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Mangrove molluscs: An overlooked faunal community with ecological and economic importance

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1. Background

Molluscs are among the important phylum of invertebrates inhabiting aquatic and terrestrial ecosystems, also found in the mangrove ecosystem. A recent report by Rosenberg [1] estimated 70,000‒76,000 molluscan species which includes marine (43,600 ± 900), freshwater (5,100 ± 150) and terrestrial species including Stylommatophora (24,380 ± 2000). Molluscs form an integral part of the mangrove ecosystem and contribute to the bulk of the biological community structure. The complex physical structure of the mangrove habitats with micro-climate conditions ensures low predation pressure and circulation of nutrients through tidal actions in the creeks offering scope for food sources [2,3]. On the other hand, a rich diversity of molluscan fauna within the mangrove ecosystem maintains the ecosystem's health, structure, and functions. It acts as a vital link in the molluscan food web for energy transfer; promotes nutrient cycling by feeding on plant materials, sediments, and decay material; and acts as an indicator to reflect the ecosystem health. Globally, research efforts are underway to study the diversity potential of associated molluscan species in the mangroves. Further, the extreme environmental conditions prevailing in the mangroves *viz.*, varying salinity, temperature, low oxygen conditions, waterlogged soils, and tidal inundations make the inherent biodiversity with few adaptations to overcome the harsh habitat conditions. Hence, many molluscan species in the mangrove ecosystems have overlapping habitats too.

In recent times, mangrove molluscs received attention from researchers around the globe as many inventories have been made to showcase the diversity potential of mangrove ecosystem for molluscan fauna [4-11]. As the mangrove ecosystem faces continuous pressure from the human community, an apprehension on molluscan fauna concerning their distribution, ecological, economic role, threats and, conservation are vital for sustainable utilization and development.

2. Habitat-based mangrove mollusc types

The macrobenthic molluscs in the mangrove ecosystems are broadly grouped under three categories based on the habitat they occupy, though overlap was reported for some species [12]. Those were: i) Epifauna: molluscs living on the surface or muddy area of the mangrove. E.g. *Assiminea brevicula*, *Neritina violacea*, and *Onchidium* spp. This is the dominant faunal community in mangroves which include mainly detrivores [13]. ii) Infauna: molluscs which are burying themselves in the benthic substratum i.e. the upper layer of the mangrove sediment. The mangrove clam *Geloina* spp. are well adapted to the mangrove habitat, found buried in the mangrove mud and resumes filter feeding when inundated [14]. iii) Arboreal: This includes molluscs living on the mangroves including prop roots, trunks, leaves, and other tree parts. This group has an adaptive capacity towards dry conditions, hence attaching themselves to stems and surviving during the tidal exposure period [15]. The species under the families Littorinidae, Potamididae, and Ellobiidae are mostly arboreal. [16]. *Littoraria* species are classified as oceanic, spend their entire life on mangrove vegetation, and undertake vertical migration (canopy to trunk) between tides to forage [17].

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Figure 1. *Cassidula* sp., an arboreal gastropod up an *Avicennia* tree along the Mumbai coast, India.

Figure 2. An epifaunal molluscan assemblage among mangrove root structures along the Mumbai coast, India.

3. Biogeography of mangrove molluscs

The rich diversity of mangrove species reported in the Indo-West Pacific region [18]. Further, the distribution of mangrove-associated gastropod species exhibits a similar pattern according to the mangrove species richness and correlates with the mangrove canopy cover [19]. According to Ellison *et al.* [19], the mangroves and associated gastropods originated from the Tethys Sea and their modern distribution is linked to vicariance events. Among the molluscan faunal group, higher diversity was reported for gastropods in contrast to bivalves. This is mainly due to the high tolerance capacity of gastropods to hard conditions that prevail in the mangrove ecosystem [20].

The comprehensive checklist of mangrove-associated gastropods and bivalves revealed the occurrence of 274 species in India [21]. Das and Roy [22] reported 98 mollusc species from Andaman and Nicobar mangroves while Kantharajan *et al.* [7] documented 61 species from the Mumbai mangroves. The predominant gastropod families reported in Indian mangroves were Neritidae, Muricidae, Nassariidae, and Ellobiidae, while Teredinidae and Veneridae were the dominant bivalve families.

Printrakoon *et al*. [23] reported 47 molluscan species from six sites in the upper Gulf of Thailand. Zvonareva *et al.* [6] documented a total of 53 gastropods in a planted mangrove area in central Vietnam. Pepito and Cabili [24] reported 49 species of molluscs from northern Samar in the Philippines.

4. Environmental factors on the distribution

Mangroves and their zonation pattern play a significant role in structuring the arboreal, epifaunal, and infaunal molluscan communities with surface elevation. The existence of mangroves influences the sediment characteristics including grain size, organic matter, and micro-habitat availability. The abundance/density, width, and age of the mangrove stand influence the availability of micro-habitats in the ecosystem. This determines the overall diversity, assemblage structure, composition and abundance of molluscan species [25,26]. The distribution and density of an arboreal mangrove mollusc *Littoraria melanostoma* was reported to be positively influenced by the abundance *Aegiceras corniculatum* while it was negatively correlated with the abundance of *Bruguiera gymnorhiza* attributed to their tree height and crown structure [27]. Overall benthos diversity and abundance of epifaunal molluscs in particular, are positively influenced by *Avicennia marina* which is known to trap a high volume of drift algae in its pneumatophores, which acts as a food source [28].

The distribution and diversity of molluscs in intertidal ecoregions including mangrove forests are influenced by various environmental parameters *viz.*, water temperature, pH, salinity, turbidity, current velocity, dissolved oxygen, and nutrients (phosphate, nitrate) [29,30]. The water temperature influences the molluscan assemblage structure and diversity [10]. Likewise, salinity influences the species assemblage and distribution pattern. For example, the landward edge of the mangrove forest area receives a sizeable inflow of freshwater often inhabited by freshwater and brackish water molluscs including, gastropod genus *Faunus*, *Macrochlamys*, and *Physella* [7,31]. The low species richness reported in the mangrove ecosystems of Gulf countries is attributed to the prevailing high salinity and temperature [10].

Few studies have documented the zonation pattern in the mangrove molluscs nevertheless there is a marked habitat overlap. The arboreal molluscs attach themselves to tree trunks at various heights to avoid predation and physiological stress during tidal inundation. *Littoraria scabra* is a typical oceanic and arboreal species intolerant to turbid water and substrate sediment restricted to the lower intertidal zone mangroves [17]. The major factor limiting the vertical distribution of infaunal molluscs in the mangrove forest is food availability. The majority of the infaunal molluscs consume detritus and decomposing material comes into their contact during tidal inundation [16].

Species with ubiquitous distribution *viz., Telescopium telescopium,* and *Terebralia sulcata* are linked with their lifestyle requirements and adaptations to the hardy environment [16,32]. With regards to bivalve molluscs, they prefer to stay in the vegetation area on a muddy, soft substrate with regular inundations. Hence, they are confined to a very narrow zone in the low tide area towards the seaward limit. However, few bivalves *Geloina*, *Glauconome*, *Pharella*, and *Crassostrea* are well adapted to the spray zones with varying habitat conditions [7,33].

5. Ecological role

Mangrove ecosystem structure

The predatory gastropod molluscs (e.g. *Thais* sp.) feed on the encrusting barnacles and oysters from the mangrove root structure which impede the growth of mangroves [34]. Further, the positive influence of burrowing and feeding activities of molluscs on growth and recovery in the planted mangroves was reported by a few researchers [6,26] as a ‘bioturbator’.

Few mangrove molluscs (e.g. *Cerithidea decollata* and *Terebralia palustris*) release slime which binds the surface soil particles together and helps stabilize the soil in the mangrove ecosystem [35]. This implies that the conservation of mangrove molluscs is essential for maintaining the structure and functioning of mangroves.

Habitat provision

The mangrove molluscs provide a habitat for a wide variety of faunal and floral resources including bivalves, hermit crabs, microbes, and protection against predators. A study by Barnes and De Grave [36] reported that hermit crabs use gastropod shells of mangrove-dwelling origin (>40% shell abundance) in Quirimba Island, Mozambique. Few mangrove molluscs (e.g. *Lampanella minima* and *Faunus ater*) also act as an intermediate host for trematode parasites attributed to the transmission by avian fauna visiting the mangrove forest [31,37].

Energy transfer

The molluscs in the mangrove ecosystem ensure a balanced energy flow between different trophic levels. Mangrove molluscs have multiple feeding strategies *viz.*, herbivores, carnivores, filter feeders, detritivores, and scavengers [23] that participate in the food web-based energy flow within the ecosystem. Gastropods graze the fallen mangrove leaves and consume mud formed by mangrove litter. The high density of molluscan populations reported in the mangrove ecosystem contributes to the conversion of primary production (plant material) to tertiary production (animal tissue) [23]. For instance, to a certain extent species under the genera *Cassidula*, *Ellobium*, *Melampus* and *Pythia* break down mangrove leaves and humus and induct them into the food web. These materials act as a food source for microbes, algal species, and other tiny invertebrates. The detrivores molluscan species graze on detritus material plays a vital role in energy transfer. Likewise, bivalves capture suspended particles available in the mangrove ecosystem through their filter-feeding mechanisms [38]. Molluscs in the mangrove ecosystem serve as a food source for larger organisms including finfish, shellfish, and water birds and constitute an important link between the base and tertiary levels of the food web.

Nutrient cycling

The contribution of benthos in the cycling of nutrients is well recognized. Molluscan communities are one of the most dominant groups of benthic macrofauna in the mangrove ecosystem and contribute to the process of nutrient cycling. Molluscs in the mangrove ecosystem accelerate the leaf litter degradation process through which nutrients are leached to nearby estuaries and coastal waters thus increasing productivity. For example, mud whelk *Terebralia palustris* graze on fallen mangrove leaves and mud contributes to litter dynamics and entrapping the carbon (decomposed leaf litter) within the ecosystem efficiently [39]. Molluscan faunas are involved in sediment bioturbation which leads to the reworking of anoxic sediments, and an increase in surface area thus accelerating litter degradation through enhanced microbial proliferation; trapping organic carbon inside the burrowing [40]. The mineralization of empty molluscan shells also leaches various nutrients to the water.

Biomonitoring

The diversity, distribution and dynamics of benthic organisms are vital to the health of any ecosystem and vary among pristine and disturbed habitats [41]. Molluscs, as an assemblage or individual species considered an excellent indicator of environmental health in response to the existing anthropogenic pressures for any location. This association is explored for their possible applications in environmental biomonitoring programs as bioindicators. The bioindicator assessment by Desrita and Ezraneti [42] for *Littoraria* spp., a widespread mangrove mollusc fulfilled the requirements to be a species or group of bioindicator species used in the biomonitoring program in the tropical regions. For instance, the characterization of *Littoraria scabra* from polluted mangroves revealed less abundance, smaller sized, and low-weighted individuals in comparison to the individuals collected from the unpolluted mangroves along the Tanzanian coast [43].

The gastropod species which are commonly found in the intertidal areas *viz.*, *Cerithidea obtusa*, and *Nerita crepidularia* have substantial potential to act as a biomonitor for assessing heavy metal pollution in the mangrove forests [44,45]. The occurrence of a few gastropod species *viz.*, *Neripteron violaceum*, *Cassidula* spp., and *Melampus* spp. is considered a pollution indicator in the mangrove ecosystems [5,46,47].

The long-term monitoring of gastropod molluscs in the mangrove plantations in central Vietnam revealed the dominance of eurybiotic gastropods and suggested the transitional state of the plantations. Later, Salmo *et al.* [12] demonstrated the bioindicator potential of molluscan assemblage for understanding the restoration process in planted mangroves in the Philippines. The occurrence of *Nerita polita* (infaunal and epifaunal assemblage), *Terebralia sulcata*, and *Nerita planospira* (arboreal assemblage) act as indicator species to assess the restoration trajectory of mangrove plantations. Salmo *et al.* [26] suggested that the molluscan assemblage pattern shall also be considered as an indicator for the assessment of the post-typhoon recovery in the mangrove ecosystems.

Climate change mitigation: Blue carbon

The calcareous molluscan species are considered an important storehouse of carbon which has the potential to sequester carbon in their shells made up of $CaCO_3$ (calcium carbonate) though in the (biocalcification) process, it generates some CO_2 [48,49]. The carbon in molluscan shell carbonate is obtained from atmospheric CO_2, food, water and carbonate rocks and it may lock up for millenniums. The mean values of total carbon concentration (% dry weight) of *Telescopium telescopium* collected from the eastern sector of Indian Sundarbans were reported at 37.59 and 13.90 in the soft tissues and shells, respectively [48].

Economic importance

The molluscs in the mangrove ecosystems are known for their food and medicinal values. The local community living along the backwater belt collects and consumes the gastropods and bivalves. Some commercially important mollusc species distributed in mangrove mudflats are *Tegillarca granosa* and *Crassostrea* spp. Which are widely being collected by the locals for consumption and trade. The collection of seeds of various bivalves from the mangrove environment also supports the livelihood of the mangrove-dwelling communities. Further, molluscan shells collected from mangrove mudflats are also used as ornaments, for manufacturing lime, and as poultry feeds etc. [50].

The studies on selected mangrove mollusc species revealed that it has various potential bioactive compounds and possesses antimicrobial, antioxidant, anticancer, anti-inflammatory and neuro-morphological properties. For instance, the biological extract of *Telescopium telescopium*, a mangrove epifaunal gastropod produces central nervous system (CNS)-depressant activity and decreases residual curiosity and muscle coordination [51].

6. Threats to mangrove molluscs and conservation

The environmental setting of the mangroves in the intertidal region with dynamic climatic and habitat conditions makes this ecosystem hardier for its associated biodiversity. Apart from this natural set-up, the mangrove ecosystem acts as an interface between the terrestrial landscape with a dense human population and the coastal aquatic ecosystem. Hence it faces numerous natural and anthropogenic stressors, which disturb the associated flora and faunal species including molluscs.

With regards to man-made hazards, the urbanisation and illegal felling of mangroves lead to the loss of habitats for the molluscan fauna. Mangrove deforestation and habitat modification significantly influence the distribution, diversity, and assemblage structure of the molluscan fauna. Maintaining the heterogeneous structure of the mangrove vegetation is essential to ensure the provision of complex habitats to the associated molluscs. Hence, conservation efforts should aim for the preservation and improvement of habitat integrity together, rather than the spatial extent [52].

The discharge of untreated wastewater from settlement areas/aquaculture farms and industrial effluents causes anoxic conditions in the mangrove ecosystem which eliminates the associated biodiversity from the region. The oil spill is another major pollutant that affects the benthic communities. Plastic and polyethene are regarded as major threats to the mangrove ecosystem in many parts of the world. The complex mangrove root structure traps plastic wastes both during tidal inundation and the wastewater inflow from settlement reduces the available habitat space and food availability to the benthic organisms [47].

Climate change and associated processes *viz.*, sea level rise (SLR), ocean currents change, occurrence of storm events, increased temperature, and changes in rainfall patterns affect the mangrove ecosystem [53]. The sea level rise is a major threat to the mangrove ecosystem and associated biodiversity including molluscs. It causes coastal erosion which causes the poor survival of mangroves [54]. The higher rates of SLR (8.14–6.00 mm/y) force the molluscan fauna to move towards the landward side. However, in such cases, the movement of molluscan species in the higher intertidal zone is blocked by terrestrial boundaries on the landward side. This is expected to cause interspecific competition and predation among the arboreal and infaunal molluscs in the higher intertidal zones and disturb the assemblage structure [16]. This calls for a concerted effort towards the conservation of the biota occupying the landward mangrove areas.

The occurrence of extreme events *i.e.* typhoons/storms/cyclones damages mangrove vegetation (canopy and tree density) and affects the associated faunal communities. The loss of habitat quality due to disturbed vegetation and bottom sediments and the loss of food sources due to typhoons caused the molluscan assemblage shift in the mangroves of the Philippines [26]. The sedimentation in the mangrove ecosystem alters the substrate conditions thus damaging their functional ability and biological integrity which disturbs the benthic community including molluscs [35].

The extreme change in the precipitation alters the inflow to the estuarine ecosystem where the mangroves spread predominantly. The change in the salinity conditions influences the distribution of mangroves and reduces their growth. The reduced precipitation coupled with increased evaporation forms hypersaline mudflats and affects the infaunal molluscan assemblages [53].

The occurrence of widespread mangrove dieback is linked to numerous factors, including weather, insect attack, eutrophication, sedimentation and climate change. These events cause the degradation of mangrove areas and significantly affect the richness and abundance of molluscan species [55]. The shipworms are a group of bivalves that attack dead stumps and also cause serious damage to different live mangrove plants. The studies on evaluating the ecology of mangrove molluscs including the distribution and zonation pattern, adaptability to environmental conditions, and influences of natural and anthropogenic stressors including climate change are scanty. Hence, due attention to be given to studying the biological interactions between the mangroves and the molluscan communities for their conservation and sustainable utilisation

The conservation and management of mangroves is paramount for sustainably managing and utilising the associated biodiversity including molluscs. Profiling of molluscan diversity associated with mangrove ecosystems is vital for sustaining the molluscan fishery which supports the livelihood of mangrove dwellers and explores its nutraceutical and medicinal importance. Understanding the distribution pattern of molluscs in the mangrove ecosystem under changing climatic conditions is necessary for conservation and restoration planning. Efforts may be initiated to train/capacity-building the fishers/stakeholders whose livelihoods depend on highly exploited mangrove areas towards alternative fisheries-based livelihood opportunities to reduce the pressure on mangrove ecosystems. Restoration of degraded mangrove areas and conservation of existing pristine mangrove stands will ensure sustainable management of mollusc resources in the mangrove ecosystem.

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