrophication by decreasing phytoplankton biomass and increasing primary production by processing sediment and cycling the nutrients (thus able to shift phytoplankton community composition) (Hwang *et al.,* 2011). Bivalves are ideal candidates as a biomechanical filter, and they are used as an inexpensive method for removing suspended solids and dissolved nutrients for controlling algal growth in both marine and freshwater systems. Their filtration effectively transfers the nutrients from the water column into the sediments (Mckenzia and Özbay, 2009).

Mussels are useful tools for economical filtration in recreational lakes to control algal problems, wastewater treatment ponds, aquaculture ponds/tanks (Delegrange *et al.,* 2015), and restoration of eutrophic lakes by biomanipulation (Reeders *et al.,* 1990). Mussels are sessile and filter-feeding animals, play a significant role as cheap and valuable seafood,and they are popular as bio-indicator species for environmental degradation, such as pollution, hyper nitrification and eutrophication, including toxic algae blooms (Stirling *et al.,* 1990). They remove algae, bacteria, pollutants, and nutrients in suspended organic matter, including particle-bound phosphorus from water via filter-feeding and have a large impact on aquatic food webs. Molluscs like gastropods and bivalves can filter water by capturing food particles from the surrounding water and have substantial impacts in freshwater ecosystems. Freshwater mussels (*Lamellidens* sp.) are ciliary feeders with borrowing habits. They feed by filtering water and bioturbation of sediments. The food consists of detritus suspended in water and microorganisms like bacteria, protozoa, etc. As they filter the water, they extract nutrients bound in suspended particles, changing the properties of the water around them.

Lamellidens is used as food and produce pearls of small sizes in India and Bangladesh. They are long-lived, stationary and sensitive to changes in water quality; thus mussels are commonly used as bio-indicators of aquatic ecosystem health (Vaughn *et al.,* 2004). Freshwater snails are used as food in several countries, including Mexico, Taiwan, China, the Philippines, Thailand, Bangladesh and India. In Bangladesh, tribal people like, for instance, the Bawm, Chakma, Rajbangshi, Hajong, Garo, Marma, Manipuri, Murang, Santal, Tachanga, and Tripuri, consume snails (Baby *et al.,* 2010). Borkakati *et al.* (2009) reported nine edible freshwater snail species in North-East India. Freshwater molluscs (*Pila globosa, Bellamya bengalensis*, *Melania tuberculata,* and *Lamellidens*) play a vital role in the economy and tradition of West Bengal in India, serving as a food for 81% families belonging to more than 30 castes of general scheduled and tribal people (Baby *et al.,* 2010). *Pila globosa*, commonly known as apple snail, is a facultative filter-feeder that feeds on detritus, grazes on both epiphytic algae using its radula, and collects food both by filter-feeding and by grazing. They are delicious and protein-rich in importance next to fishes and prawns. Freshwater snails play an important role in an aquatic ecosystem, providing food for many fish species. *Pila* is one of the most preferred gastropod species and a valuable source of nutrition for ducks and fishes (Ghosh *et al.,* 2016).

Bivalve filtration rates vary with nature and concentration of algae and quality of algal diet (Cranford *et al.,* 2011), temperature (Vanderploeg *et al.,* 1995), water velocity, particle size and resting periods (Reeders *et al.,* 1990). Mussels follow some circadian rhythm and may be entrained in the light cycle (Englund and Heino, 1996). Differences in clearance rates may also reflect the experimental techniques and methods used. Most studies on mussel filtration have used the clearance method in which the decrease in particle concentration in an enclosed chamber is measured (Lei *et al.,* 1996). Most studies were conducted to improve water quality and to clarify water by using bivalves such as Asian clam (*Corbicula* sp.) and the zebra mussel (*Dreissena polymorpha*) (Reeders *et al.,* 1990). However, there are no reports on the filtration capacity of freshwater snails (*P. globosa*) and mussel (*L. marginalis*). Therefore, the present study was conducted for 48 hr in astatic indoor aquarium to observe the filtration rates of freshwater mussel (*L. marginalis*) and snail (*P. globosa*) and their potential effects on water quality metrics, *i.e.,* chlorophyll concentration, turbidity, and dissolved oxygen. The trial outcome will help in understanding the filtration behaviour of freshwater mollusc species, which has consumer preference, and economic value in North-eastern India, to develop a freshwater integrated multi-trophic aquaculture system (FIMTA) model, mollusc as organic extractives.

Materials and Methods

Animal collection and experimental design: Live adult *P. globosa* (22.97±1.55g: T_1) and *L. marginalis* (67.77± 0.64g: T_2) were procured from a local market and acclimatized for 15 days under outdoor conditions (temperature 30.5±0.5). A day prior to the commencement of the experiment, both species were transported to a clear water system for the removal of faecal matter. The experiment was conducted in an aquaria in a completely randomized design in triplicate to assess the filtering capacity of freshwater mussel and snail in the Wet Laboratory of the College of Fisheries, Lembucherra, Tripura under Central Agricultural University, Imphal, India. The glass aquaria were thoroughly cleaned and washed with $KMnO_4$ (0.1% w/v), rinsed

profusely with tap water, and air dried. The aquaria were filled with 30l of mixed algae-rich water (70% *Chlorella* sp. dominated) with initial chlorophyll-a concentration of 506.20±7.46 μgl^{-1}. Thereafter, each aquarium was stocked with the same biomass (202 ±1.5 g) of snail (T_1) and mussel (T_2) and kept in a closed chamber and maintained photo-period (L: D = 12:12), light intensity (2000 lux), and the temperature ranged between 30.0 to 30.5^{0}C.

Culture of algae, measurement of water parameters and filtration rate: The algae were cultured before the experiment in an outdoor FRP tank (500 l) by fertilization and maintaining N: P: K ratio of 12:6:4 for having a stock culture of concentrated algal cell. The water quality parameters, *i.e.,* conductivity, total dissolved solids, turbidity, and chlorophyll-a, were measured for 2 days with an EXO multi-parameter sonde, (YSI, USA)(APHA, 1998). Total ammonia, nitrate, nitrite and orthophosphate were measured utilizing a Continuous Flow Analyzer (SA3000/5000, SKALAR) equipped with an auto-sampler (SA 1100, SKALAR) as per standard methods (APHA, 2005). The plankton cells were collected and preserved in Lugol's solution and counted with a hemacytometer. The filtration rate was measured by the clearance method, where the decrease in the concentration of particles through time is estimated (Coughlan, 1969).

Statistical analyses: The results for different parameters of each treatment are expressed as mean ± S.E. The experiments were carried out in triplicate. The significant differences between means were established through a t-test utilizing SPSS (version 16) at P = 0.05.

Results and Discussion

The results of the relative impact of mussels and snails on water quality parameters, *i.e.,* conductivity, turbidity, TDS,

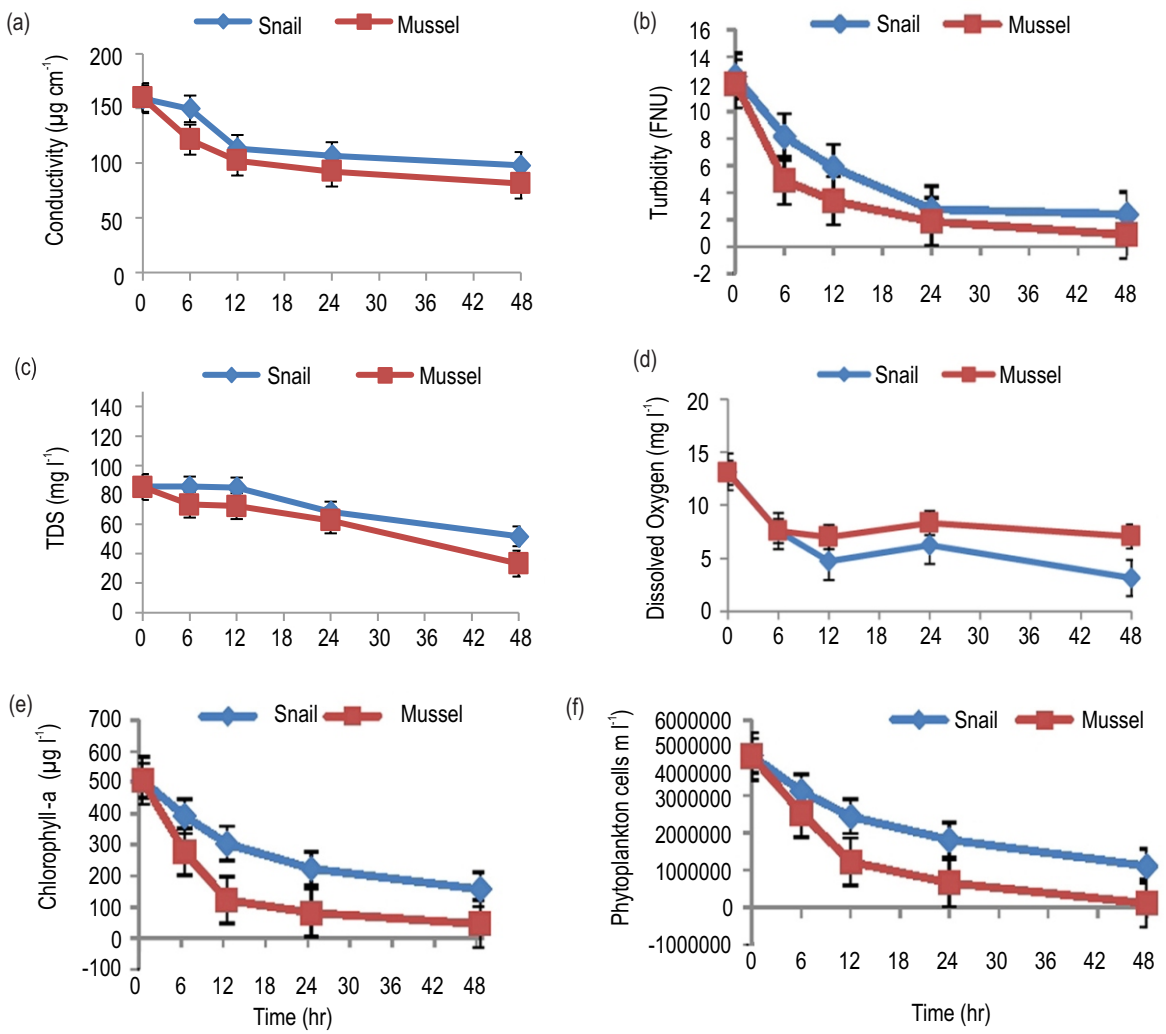

Fig. 1: Water quality parameters of freshwater integrated multi-trophic aquaculture systems: (a) Conductivity, (b) Turbidity, (c) TDS, (d) Dissolved oxygen, (e) Chlorophyll-a and (f) Phytoplankton cells during different time period upto 48 hr.

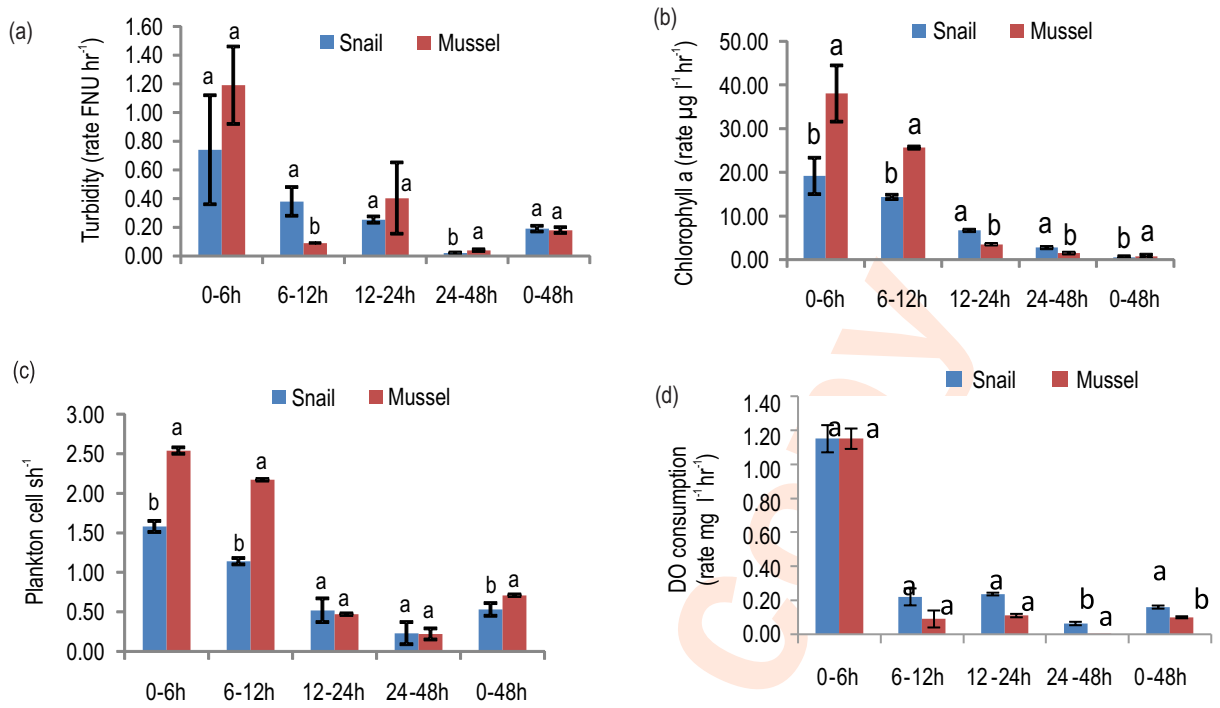

Fig. 2: Removal rates for (a) Turbidity, (b) Chlorophyll-a, (c) Plankton cells and (d) Dissolved oxygen consumption rate during different time period upto 48 hr. Values are Mean ± S.E., those that are statistically significant are presented as a,b.

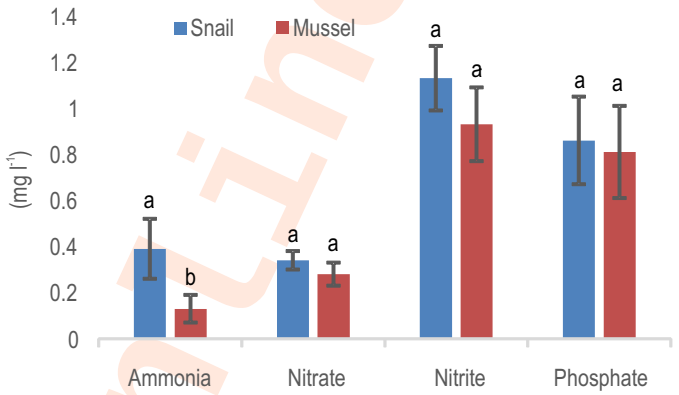

Fig. 3: Total ammonical nitrogen, Nitrate nitrogen, Nitrite nitrogen and Dissolved phosphate concentrationsat 48 hr of freshwater integrated multi-trophic aquaculture systems. Values are mean ± S.E., statistically significant are presented as a,b.

dissolved oxygen, chlorophyll-a, and plankton cells are shown in Fig. 1 (a-f). The mussel showed a more significant decreasing trend in most water quality matrices than snail. The rates of change in turbidity, chlorophyll-a, plankton cells and dissolved oxygen over time intervals are presented in Fig. 2 a-d. The removal rates of snail and mussel differed significantly during 6-12 hr and 24-48 hr for turbidity. Upto 24hr the removal rates for chlorophyll-a and plankton cells were higher in mussels than for the snail. The result indicates that the mussel was more effective as a biofilter of high concentrations of plankton cells than snail. It was observed that above 25×10^6 cells m l^{-1} concentration, the mussel filter more efficiently than the snail. However, below 25×10^6 cells ml^{-1} concentration, there was little difference between the species. The oxygen consumption rate (Fig. 1d, 2d) and ammonia excretion rate (Fig. 3) were greater for the snail than for the mussel. The snail showed a more strong significant correlation than the mussel.

L. marginalis exhibited filtration rates of 934.7 cells min^{-1} $mussel^{-1}$ and 13.79 cells g^{-1} min^{-1}) against 261.8 cells min^{-1} $snail^{-1}$

and 9.74 cells g^{-1} min^{-1} for *P. globosa* at 30^0C. There were not much reports on filtration of *Lamellidens* and *Pila* and their effects on water quality to compare our results. The filtration rates of zebra mussel (*Dresseina polymorpha*) communicated 40 to125 mlh^{-1} $individual^{-1}$ at 22^0C (Berg *et al.,* 1996). The average *in-situ* filtration rates of freshwater mussels namely *Parreysia caerulea* and *L. marginalis* reported 247-900 ml l^{-1} (Choudhury *et al.,* 2016). Ibrahim *et al.* (2002), found that the filtration rate was low at <5x 106 cells l^{-1}, maximum between 10-20x10^6 cells l^{-1} and decreased above 20x10^6 cells l^{-1} for *Mytilus* species. The average filtration rates of Chinese mystery snail, *Bellamya* described by Olden *et al.* (2009) was 106-113 ml $snail^{-1}$ hr^{-1}. Bellamya display an ontogenetic shift in feeding behavior from primarily radular grazing to filter-feeding with increasing size (age). Hence, *Bellamya chines* is play a role in coupling benthic and pelagic food webs in lake ecosystems (Wagner *et al.,* 2012). The present trial described that *P. globosa* shows both grazing and filtering behaviour, and the filtration rate was low than mussel. The filtration rate was low in snails than the mussel at high algal cell concentration, and mussel showed decreasing trend in filtration rate with reducing algal cell concentration. The findings support that the filtration rates of mollusc vary with the species, animal size, and algae concentration (Cranford *et al.,* 2011).

The results also indicated a higher ammonia concentration in the snail tank than in the mussel tank, which may be due to more excretion by snail. In snail *Biomphalaria pfeifferi*, it was reported that the amount of ammonia excreted was positively correlated with snail size (Mason, 1979). At the same time, the body content in similar mussel species *Mytilus galloprovincialis* ranged between 17.43-26.69% of live weight (Celik *et al.,* 2012) as compared to a similar snail (*Archachatina marginata*) in which the body accounted for about 38.5% of the live weight (Okonkwo and Anyaene, 2009). The presence of a higher body mass of snails without shells in the present study may explain higher ammonia content in the snail tank as compared to mussel tank. The ammonia-N production was inversely related to the quantity of food consumed (Langton *et al.,* 1977) and proportional to animal size and total carbon content (Cranford *et al.,* 2011). In the present study, *Lamellidens* performed more efficiently as biofilter than *Pila*, *i.e.,* the mussel consumed more algal cells than the snail. The results also corroborate that the mussel can efficiently remove nutrients like @ 0.11t N ha^{-1} $year^{-1}$ (Rose *et al.,* 2015). *L. marginalis* consumed less oxygen after 24 hr than *P. globosa* in the present study. The results are comparable to oxygen consumption, and the ammonia excretion rate of snail (*Pila globosa*) varied with size and species (Kim *et al.,* 2011).

Freshwater mussels perform ecological services such as nutrient recycling and storage, structural habitat, substrate and food web modification, and use as environmental monitors; regulating services such as water purification (biofiltration); and provisioning and cultural services including use as a food source, as tools and jewellery, and for spiritual enhancement (Vaughan, 2018). Mussels raised at 7.5 kg.m-3 were efficient in the bioremediation of aquaculture effluents (Siccuro *et al.*, 2020). Freshwater mussels maintain water quality in terms of total organic content, phosphorus, total nitrogen, and chlorophyll-a content in heavily polluted Dhandamoni Lake in Bangladesh (Choudhury *et al.,* 2016). Mussels such as *Mytillus edulis*, *Crassostrea gigas*, *Haliotis discus* are widely used as inorganic extractives in IMTA system to reduce chlorophyll concentration and total dissolved solids, nitrogen and phosphorus concentration (Gao *et al.,* 2019). Filippini *et al*., 2022 also confirmed that reef-forming shellfish (both oysters and mussels) can potentially act as bioremediation tools to mitigate eutrophication. The present study's results showed a similar trend mussel purify water more efficiently than the snail. Nath *et al*., (2021) also showed that *Lamellidens marginalis* mussel could be successfully included in IMTA stsyemas organic extractives to establish a harmonious relationship between aquaculture and the ecosystem. However, more research is required on food preference, correlation between size and filtration rate, and the mechanism of excretion under different environmental conditions of *P. globosa* and *L. marginalis* to standardize their stocking density in freshwater integrated multi-trophic aquaculture systems.

The results describe the understanding of mussel and snail filtration and help to predict the impact on freshwater ecosystems. To fully understand their utility in ecosystem services, it will be necessary to quantify variation in mussel filtering behaviour in response to factors such as individual size, age groups, algal composition and particle concentration. Laboratory and field studies related to feeding ecology of freshwater mussel and snail under various environmental conditions will facilitate the determination of biomass inclusion rate of these freshwater bivalves in FIMTA systems as organic extractives.

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Add-on Information

Authors' contribution: K. Nath: Designed and conducted the experiment, data analysis, writing-original draft preparation; **S. Munilkumar:** Supervision and helped in methodology and manuscript correction, editing; **A.B. Patel:** Data analysis, manuscript writing and editing; **P.K. Pandey:** Supervision; **P.B. Sawant:** Supervision.

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References

APHA: Standard Methods for the Examination of Water and Wastewater, 21st Edition.American Public Health Association, Washington D.C. USA (2005).

Baby, R.L., I. Hasan, K.A. Kabir and M.N. Naser: Nutrient analysis of some commercially important mollusks of Bangladesh. *J. Sci. Res.,* **2**, 390–396 (2010).

Berg, D.J., S.W. Fisher and P.F. Landrum: Clearance and processing of algal particles by zebra mussel (*Dreissena polymorpha*). *J. Great Lakes Res.,* **22**, 779–788 (1996).

Borkakati, R.N., R. Gogoi. and B.K. Borah: Snail: from present perspective to the history of Assam. *Asian Agri. Hist.,* **13**, 227-234 (2009).

Çelik, M.Y., S. Karayücel, I, Karayücel, R.Öztürk and B. Eyüboğlu: Meat yield, condition index, and biochemical composition of mussels (*Mytilus galloprovincialis* Lamarck, 1819) in Sinop, South of the Black Sea. *J. Aquatic Food Prod. Technol.,* **21**, 198-205 (2012).

Choudhury, G.W., A. Zieritz and D.C. Aldridge: Ecosystem engineering by mussels supports biodiversity and water clarity in a heavily polluted lake in Dhaka, Bangladesh. *Freshwater Sci.,* **35**, 188–199 (2016).

Coughlan, J.: The estimation of filtering rate from the clearance of suspensions. *Mar. Biol.,* **2**, 356-358 (1969).

Cranford, P.J., J.E. Ward and S.E. Shumway: Bivalve filter feeding: Variability and limits of the aquaculture biofilter. In: Shellfish Aquaculture and the Environment (Eds.: S.E. Shumway), pp. 81-124 (2011).

Delegrange, A., D. Vincent, M. Duret and R. Amara: The use of mussels for mitigating the noxious effect of phytoplankton spring blooms on farmed fish. *Aquacul. Enginee.,* **66**, 52–61 (2015).

Englund, V.P.M. and M.P. Heino: Valve movement of the freshwater mussel *Anodonta anatina*: A reciprocal transplant experiment between lake and river. *Hydrobiologia*, **328**, 49–56 (1996).

FAO: The State of World Fisheries and Aquaculture (SOFIA). FAO Fisheries and Aquaculture Department., 236 pages (2022).

Filippini, G., Dafforn, K.A. and A.B. Bugnot, A.B: Shellfish as a bioremediation tool: A review and meta-analysis. *Environmental Pollution*, **316**, 120614 (2022).

Gao, X., C. Ke, M. Zhang, X. Li, F. Wu and Y. Liu: N and P budgets of *Haliotis discus hanai, Apostichopus japonicas*, and *Sebastes schlegeli* in a polyculture system. *Aquacul. Res.,* **50**, 2398–2409 (2019).

Ghosh, S., C. Jung and V.B. Meyer-Rochow: Snail farming: An Indian perspective of a potential for food security. *Ann. Aquac Res.,* **3**, 1024 (2016).

Hwang, S.J., H.S. Kim, J.H. Park and B.H. Kim: Shiftin nutrient and plankton community in eutrophic lakefollowing introduction of a freshwater bivalve. *J. Environ. Biol.,* **32**, 227–234 (2011).

Ibrahim, O., N, Bascinar and M. Ozkan: The effects of phytoplankton concentration, size of mussel and water temperature on feed consumption and filtration rate of the mediterranean mussel (*Mytilus galloprovincialis* Lmk). *Turkish J. Zool.,* **26**, 167-172 (2002).

Kim, B.H., J.H. Lee and S.J. Hwang: Inter and intra-specific differences in filtering activities between two unionids, *Anodonta woodiana* and *Unio douglasiae*, in ambient eutrophic lake waters. *Ecol. Enginee.,* **37**, 1957–1967 (2011).

Langton, R.W., K.C. Haines and R.E. Lyon: Ammonia-nitrogen production by the bivalve mollusc *Tapes japonica* and its recovery by the red seaweed *Hypnea musciformis* in a tropical mariculture system. *Helgolander wiss. Meeresunters.,* **30**, 217-229 (1977).

Lei, J., B.S. Payne and S.Y. Wang: Filtration dynamics of the zebra mussel, *Dreissena polymorpha*. *Canadian J. Fisheries Aqu. Sci.,* **53**, 29–37 (1996).

Mason, P.R.: Ammonia excretion by planorbid snails-a possible mechanism for host selection by *Schistosome miracidia*. *J. Parasitol.,* **65**, 819-820 (1979).

Mckenzia, J.F. and Ozbay: Viability of a freshwater mussel (*Elliptio complanata*) as a biomechanical filter for aquaculture ponds I: Clearance rate of chlorophyll-a. *J. Appl. Aquacul.,* **21**, 205–214 (2009).

Nath, K., S. Munilkumar, A.B. Patel, D. Kamilya, P.K. Pandey and P. Banerjee Sawant: *Lamellidens* and *Wolffia* canopy improves growth, feed utilization and welfare of *Labeo rohita* (Hamilton,1822) in integrated multi-trophic freshwater aquaculture system. *Aquaculture*, **534**, 736207 (2021).

Okonkwo, T.O. and L.U. Anyaene: Meat yield and the effects of curing on the characteristics of snail meat. *Agro. Sci.,* **8**, 1 (2009).

Olden, J.D., E.R. Larson. and M.C. Mims: Home-field advantage: native signal crayfish (*Pacifastacus leniusculus*) out consume newly introduced crayfishes for invasive Chinese mystery snail (*Bellamya chinensis*). *Aquatic Ecol.,* **43**, 1073–1084 (2009).

Reeders, H.H. and A.B. Devaate: Zebra mussels (*Dreissena polymorpha*): A new perspective for water quality management. *Hydrobiologia,* **200-201**, 437–450 (1990).

Riisgard, H.U., J. Lassen. C. and Kittner: Valve-gape response times in mussels (*Mytilus edulis*): Effects of laboratory preceding-feeding conditions and *in situ* tidally induced variation in phytoplankton biomass. *J. Shellf. Res.,* **25**, 901-913 (2006).

Rose, J.M., S.B. Bricker and J.G. Ferreira: Comparative analysis of modelled nitrogen removal by shellfish farms. *Marine Pollu. Bull.,* **91**, 185–190 (2015).

Sicuro, B., B. Castelar, D. Mugetti, P. Pastorino, A. Chiarandon, V. Menconi, M. Galloni and M. Prearo: Bioremediation with freshwater bivalves: A sustainable approach to reducing the environmental impact of inland trout farms. *J. Environ. Manag.*, **276**,111327 (2020).

Stirling, H.P. and T. Dey: Impact of intensive cage fish farming on the phytoplankton and periphyton of a Scottish freshwater loch. *Hydrobiologia,* **190**, 193-214 (1990).

Troell, M., R.L. Naylor, M. Metian, M. Beveridge, P.H. Tyedmers and C. Folke: Does aquaculture add resilience to the global food system? *Procee. Nati. Acad. Sci.,* **111**, 13257-13263 (2014).

Vanderploeg, H. A., J.R. Liebig. and T.F. Nalepa: From picoplankton to microplankton: Temperature-driven filtration by the unionid bivalve *Lampsilis radiata* siliquoidea in Lake St. *Clair. Cana. J. Fisher. Aqu. Sci.,* **52**, 63–74, (1995).

Vaughn, C.C.: Ecosystem service provided by freshwater mussels. *Hydrobiologia*, **810**, 15-27(2018).

Vaughn, C.C., K.B. Gido. and D.E. Spooner: Ecosystem processes performedby unionid mussels in stream mesocosms: Species roles and effects of abundance. *Hydrobiologia*, **527**, 35-47(2004).

Wagner, A.A., S. Volkman and P.M.A. Dettintinger-Klemm: Benthic–pelagic coupling in lake ecosystems: The key role of chironomid pupae as prey of pelagic fish. *Ecosphere*, **3**, 14 (2012).