

## Effect of mangroves on distribution, diversity and abundance of molluscs in mangrove ecosystem: a review

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**Abstract.** The present study aims to identify relationship between the structural and ecological characteristics of mangrove ecosystem and mollusc communities. Bivalve and gastropod are considered as the main molluscs of mangrove forests and often show marked zonation patterns both horizontally and vertically. Gastropods have high distribution in the mangrove forests probably due to their mobile characteristic, while bivalves are often confined to a narrow seaward zone, due to feeding, larval settlement restrictions and sediment texture such as low pH and high organic matter. The abundance, biomass, and diversity of molluscs within mangrove communities are likely to be influenced by physical structure of the mangrove forest (including pneumatophores and associated epiphytic algae), sediment textures (enriched in organic carbon, higher pore-water salinities and smaller median grain size), mangrove detritus (enriched in tannins, refractory to digestion and nutritionally poor). Furthermore, comparative studies within mangrove stands have revealed differences in benthic biomass and diversity associated with the age of the mangroves. In general, this study will show that even relatively small-scale modifications to the structure of mangrove ecosystems can lead to significant effects on the diversity and abundance of molluscs in these habitats.

**Key Words:** ecological characteristics, mangrove ecosystem, Bivalve, gastropod.

**Introduction.** Mangroves are various types of trees up to medium height and shrubs that grow along the intertidal zone of coast or estuaries in the tropics and subtropics mainly between latitudes 25° N and 25° S (Giri et al 2011; Zhang et al 2007). They have special physiological adaptations to frequently inundation by the tides (Lewis III 2005). Numerous studies on mangrove habitats have demonstrated the high biological productivity and rich biodiversity of these ecosystems in tropical and sub-tropical regions (Lindgarth & Hoskin 2001; Valiela et al 2001; Ashton & Macintosh 2002; Macintosh et al 2002). Despite the physical and biological fragility of these coastal ecosystems, they provide a wide range of ecological services such as: (1) improve water quality by filtering and assimilating pollutants; (2) stabilize and improve the soil and protect shorelines from erosion; (3) maintain biodiversity and genetic resources; (4) provide feeding, reproductive, shelter and nursery sites to several terrestrial and aquatic species; (5) regulate important processes of estuarine chemical cycles and (6) capture carbon dioxide (Ronnback 1999; Sydenham & Thomas 2003; Kathiresan & Rajendran 2005).

Mangroves formerly occupied ~75% of tropical coasts and inlets (Farnsworth & Ellison 1997), but today they only line ~25% of the world's tropical coastlines (World Resources Institute 1996). For the Asia-Pacific region an annual deforestation rate of 1% is considered to be a conservative measure (Ong 1995). More than 50% of the loss in mangrove area can be attributed to conversion into shrimp pond aquaculture. Other factors influencing the global decline of mangrove systems are widespread urban,

agricultural, and industrial development, as well as pollution and overfishing (Macintosh 1996; Valiela et al 2001). These mangrove losses have resulted in a reduction in biodiversity and the abundance of macrofauna, particularly seafood. In fact, the ecological basis for economic value of seafood production is supported by mangrove ecosystems (Ronnback 1999). Mangroves play a vital role in the energy budget of tropical coastal areas by providing significant nutrient supplies to adjacent benthic and pelagic food webs (Kieckbusch et al 2004; Alfaro 2006). However, the pathways and mechanisms by which this primary productivity is transferred to higher trophic levels and its ability to support secondary productivity can be difficult to identify.

Molluscs are one of the dominant invertebrate groups in the mangrove community and are thought to play an important ecological role in the structure and function of mangrove systems (Nagelkerken et al 2008; Printrakoon et al 2008). They have been recognized as an important link in the transfer of organic matter from mangroves to the third trophic level (secondary consumer such as fish and bird) and numerically dominant species are generally viewed as the main contributors of this energy transfer (Kieckbusch et al 2004; Persic et al 2004; Alfaro 2006). Molluscs also form an edible source for coastal population. For example, human populations in northern and north-eastern Brazilian coastal areas depend heavily on certain molluscs (e.g. mussels, oysters, clams and some shipworm species) as sources of food (Pereira-Barros & Pereira-Barros 1988), especially low-income households (Glaser 2003). On the other hand, abundance and diversity of molluscs have been historically used as an indicator of ecosystem health and local biodiversity in mangrove (Amin et al 2009; Bryan et al 1983). Macintosh et al (2002) suggested the use of the family Potamididae (gastropod) as bio-indicator of ecological changes in the mangroves. Besides, molluscs are utilized for ornamental trade, pharmacological products and in the manufacture of lime and cement (Jaiswar & Kulkarni 2005). Despite their ecological and economic importance, there are few specific quantitative data on the diversity, density and biomass of molluscs in mangroves (Jiang & Li 1995; Nagelkerken et al 2008; Printrakoon et al 2008) and many species of molluscs are suffering from the threat of extinction (Kay 1995). Spatio-temporal variations in the availability of food, shelter and hydrodynamic ability of mangroves to retain immigrating larvae and juveniles affect the quality of individual microhabitats for macrofauna (Ronnback 1999).

The present study aims to identify relationship between the structural and ecological characteristics of mangrove ecosystem and mollusc communities to find whether habitat modification and changes to the structural complexity would significantly affect the diversity and abundance of molluscs in a mangrove ecosystem. Also, these findings may be useful in the selection and planning of areas for conservation and in evaluation of biodiversity in the coastal habitats.

**Dominant molluscs of mangrove ecosystem.** Together with decapod crustaceans, molluscs are the most well represented taxon of marine origin in mangrove forests (Plaziat 1984; Kathiresan & Bingham 2001). The high density and biomass of molluscs in mangroves is evidence of their ecological importance in converting primary production from the trees into animal tissue, available to higher trophic levels. Bivalve and gastropod are considered as the main molluscs of mangrove forests and comprise an important trophic component of detritus-based food webs (Coull et al 1995).

Molluscs living in mangroves can be divided into native molluscs in mangrove ecosystem (e.g., *Cerithidea cingulata*, *Terebralia palustris* and *Nerita planospira*), facultative molluscs (e.g., *Littoraria scabra* and *Crassostrea cucullata*) and migrant molluscs (e.g., *Nerita undata* and *Clypeomorus moniliferus*) (Irma & Sofyatuddin 2012). Several explanations have been proposed to explain why many mollusc species utilize mangroves during at least one stage of their life cycle. There are three most widely accepted explanations related to food abundance, shelter from predation and the hydrodynamic ability of mangroves to retain immigrating larvae and juveniles (Ronnback 1999). In mangroves, molluscs occupy all the levels of the food web, as predators, herbivores, detritivores and filter feeders (Cannicci et al 2008), but in general, filter feeders and detritivores dominate in terms of density and biomass (Printrakoon et al

2008). This is consistent with the mangrove ecosystem being a detritus-based system dependent on the breakdown of mangrove products by a combination of physical, chemical and biological activities (Hutchings & Saenger 1987).

**Gastropods.** Gastropods are typically one of the dominant and most conspicuous macrofauna in mangrove systems, and occupy a wide range of ecological niches (Cantera et al 1983; Plaziat 1984). A number of gastropod genera (e.g., *Ellobium*) and species (e.g., *L. scabra*, *T. palustris*) seem to occur exclusively in mangrove systems (Plaziat 1984). The gastropods are suitably adapted to various macrohabitats of the mangrove ecosystems. Marine species are found in the bottoms as well as in water bodies. Pulmonate snail and several other groups have conquered mangrove lands with the elimination of the gills and conversion of the mantle cavity into lungs (Shanmugam & Vairamani 1999). Also, species restricted to the tree zones have developed mechanisms such as resorbing calcium carbonate from internal shell structures which allow surviving in this difficult habitat (Sanpanich et al 2004).

Most of the mangrove gastropods live on the ground. Only 20% of the gastropods in mangroves are species restricted to the tree zones (Cantera et al 1983). Littorinids such as *L. scabra* are some of the most common snails in tropical mangrove habitats. They are often found among tropical mangrove roots, trunks, and leaves and tend to move up and down with the tide to avoid immersion. Of course, the specific patterns and reasons for this vertical migration on mangrove trees are poorly understood (Slim et al 1997; Duncan & Szelistowski 1998; Fratini et al 2001; Lee & Williams 2002). The migration pattern varies with environmental conditions. For instance, *Cerithidea decollata* - a common western Indian Ocean mangrove tree climbing gastropod - exhibits difference in migration depending on: (a) high-low tide cycle, (b) day-night cycle and (c) spring-neap tidal cycle; in addition, (d) the whole pattern is strongly influenced by the zonation within the wide area that the snails are able to colonize, and which overlaps with the *Avicennia marina* belt, the mangrove species which they tend to aggregate around or cluster on (Vannini et al 2006).

The trophic position of gastropods varies in the mangrove habitat: sediment dwellers feed - selectively or not - on sediment organic matter and/or microphytobenthos (e.g., *Assimineia* spp. and *C. cingulata*) (Bouillon et al 2004), grazer snail feed on epiphytic algae on tree trunks or pneumatophores (e.g., *Onchidium* spp. and *Littoraria* spp.) (Christensen et al 2001; Lee et al 2001; Bouillon et al 2004) and some species have been reported to feed on mangrove litter and/or propagules (e.g., *Melampus coffeus* and adult *T. palustris*) (Proffitt & Devlin 2005). Predatory and scavenging species such as *Thais* spp. and *Nassarius* spp. are much less abundant (Nagelkerken et al 2008).

**Bivalvia.** Mangroves are highly zoned, typically occupying the upper half of the eulittoral and dominating the supra littoral fringe. They also grow best in the soft mud. These two aspects alone partially explain the lack of the data on mangrove bivalves, especially endemic species; the bivalves are in general best adapted to lower tidal levels and to firmer deposits. Although, *Lasaea rubra* is one of the few bivalves capable of colonizing the high inter tidal almost worldwide (Shanmugam & Vairamani 1999). Many bivalves in other marine habitats burrow into sediments but a relatively few species do this in mangrove habitats because of the anoxic conditions of the sediments. Those that do are either shallow burrowers or have special adaptations for life in anoxic conditions (Ponder et al 2000). According to Plaziat (1984), Isognomonidae and Ostreidae are abundant in mangrove area because they have higher adaptation ability in changing environmental factors such as drought due to low tide and salinity. A number of bivalves with chemo-symbiotic associations such as Lucinidae have been reported from mangroves (Lebata & Primavera 2001). Also, some bivalves, notably shipworms (Teredinidae) burrow into wood and play a very important role in the breakdown and recycling of dead wood. For example, Sivakumar & Kathiresan (1996) reported 5 species of teredinids viz., *Bankia campanellata*, *B. carinata*, *Dicyathifer manni*, *Lyrodus pedicellatus* and *Teredo furcifera*;

and 2 pholadids viz., *Martesia striata* and *M. nairi* in Pichavaram mangrove of southeast coast of India.

**Distribution of mollusks in mangrove ecosystem.** Molluscs often show marked zonation patterns in relation to tidal elevation, forest type and sediment properties in mangrove systems (Ashton 1999; Dittmann 2001). They are zoned both horizontally (i.e. along the sea-land axis) and vertically (i.e. at different heights from the ground) (Cannicci et al 2008). Therefore, mollusc communities in high and low intertidal mangroves are often distinctly different, and this relates in part to highly different environmental conditions such as hydroperiod, availability of organic matter and sediment characteristics (Lee 2008). Lower intertidal mangrove sediments (typically organic matter and silt- or clay-dominated) provide substratum for growth of benthic microalgae and macroalgae (Aikanathan & Sasekumar 1994; Sarpedonti & Sasekumar 1996). In high intertidal mangroves, the substratum is often more sandy, and the reduced frequency of tidal inundation results in a drier, more saline environment where more leaf litter accumulates and which is less suitable for growth of micro- and macroalgae. Frequent inundation in the low intertidal zone also favours the presence of filter feeders and deposit feeders (e.g., *Anomalocardia*, *Tagelus*, *Tellina*, *Macoma*, *Mya* and *Paphies australis*), whereas fauna in the high intertidal zone does not have frequent direct access to such food sources and other trophic groups such as some of bivalvia (e.g., *Donax*) and its gastropod predator (*Natica*) therefore predominate there (Beasley et al 2005; Nagelkerken et al 2008).

The distribution of gastropod species in mangrove ecosystem is influenced by a variety of factors such as light (as a major factor determining algal growth and as a factor influencing humidity), tidal elevation, salinity, sediment textures and forest type (Nagelkerken et al 2008). For example, the soil in the *Rhizophora* zone is higher in total nitrogen than *Avicennia* zones. Also, sediments containing higher salinity may reduce availability of nutrients for organisms (Kathiresan et al 1996). Almost all gastropods are categorized as a tree climber, moving up and down to follow the tide to avoid immersion (Tee 1982). Gastropods often have species-specific habitat preferences and tolerance such as particular depths or vegetation structure (Lodge 1986; Thomas 1990). However, the gastropods have high abundance and distribution in the mangrove forests probably due to their mobile characteristics (Irma & Sofyatuddin 2012).

Bivalves are often considered to be confined to a narrow seaward zone, due to feeding and larval settlement restrictions (Plaziat 1984). For example, because oysters and mussels are filter feeders, they are confined to microhabitats below mean high water, and are usually abundant in areas adjacent to open water (Macintosh 1982; Menzel 1991). Also, it may be impossible for the soft fleshy feet of infaunal bivalvia to penetrate the root masses of mangrove (Nagelkerken et al 2008). Therefore, the blood clam, *Anadara granosa*, and other cockles can be found in large numbers in mudflats on mangrove habitats, where it lies partially buried in the sediment (Macintosh 1982). In other hand, bivalves are obviously unable to tolerate long periods of exposure to air and fluctuating salinities (Sasekumar 1974). In Southeast Asia, however, *Polymesoda erosa* is adapted for a semi-terrestrial existence by living on the high shore where only occasional high tides inundate the habitat (Nagelkerken et al 2008). The conspicuous absence of bivalves in some areas of mangroves can also relate to sediment texture such as lower pH and higher organic matter. A lower sediment pH could result in exterior exoskeleton and shell erosion (Ashton et al 2003). The organic content often influences molluscan community structures and can mask the effects of low levels of contamination (Wilson & Elkaim 1992).

**Diversity and abundance of molluscs in mangrove ecosystem.** Generally, structurally complex habitats, such as seagrasses, marshes, and mangroves are known to support higher densities and diversity of benthic organisms as compared to non-vegetated areas (Edgar 1990). The complex architectures of coastal habitats provide greater number of settlement sites and enhanced nutrient availability, as well as lower predation pressure (Davis et al 2001). Numerous studies have highlighted the rich

biodiversity of mangroves associated molluscs throughout the world, including: 47 species of molluscs (31 gastropods and 16 bivalves) in mangroves of the upper Gulf of Thailand (Printrakoon et al 2008), 45 mollusc species (22 gastropods, 15 bivalves and 8 chitons) in a Venezuelan mangroves (Marquez & Jimenez 2002), 44 mollusc species, mostly gastropods, in a well-conserved mangroves in Sarawak, Malaysia (Ashton et al 2003), 39 species of gastropods in an Australian mangroves (Camilleri 1992), 28 species in the Chinese mangrove (Jiang & Li 1995) and 20 species in the Pichavaram mangrove (Kathiresan 2000). The high mangrove molluscan diversity is mainly due to the availability of a diverse range of microhabitats. On the other hand, species diversity differs strongly in different parts of the world, for example, *M. coffeus* is the only gastropod present in the mangroves of Guadeloupe (Plaziat 1984). There are several potential physical and biological differences between tropical/sub-tropical and temperate mangroves that may make extrapolations of studies inappropriate from one region to another. Mangrove stands in tropical and sub-tropical regions are regarded as highly productive ecosystems that support a rich diversity of organisms and provide important nursery habitats. The lower density and diversity of the benthic component within temperate mangroves may be related to sediment loads, tannin concentrations, lack of structural complexity, degree of consumption and decomposition of mangrove litter and tidal inundation. Lower temperatures and lower tidal inundations in warm temperate region (New Zealand) may result in lower rates of organic matter decomposition as compared to tropical and sub-tropical mangrove ecosystems. In this regard, mangrove species are important; the warm temperate region is confined with least mangrove diversity in particular *A. marina* (Alfaro 2006). The global pattern in species richness of mangrove gastropods appears to follow global patterns in mangrove tree species richness (Ellison et al 1999). Also, the higher abundance of bivalves in some area is due to the higher density of mangroves with profusely branched aerial roots for colonization of bivalves (Irma & Sofyatuddin 2012). Different mangrove plants have different environmental niches and affect their surroundings differently. For example, Printrakoon et al (2008) reported molluscan diversity in *Rhizophora* was lower than in *Avicennia*. The differences in the physical structure of the mangrove forest including pneumatophores and associated epiphytic algae can lead to significant changes in the abundance and diversity of molluscs. An experimental reduction of the abundance of *A. marina* pneumatophores and the associated epiphytic algae in the forest habitat of Moreton Bay, Queensland, Australia led to significant declines (by as much as 83%) in the number of molluscs utilising the substratum within the modified plots. Faunal composition within pneumatophore zones indicates that these habitats are important ecological transition environments between seagrasses and mangroves. Pneumatophores usually are found in high densities along the mangrove fringes, where they provide extensive surface area for settlement of transient organisms within a complex three-dimensional structure (Alfaro 2006). The presence of emergent structures, such as pneumatophores can also reduce flow rates near the bottom causing localised deposition of material suitable as food for deposit feeders (Skilleter & Warren 2000). In addition, the pneumatophores tend to trap high densities of drift algae (up to 100% cover), especially the resident floating alga, *Hormosira banksii*, which provides feeding grounds for a variety of snails (i.e., *Turbo smaragdus*, *Diloma subrostrata*, *Melagraphia aethiops*) and other invertebrates. This algal cover tends to persist over tidal cycles, and may provide a constant supply of nutrients to associated organisms (Alfaro 2006). The associated epiphytic algae also form a dense canopy that often completely obscure the sediment/leaf litter on the substratum. The presence of this dense mat of algal material may have provided protection and cover for the molluscs from predators such as toadfish *Tetractenos hamiltoni* which are locally common and are known predators of gastropods in mangrove systems (Hughes 1984; Warren 1990). The effect of removal of the epiphytic algae from the surface of the pneumatophores is reportedly as great as the removal of the entire pneumatophore (with attached algae) suggesting the molluscs may be responding primarily the presence of the algae (Kelaheer et al 1998b; Skilleter & Warren 2000).

Other factors such as mangrove detritus, the age of the mangroves and sediment characteristics can also influence the diversity and abundance of mangrove molluscs. The

diversity and total abundance of the benthic fauna is reported to vary and this is firstly dependent on detritus biomass (ash-free dry weight) and secondly on sediment composition. In addition, the most important predictor of dominant macrobenthic taxa is the detritus biomass. Although, detritus itself may not have a direct effect on the composition and abundance of benthic fauna, the source and the age of the detritus seem to be more important than the amount of the detritus for the fauna consumption (Netto & Gallucci 2003). Mangrove detritus, particularly that of *Rhizophora mangle*, is rich in tannins (Robertson 1988; Sessegolo & Lana 1991; Lee 1999). Tannins are known to be toxic to many organisms and can interfere with the feeding, digestion and colonization of detritivores (Sivakumar & Kathiresan 1990; Tietjen & Alongi 1990; Lee 1999; Rajendran & Kathiresan 1999). However, tannin concentrations increase with depth (Boto et al 1989) and it is unlikely that the lower values near the sediment surface could inhibit the small infauna occurring there. In Australia, the high proportion of tannins from mangrove detritus and mud associated with mangrove habitats has been suggested to be responsible for lower densities and biodiversity of macro-fauna within these habitats (Alongi & Christoffersen 1992; Lee 1999; Alongi et al 2000; Ellis et al 2004), and also are likely to play a major role in structuring mangrove ecosystems in New Zealand. In addition, even after a significant microbial decomposition, mangrove-derived detritus are refractory to digestion and nutritionally poor as compared to other marine detrital source (phytoplankton, microphytobenthos and macroalgae), having a high C:N ratio and relatively high lignin content (Robertson 1988; Alongi 1998). However, the results of investigations that were carried out in Brazilian mangrove showed a positive correlation between benthic fauna and detritus biomass (Netto & Lana 1997, 1999; Netto & Gallucci 2003). The answer to this apparent contradiction is probably not related to the direct consume of the detritus itself, but to the microhabitat originated by the low or high biomass of detritus in different degree of decomposition.

Sediment characteristics exhibit clear differences among habitats, except for pneumatophore and seagrass habitats. Several factors have been proposed to regulate infaunal densities and species composition in mangrove sediments: physical properties of the sediment, food availability, geochemical environment and changes in predator-prey relationships (Alongi 1989; Alongi & Sasekumar 1992). However, sediment properties vary with tidal elevation and forest type (Guerreiro et al 1996). In general, mangrove sediments are high in organic carbon, pore-water salinities and smaller median grain size (Demopoulos 2004). These sediment characteristics have crucial importance for infaunal species, since their feeding strategies tend to be highly adapted to sediment types (McLachlan et al 1995; Zhuang et al 2004). For example, Lana & Guiss (1991) found a positive correlation between increased macrofaunal abundance, organic matter and decreased sediment grain size in the mangrove of southeast Brazil. Also, changes in the sediment characteristics of northern Brazil mangrove due to currents and wave action may cause the dislocation of banks of *Mytella* and other species that burrow in soft intertidal sediments (Beasley et al 2005). On the other hand, the effects of erosion and sedimentation on coastal vegetation may affect molluscs and other benthic organisms. Areas of mangroves may die due to sand invading and asphyxiating the vegetation (Cohen & Lara 2003). Mussels and certain epibenthic gastropods may disappear in degraded areas. However, the trunks and roots that remain for some time in the substrate provide habitat for *Martesia*, Teredinidae, *Neritina* and *Littoraria*, while compacted peat remaining from degraded mangrove areas is a habitat for burrowing Pholadidae (Beasley et al 2005). Therefore, increased sedimentation within mangrove habitats can result in negative functional and structural effects on benthic communities (Ellis et al 2004).

Another factor that appears to have a significant influence on the diversity and abundance of molluscs is the age of the mangroves, which influence structure and function of mangroves. Morrisey et al (2003) showed that there were substantial differences in the abundance and composition of the fauna of younger (3–12 years older) and older (>60 years older) mangrove areas. It is hypothesized that as mangrove stands mature, the focus of faunal diversity may shift from the benthos to animals living on the mangrove plants themselves, such as insects and spiders. Therefore, numbers of benthos

taxa and numbers of individuals of each taxa were found larger at younger sites. But, the total number of individuals was not different between the two age-classes, mainly due to the presence of large numbers of the surface-living gastropod *Potamopyrgus antipodarum* at the older sites. Subsequent to mangal Extension, major environmental parameters also alter including, rates of water flow, sediment grain size and organic-matter content, oxygen and sulfide concentrations (both in bottom and pore-waters), salinity and the availability of hard substrates (Robertson & Alongi 1992). For example, the sediment of mature mangroves is inundated less frequently and becomes more compacted, and the abundance and diversity of the infauna decrease (Morrisey et al 2003). There were also more pneumatophores in the more compacted sediments of the older stands, because of lower oxygen concentrations in those sediments (Kelaheer et al 1998a, 1998b; Skilleter & Warren 2000; Morrisey et al 2003). Differences in densities of pneumatophore may also indicate that root competition is lower in younger stands, leading to more nutrient rich leaf tissue. Measurement of leaf chemistry showed that mangrove plants in the younger stands were able to take up more N and P than those in the older stands. However, plants at younger sites have lower  $K^+ : Na^+$  ratios, which suggest the presence of a higher salinity than the older sites. This is consistent with their location at the seaward front of the mangal where their roots are inundated for a longer portion of the tidal cycle. Another important difference that can be mentioned is that the sediment of older stands contains more organic matter and leaf litter than that of younger stands do (Medina et al 1995; Morrisey et al 2003). All of these factors can substantially influence the structure and dynamics of benthic communities such as the diversity and abundance of them (Posey et al 1993, 1997; Snelgrove & Butman 1994; Arrow et al 2000; Levin & Talley 2000). Macintosh et al (2002) studying Ranong mangrove ecosystem in Thailand, observed the diversity and abundance of *Littoraria* species were high at one location where plantation trees were still very young, whereas low numbers were observed at an older plantation, and they were absent in mature forest. But, opposite results have sometimes also been reported. For example, pulmonate snails (Ellobiidae) tend to be associated with mature forest, upper shore and back mangrove (Macintosh et al 2002). Also, Irma & Sofyatuddin (2012) showed that the abundance of gastropods increases with increasing mangroves age, but the age of mangroves does not affect the abundance of bivalves. The higher abundance of gastropods in the older stands is due to the higher C-organic content of sediment. In addition, these differences are suggested to be a result of increased silt/clay sedimentation in the older stands (Ellis et al 2004). According to Rangan (1996) the substrate condition influences the development of biotic communities, where sediment with a little clay is a desirable substrate for gastropods.

**Molluscs impacts on mangrove ecosystems.** Molluscs are ecologically significant in playing an important role in mangrove food webs and trophic dynamics (May 1999; Morrisey et al 2003; Ellis et al 2004). They are able to entrap additional primary production before it is removed by ebbing currents (Slim et al 1997; Fratini et al 2004). Gastropods contribute to entrap primary production within the system, both grazing fallen leaves and consuming mud (mainly composed by mangrove litter) (Plaziat 1984; Kathiresan & Bingham 2001). For example, *T. palustris* are protagonists in fallen leaf consumption and degradation. It is experimentally demonstrated that in a Kenyan mangrove during a single low tide, if fed ad libitum, *T. palustris* population alone is able to consume about five times the daily *Rhizophora mucronata* leaf production. Moreover, *T. palustris* leaf consumption is not restricted to low tide, since this species eats at high tides too chemically locating the fallen leaves underwater (Fratini et al 2004). Bivalves are efficient filter feeders and able to capture suspended particles of various origins (Plaziat 1984; Kathiresan & Bingham 2001). In addition, some bivalves, notably shipworms (Teredinidae) play a very important role in the decomposition and recycling of dead wood (Ponder et al 2000). Anatomical features of *Neoteredo reynei*, the most common shipworm in the mangrove of Bragança (Pará, North Brazil), indicate that this species primarily consumes wood and to this end depends on nitrogen-fixing and cellulase-producing bacteria in specialized pouches in the gill (Moraes & Lopes 2003).

Reduced dependence on suspended food and tolerance to variation in salinity allows *N. reynei* to colonize wood even in the areas of the mangroves that are less frequently inundated by the tide (Reis 1995; Beasley et al 2005). Also, the teredinids along with fungi are important decomposer organisms in mangroves, but differences in the time taken to completely break down the wood varies with the nutrient status of the water, which may be important for bacterial symbionts, and differences in tidal fluctuations that may limit the development of certain species due to desiccation (Kohlmeyer et al 1995).

Impact of molluscs on mangrove trees is also considerable: although, the presence of epibenthos such as oysters (both living and dead shells) on trees may provide habitat for other molluscs (Minchinton & Ross 1999), but they foul mangrove roots and trunks (Pinto & Wignarajah 1980; Ross & Underwood 1997). Heavy oyster and mussel cover can damage or break prop roots and negatively affect root growth (Ellison & Farnsworth 2001). Besides, in many mangrove forests world-wide, oysters are consumed by local people, and the breakage of the aerial roots where the growth of molluscs is a consequence of oyster harvests (Pinto & Wignarajah 1980), while the gastropods due to their predatory nature, occupy a central role in maintaining the functioning and productivity of mangroves through "cleaning" root systems from the encrusting fauna like barnacles and oysters (Shanmugam & Vairamani 1999). For example, *Thais* may feed on barnacles encrusted on mangrove roots and predation pressure by these snails may positively influence mangrove root growth by cleaning the aerial root system (Koch & Wolff 1996). Also, evidences showed that increasing the density of the snail population can significantly reduce the quality and diversity of epiphytic algae (Watson 2002). On the other hand, some gastropods such as *T. palustris* consume propagules of *A. marina* and Rhizophoracea, and thus influence mangrove restoration and regeneration (Plaziat 1984; Dahdouh-Guebas 2001; Fratini et al 2004; Bosire et al 2008). Some other gastropods are seed predators in mangrove forests and they play an important role in determining plant community structure (Smith et al 1989).

Another important effect of molluscs in mangroves is the destabilization of the sediment due to the tracks left by their heavy shells. Carlen & Olafsson (2002) have experimentally demonstrated that the presence of adult individuals of *T. palustris* induces mud surface rearrangement, affecting the abundance of meiofaunal community (decreasing density) and of the cyanobacteria carpet (complete disappearance).

Finally, the diversity and abundance of molluscs are potent biological indicators of changing habitat in mangrove ecosystem (Macintosh et al 2002). Gastropods and bivalves can produce a billion of larvae in the form of meroplankton that sustains the biotic population. Thus, the impact of pollution in mangrove forests can be assessed based on the structure of the molluscan assemblages. Snails also serve as intermediate host for many trematode parasites (Shanmugam & Vairamani 1999; Irma & Sofyatuddin 2012).

**Conclusions.** This article illustrates the role of mangrove ecosystem on molluscs. Bivalve and gastropod are considered as the main molluscs of mangrove forests and comprise an important trophic component of detritus-based food webs. Gastropods have high distribution in the mangrove forests probably due to their mobile characteristic, while bivalves are often confined to a narrow seaward zone, due to feeding, larval settlement restrictions and sediment texture such as low pH and high organic matter. Species richness and abundance of mangrove molluscs tend to increase towards the lower intertidal. This relates in part to highly different environmental conditions such as hydroperiod, availability of organic matter and sediment characteristics. Several other factors such as the physical structure of mangrove forest, mangrove detritus and the age of the mangroves can also influence the diversity and abundance of mangrove molluscs. So, it is clear that even relatively small-scale modifications to the structure of mangrove ecosystems can lead to significant effects on the diversity and abundance of molluscs in these habitats. Also, information provided here may help address questions relating to mangrove management and restoration, such as if the area of mangrove is to be managed by removal, is it better to take out older, impacted areas or younger areas that are currently less productive but can be protected as they develop?



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