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RESEARCH ARTICLE

Occurrence and Preservation of Gastropod Shells in Recent Riverine and Estuarine Sediments of Chennai, SE-India

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Abstract

Objectives: The distribution of aquatic gastropod shells was investigated in riverine and coastal sediments of Chennai, India. Next to taxonomic identification, the shell preservation was characterized and quantified with a taphonomic grade. **Methods**: Sediments of the Adyar and Cooum rivers as well as of coastal backwaters of the metropolitan area were taken down to a maximum depth of 81 cm using a handheld geoslicer and inspected by optical and electron microscopy. Taphonomic features (i.e. exfoliation, external luster, cracking, fragmentation, edge preservation, bioerosion, encrustation) reflecting different destructive post-mortem processes were observed, individually ranked and averaged in a composite taphonomic grade for each specimen. **Results:** Shells and shell fragments of various families occur with markedly different abundances between 63.7 and < 1% (in decreasing order *Potamididae, Bithyniidae, Stenothyridae, Planorbidae, Thiaridae, Bullinidae, Nassariidae, Neritidae, Paludomidae*). Their distribution invokes salinity as a major factor controlling occurrence in a habitat. The lack of larger and globose shells in freshwater river sediments may reflect the preference of stagnant water habitats and limited preservation in sedimentary transport. The predominance of *Pirenella cingulata* among the shells found in sediments of brackish environments probably reflects mechanical robustness and its extreme abundance in tidal flats. Due to post-mortem destruction most shells are incomplete. Roughly 25% of all specimens are almost complete shells not only showing spire and body whorl but at least in part also apex and/or aperture and outer lip. More than 50% represent spires or combinations of apex and spire. Composite taphonomic grades for gastropod families show a large range and reach high values. The lowest grades, indicative of best preservation, are observed for *Stenothyra blanfordiana* and *Bithynia sp.* **Novelty:** The distribution of gastropods in riverine and coastal environments represents a valuable ecosystem characteristic. Shell preservation shown here for sediments of Chennai is the basis for retrospective environmental characterization.

Keywords: Gastropods; shells; river sediments; taphonomy; Chennai

1 Introduction

Benthic organisms are easily affected by anthropogenic aquatic discharges due to the particle reactive character of many metallic or organic pollutants. These organisms reflect exposure to toxic substances showing a broad range of responses, such as reduced locomotive ability, growth inhibition, morphological changes, alterations of populations and associations or biochemical reactions [1,2]. Therefore, they serve as valuable bioindicator for environmental quality.

Furthermore, benthic organisms, such as molluscs, capable of biomineralization may (i) incorporate pollutants in skeletal parts or shells; or (ii) they show growth characteristics indicative of adverse environmental conditions. If biomineral parts are preserved in sediments, they can therefore serve as environmental archives. This is particularly important in riverine systems, which are mainly dominated by coarse clastic sediments and thus show a lack of environmental archives compared to other aquatic systems (e.g. warves, peat bogs in limnic systems or carbonate reefs in marine systems). Riverine ecosystems are either dominated by freshwater or characterized by brackish conditions in coastal transition zones. In such systems aquatic gastropods represent the most abundant zoological order among the shell forming organisms. The group of grazing or carrion feeding benthic gastropods, which constitutes an important link between aquatic and terrestrial food chains, shows a range of habitat preferences and ecological tolerance (e.g. with respect to desiccation, salinity, food availability [3]).

The presence of shells, associations of species as well as shell growth characteristics thus yield information on the ecological conditions of the depositional environment and/or of the sedimentary provenance area. Therefore, the characterization and evaluation of gastropod shells in riverine sediments is an important research target, particularly in systems that are highly affected by anthropogenic discharges.

However, the preservation of gastropod shells can strongly be affected by mechanical, chemical or biological processes post-dating life of the individual organism. Such post-mortem effects, which are not indicative of the gastropod's living conditions, must therefore thoroughly be described, characterized and evaluated in a taphonomic study if shells, their species associations or growth characteristics are intended to be used as environmental indicators.

Highly accelerated and uncontrolled urban development that can be observed on several continents is mainly focused in coastal areas around riverine or estuarine settings and places these ecosystems into the focal point of anthropogenic environmental impact. The megacity of Chennai (Tamil Nadu), one of India's largest urban agglomerations with more than 10 million inhabitants, is a marked example of this development in a tropical region. With the two rivers Adyar and Cooum as well as coastal backwaters there are major freshwater and brackish aquatic settings showing significant environmental impact [4 and references therein]. The Muttukadu backwaters in the South of Chennai are representative of the large brackish water systems that occur close to the coast of this region (Figure 1).

While the surface distribution of recent gastropods was studied in lakes or ponds and ditches as well as in coastal settings of SE India [4–7], gastropod shells and their preservation in riverine and brackish urban sediments have so far not been investigated in detail.

It is the aim of this study to deliver an overview of the presence and distribution of gastropod shells in sediments of the Adyar and Cooum rivers as well as of the Muttukadu Backwaters representing coastal brackish systems. Furthermore, the study aims at providing a thorough taphonomic characterization of shells allowing to evaluate their potential use as environmental indicator.

2 Materials and Methods

2.1 Study area and sampling

Chennai is the largest city in South India and characterized by a strongly enhanced economic and industrial growth in the last decades. This is in line with a tremendous increase of population reaching 11.12 x 10^6 inhabitants in the Chennai Metropolitan Area, covering 1189 km^2 [8]. Surface water of the Metropolitan Area is drained to the Bay of Bengal via several E-W trending rivers of which the Adyar and Cooum rivers are two outstanding examples of the most densely populated areas. Along the shore of Chennai coastal barriers separate backwaters in which urban surface waters and seawater mix leading to brackish conditions. Due to intensive discharge of industrial and domestic wastewaters river sediments and water have for long time been known to be highly affected by anthropogenic contaminants [8]. Following the research target of this study gastropod shells were investigated in sediments of the major rivers (Adyar and Cooum) and in sediments of the Muttukadu Backwaters, which is one of the largest brackish water bodies of Chennai (Figure 1).

The investigation was carried out at sampling sites covering the Adyar and Cooum rivers from the rural suburban areas with an elevated proportion of cropland (Figure 1, sites AD9, AD8, A5, A4, C3) to the densely populated urban areas (Figure 1 , sites A3, A2, A1, AD10, AD4, AD5, AD6, AD7, C2, C1). In addition to the estuarine mouths of both rivers, coastal settings were also investigated in the Muttukadu backwaters (Figure 1 , sites AD11, AD12, AD15, MU2, MU3, MU4, MU6, MU7, MU9). At these sites, sediments were obtained from a maximum depth of 81 cm using a handheld geoslicer [9] during a campaign in June and July of 2019. Sediments are mainly composed of poorly sorted medium to fine sands with variable portions of silt and clay. Locally, alternation between silt and sand dominated units can be interpreted to reflect formation during seasons with highly variable discharge of water (i.e. monsoon and post monsoon seasons). The general abundance of plastic, brick and charcoal particles attests to the important role of anthropogenic urban sediment sources. A more detailed sedimentological study of this material will be presented by Bellanova et al. (in prep.).

2.2 Sample preparation and inspection of gastropod shells

After air drying and sieving of sediments gastropod shells were sampled in fractions > 2 mm and optically inspected using a binocular lens with 10x magnification. Shells were carefully washed in water and cleaned with a soft brush. Some shells showed a sediment filling that could not be removed. Intensive cleaning with a harder brush or ultrasonic bath or mechanical attempts to remove sediments from the surface or internal volumes of the shell were not performed to avoid shell damage. Photographic documentation was carried out with a digital camera (Pentax K50) equipped with a bellow and a macro lens (Pentax DFA, 50 mm, F2.8).

Selected samples were carbon coated and investigated by scanning electron microscopy (SEM). Secondary and backscatter electron imaging was performed with a Quanta 650 F SEM (FEI/Thermo Fischer) operated with an acceleration voltage of 15 kV and a beam current of 10.00 $^+/_-$ 0.05 nA.

Taxonomic identification was performed to the lowest level possible. In some cases, species level was achieved using descriptions given in [10–14]. Terminology of taxa was according to actual entries for gastropods of marine, fresh and brackish water in the World Register of Marine Species [14].

Incomplete shells and fragments were characterized. For indication of the shell area represented by a fragment, it was denoted according to the standard shell areas: 1 = apex, 2 = spire, 3= body whorl, 4 = outer lip, 5 = operculum, 6 = unknown, which is a slight modification of the key of [15]). To indicate shells of species which do not form an apex, e.g. planorbid species, these were characterized with a "p".

The preservation of shells or shell fragments was expressed using three ranks (i.e. good, fair, poor), which separately measure different taphonomic features [16]. The ranks were numerically measured with values of 0, 1 and 2 for the ranks good, fair and poor, respectively. A composite taphonomic grade based on the average calculated from the individual ranks was determined for each specimen as a numeric value representing shell preservation. Slightly modifying the procedure of Kowalewski et al. (1994)

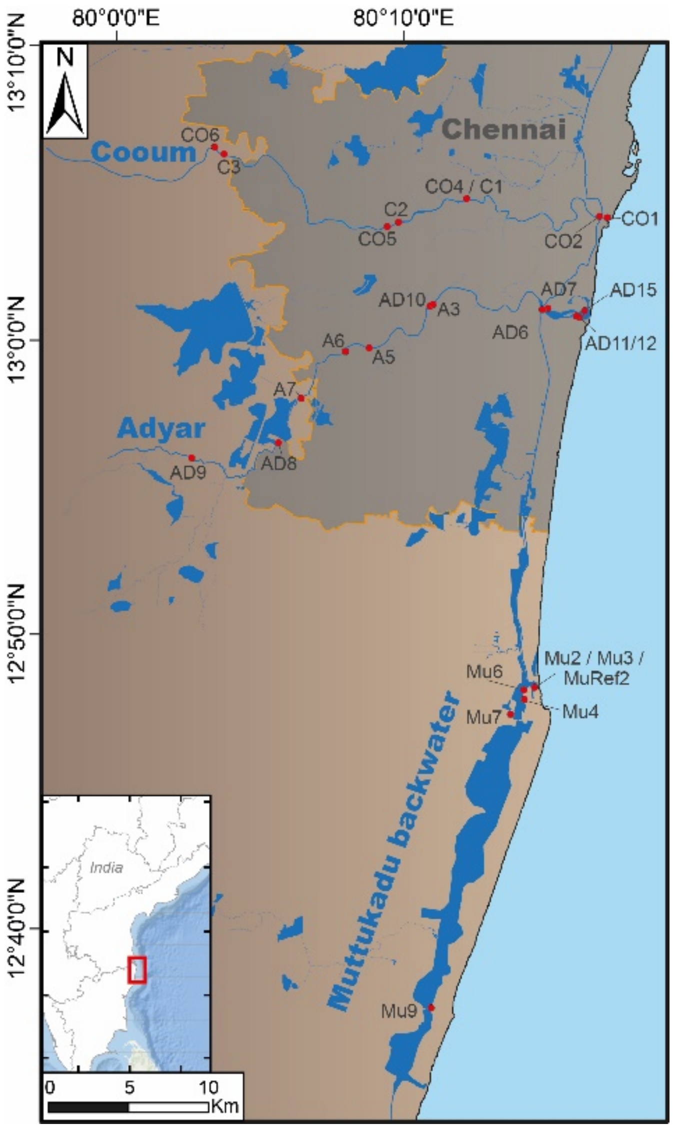

Fig 1. Sketch map of the Chennai Metropolitan Area with sampling points along the Cooum river (C, CO), Adyar river (A, AD) and the Muttukadu backwaters (MU), based on Google Maps © 2021. Inset shows position of the study area, Chennai, in South India, based on Google Earth Data SIO, NOAA, U.S. Navy, NGA, GEBCO, Image Landsat Copernicus.

the following taphonomic features were employed in this study: bioerosion, encrustation, fragmentation, cracking, exfoliation, edge preservation, external luster. The feature "bioerosion" indicated the extent of shell surface alteration by eroding organisms while the feature "encrustation" reflected presence or relics of encrusting organisms on the shell surface. Completeness of a shell was expressed by the feature "fragmentation". For all of the three parameters a limit of 10% was applied to define a poor rank, i.e. shell alteration by bioerosion, encrustation or loss due to fragmentation exceeding 10% of an unaltered shell. A fair rank was defined by shell alteration or loss of less than 10%, and a good rank for unaltered or complete shells. The presence of cracks was expressed by the taphonomic feature "cracking". Here, occurrence of cracks that were long (> 10%) with respect to the largest shell diameter was reflected by a poor rank, while shorter cracks led to a fair and absence of cracks to a good ranking. Removal of the periostracum is described by the feature "exfoliation". It was categorized as poor in case of extensive removal and as fair, if only slight removal can be observed. This feature would get a good ranking, if a shell shows an unaltered periostracum. Lips of apertures as well as apices can be abraded, which was represented by the feature "edge preservation". For this feature extensive abrasion leading to either very smooth or rugged edges or apices was categorized as poor. If edges or apices were only partly abraded while other parts were preserved, the shell was ranked as fair. Shells with complete edges and apices were considered as good. The feature "external luster" described the preservation of colour and glossiness of the external surface. It was ranked as good in case of well preservation, fair in case of partial loss and poor in case of total loss of colour and glossiness. Shells of different species allowed observation of features, such as luster or preservation of structures, on the internal surfaces to markedly different degrees. Furthermore, many shells were filled with sediment. Consequently, internal features were hardly comparable for all species. Therefore, preservation of internal features was not considered in this study.

3 Results and Discussions

3.1 Gastropod taxa and their distribution

A total of 171 specimens of gastropod shells or shell fragments, which belong to nine different families, were found in the sediments of Adyar and Cooum rivers as well as of the Muttukadu backwaters (Table 1). The gastropod families and their relative abundance are the *Neritidae* (0.6 %), *Paludomidae* (0.6 %), *Potamididae* (63.7 %), *Thiaridae* (3.5 %), *Bithyniidae* (10.5 %), *Stenothyridae* (5.3 %), *Nassariidae* (0.6 %), *Bullinidae* (0.6 %) and *Planorbidae* (4.1 %, Table 1). A fraction of 10.5% of shells and fragments could not be taxonomically identified. Representative samples are displayed in Figure 2.

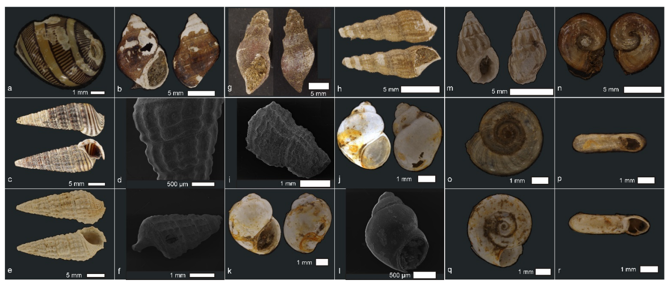

Fig 2. Photographs of gastropod shells, a,*Clithon* sp.; b, *Paludomus tanschauricus*; c, *Pirenella cingulata;* d, *Pirenella cingulata,* AD12 10-17 D2, SEM secondary electron image; e, *Pirenella incisa;* f, *Pirenella cingulata*, AD12 10-17 E, SEM secondary electron image; g, *Mieniplotia scabra;* h, *Melanoides tuberculata*; i, *Melanoides tuberculata*, A7 10-15 a, SEM secondary electron image; j, *Bithynia sp., operculum; k, Bithynia sp.; Stenothyra blanfordiana,* SEM secondary electron image; m, *Nassarius sp.*; n, *Indoplanorbis exustus*; o, *Gyraulus sp*., A5 0-5 A; p, *Gyraulus sp.*, A5 0-5 A; q, *Gyraulus sp*., C3 5-10 A; r, *Gyraulus sp*., C3 5-10 A.

Shells of the genus *Pirenella (Potamididae*), dominantly *P. cingulata* and rarely *P. incisa*, constitute more than 60% of all specimens found in the river and backwater sediments (Table 1). Second most abundant are shells of the genus *Bithynia (Bithyniidae),* followed by *Stenothyra (Stenothyridae),* which is only represented by the species *S. blanfordiana.* Two other minor groups, which can nevertheless be observed in various sampling sites, are shells of the families *Planorbidae (Gyraulus sp.)* and *Thiaridae (Mieniplotia scabra, Melanoides tuberculata).* In contrast, several families *(i.e. Paludomidae, Bullinidae, Neritidae, Nassariidae)* are each only represented by one shell specimen *(Paludomus tanschauricus, Indoplanorbis exustus, Clithon sp., Nassarius sp.,* respectively).

Gastropod shells are found in sediments of the entire study area from rural zones to the urban estuarine and backwater settings, although not in any sampling site. Two major groups of taxa can be distinguished, which do not overlap. These are *Mieniplotia scabra, Melanoides tuberculata, Indoplanorbis exustus, Paludomus tanschauricus* as well as species of *Gyraulus sp.* and *Bithynia sp.* in the rural and urban river sediments. In contrast, the *Pirenella* species as well as *Stenothyra blanfordiana, Clithon sp. and Nassarius sp.* exclusively occur in the samples taken in the estuarine mouth of Adyar river and in the Muttukadu backwater sediments (Table 1,Figure 1).

3.2 Taphonomic characterization

Several destructive post-mortem processes can be distinguished. They altered the gastropod shells to different degrees, which is expressed by individual rankings (good, fair, poor) for the different taphonomic features exfoliation, external luster, cracking, fragmentation, edge preservation, bioerosion and encrustation (Table 2, modified from [16]).

Almost all specimens are affected by exfoliation and have lost most or all of the periostracum. Only rare exceptions can be observed (Figure 2 b.). A majority has furthermore lost parts of outer shell layers, which is also expressed by the fact that 84.8% have rank "2" for the taphonomic feature exfoliation. Figure 2d, which shows an SEM secondary electron image of a *Pirenella cingulata* shell from Adyar sediments (AD12, depth 10-17 cm) reveals that removal of outer shell layers liberates

Table 1. Sampling sites and occurrence of gastropod shells in sediments of the study area

Sample site	Site character	Depth range(cm)[1]	Taxa (number of specimens)
Adyar			
A3	urban	25 - 35	*Mieniplotia scabra* (2)
A5	rural	0 - 5	*Gyraulus sp.* (1)
A6	urban	5 - 30	*Indoplanorbis exustus (1), Bithynia sp. (6), Melanoides tuberculata (1), gastr. unspec. (2)*
AD6	urban	48	*bivalve fragments*
A7	rural	0 - 15	*Melanoides tuberculata* (1), *gastr. unsp.* (3), *bivalve shell* fragments
AD7	urban	-	n.m.s.[2]
AD8	rural	7 - 29	*Bithynia sp.* (5), *Melanoides tuberculata* (1), *gastr. unspec.* (1)
AD9	rural	2 - 36	*Paludomus tanschauricus (1), bivalves*
AD10	urban	12 - 20	*Melanoides tuberculata* (1)
AD11	estuarine	12 - 60	*Pirenella cingulata* (2), *Pirenella incisa* (1), *Pirenella sp.* (2)
AD12	estuarine	1 – 70	*Pirenella cingulata* (13), *Pirenella conica* (1), *Pirenella sp. (*27), *Stenothyra blanfordiana* (3), *Nassarius sp.* (1), *gastr. unspec.* (1), b*ivalve shell fragments*
AD15	estuarine	8 - 15	*Pirenella cingulata* (2), *Pirenella sp.* (1)
Cooum			
C1	urban	5 - 30	*Gyraulus sp.* (2), *operculum* (1), *gastr. unspec* (1)
CO1	estuarine	5 - 30	*bivalve shell fragments*
C2	urban	5 - 10	*gastr. unspec.* (2)
CO2	estuarine	8 - 15	*bivalve shell fragments*
C3	rural	0 - 10	*Gyraulus sp.* (4), *Bithynia sp.* (7), *operculum* (1), *gastr. unspec* (5)
CO4	urban	-	n.m.s.
CO5	urban	-	n.m.s.
CO6	rural	-	n.m.s.
Muttukadu			
Mu2	backwater	5 - 9	*Pirenella cingulata* (2)
MuRef2	backwater	0	*Pirenella cingulata* (1)
Mu3	backwater	1 - 25	*Pirenella cingulata* (8), *gastr. unspec.* (1), disarticulated bivalve shell
Mu4	backwater	1 - 81	*Pirenella cingulata* (17), *Pirenella incisa* (1), *Pirenella sp.* (9), *Stenothyra blanfordiana* (6), bivalve shell fragments
Mu6	backwater	1 - 16	*Pirenella cingulata* (6), *Pirenella sp.* (6), *Clithon sp.* (1), bivalve shell fragments
Mu7	backwater	15 - 35	*Pirenella cingulata* (3), *Pirenella sp.* (5)
Mu9	backwater	17 - 35	*Pirenella cingulata* (2)

[1]Upper and lower limit of shell containing sediment in cm
[2]n.m.s. = no molluscan shell

crystalline domains and microstructures, which causes a rough surface. This also causes loss of glossiness and has an effect on the feature external luster. Accordingly, this feature shows a distribution of individual ranks that is similar to that of the feature exfoliation (Table 2). Several shells of *Bithynia sp.* also show a brownish staining, which is most probably formed by precipitation of hydrous Fe-oxides (Figure 2 j, k). In polished sections of the same shells, they feature single semicircular structures with diameters ranging between 50 – 100 μm extending from the surface into the shell (Figure 3 a). In BSE images they are much darker than the surrounding shell indicative of a loss of density. Due to the semicircular shape of these features it is assumed that such loss is caused by a reaction that leads to carbonate dissolution and progrades from the surface towards inner shell areas.

Table 2. Distribution of ranks (in %) for different taphonomic features of gastropod specimens from sediments of the Adyar and Cooum rivers and the Muttukadu backwaters

Rank of taphonomic feature	0 good	1 fair	2 poor
Bioerosion	65.5	33.3	1.2
Fragmentation	6.6	18.2	75.2
Cracking	11.0	28.9	60.1
Exfoliation	0.0	15.2	84.8
Edge preservation	7.2	11.5	81.3
External luster	2.4	17.0	80.6

Two specimens of *Pirenella sp.* show shallow perfectly spherical holes that penetrate the shell (Figure 3b). They have a conical or slightly parabolic shape and the outer edge only slightly beveled to the interior, which is most likely to boring by predatory gastropods (e.g. *Natica sp.*, known to occur at the SE Indian coast, [13]) and thus a clear example of bioerosion. In particular, shells of *Bithynia sp.* show numerous pits with rounded to subrounded equidimensional or in part elongated groove-like outline (Figure 3 c, d). The largest extensions can reach 400 μm but usually do not exceed 100 μm and mainly are < 50 μm. The smaller pits have a bowl-shaped or rounded profile and are only locally penetrating. In contrast, the bottom surfaces of circular erosive marks with large diameters still are parallel to the surface of the shell wall, suggesting that erosive activity was due to an organism aiming at consumption of the biomineral shell matter. Locally, equal sized pits are arranged along straight trails or in irregular patches indicative of a single organism carrying out repeated boring after steps of movement. The high variability of bioerosive traces on single shells of Bithynia invokes activity of different boring organisms. Several shells of *Pirenella sp.* and *Bithynia sp.* show round to oval shaped holes with diameters < 10 μm, which can locally extend to elongate grooves (Figure 3 e, f). Electron microscope images of polished sections show that such holes form part of a network of boreholes. It reaches from the outer surface for about 100 μm into the shell with decreasing density at deeper levels. At the shell surface high abundance of boreholes can cause significant disintegration of shell matter. Such patterns are considered as endolithic microborings that can be produced by fungal hyphae, branched filamentous cyanobacteria, algae, clionid sponges or by annelid worms [17–19]. The occurrence of biogenic encrustation on gastropod shells is negligibly rare and confined to two specimens from the Muttukadu sediments, which show an undefined organic layer in one case and faint circular overgrowths with diameters of 0.8 to 1.0 mm. It must be noted that most bioerosive traces or biogenic encrustation can only be observed on shells that are not significantly affected by exfoliation. In fact, features of bioerosion may get lost during protracted exfoliation and destruction of the shell surface. This is in line with the reverse relationship of rank distributions of the taphonomic features exfoliation and bioerosion (Table 2).

Exceeding the effect of biogenic activity mechanical processes, such as cracking or abrasion, also caused fragmentation or loss of shell matter. More than 90% of all shell specimens are incomplete, with fair or poor ranks of the taphonomic feature fragmentation. Almost the same percentage shows fair or poor ranks for the feature cracking. Fragmentation mainly affected apices as well as apertures. Cracking, which dominantly happened along whorls, most often left spires. Highly advanced fragmentation only left internal sections of the columella or parts of walls, for which assignment to either spire or body whorl is impossible.

Due to these post-mortem destructive processes most specimens are fragmented and represent different parts of the formerly complete shell. Their characterization using standard shell areas and combinations of them as shown in Table 3 , allows to classify different shell types reflecting various degrees of preservation. More than half of all specimens represent spires or combinations of apex and spire. This is certainly due to the dominance of the high-spired *Pirenella* species in the sample suite. However, fragmentation of more globose species, such as *Bithynia sp.*, also shows that the aperture and body whorl are affected first by destructive post mortem effects leaving parts of the spire in the sediment. Roughly 25% of all specimens are almost complete shells not only showing spire and body whorl but at least in part also apex and/or aperture and outer lips (types 123, 234, 1234,

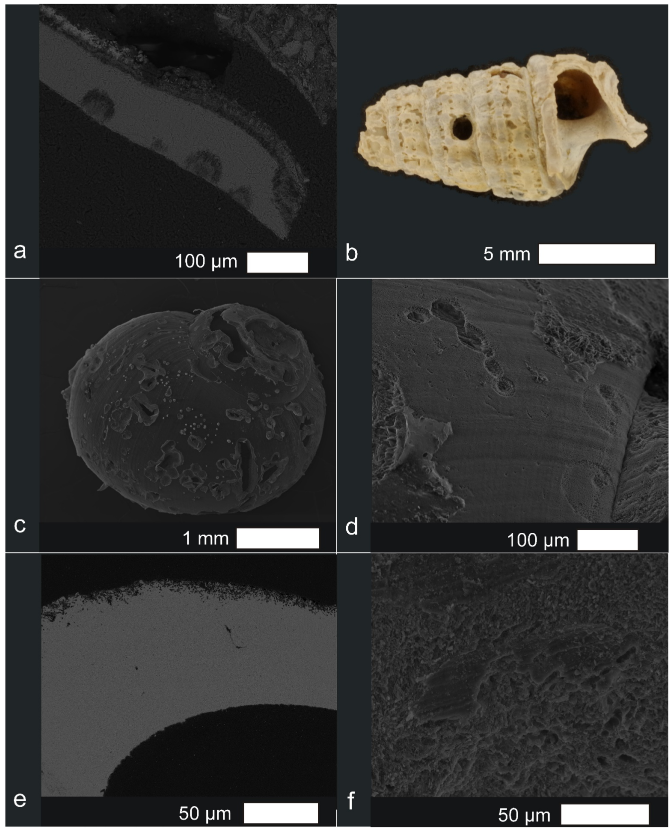

Fig 3. Examples of erosive and bioerosive effects; a, *Bithynia sp.*, AD8 24-29B, shell dissolution at shell surface, SEM backscatter electron image; b, *Pirenella cingulata*, Mu7 15-20 A, borehole of predatory gastropod; c, *Bithynia sp.*, C3 5-10 E, bioerosive traces; d, *Bithynia sp.*, C3 5-10 F, bioerosive traces; *Bithynia sp.*, AD8 24-29 B, microborings; *Pirenella sp.*, AD12 10-17 D, holes produced by microborings.

2345 and P23). Note that shells of type 2345 were found with operculum.

Table 3. Types of shells and shell fragments based on standard shell areas

Type	Description	Percent
1	apex	0.6
2	spire	45.6
12	apex+spire	16.4
23	spire+body whorl	7.0
123	apex+spire+body whorl	6.4
234	spire+bodywhorl+outer lip	5.3
1234	apex+spire+bodywhorl+outer lip	8.2
2345	spire+bodywhorl+outerlip+operculum	2.3
P2	planorbid-spire	2.9
P23	planorbid-spire+body whorl	2.3
5	operculum	1.2
6	unspecified	1.8

1 Standard shell areas, modified after [23], 1 = apex, 2 = spire, 3 = body whorl, 4 = outer lip, 5 = operculum, 6 = unknown, p = planorbid shell without apex

The composite taphonomic grade, averaging the individually ranked taphonomic features of each shell, yields a general characterization of the preservation of each specimen. Gastropod families represented by several specimens *(Potamididae,* *Thiaridae, Bithyniidae, Stenothyridae, Planorbidae)* as well as the group of unspecified shells and shell fragments show larger ranges of composite taphonomic grades (Figure 4). Most values, in particular those of the group of unspecified specimens, vary between 1.00 and 1.71. Except for one example of *Gyraulus sp.* (*Planorbidae*) grades < 0.5 are mainly reached by *Stenothyra blanfordiana (Stenothyridae)* and by *Bithynia sp.* (*Bithyniidae*).

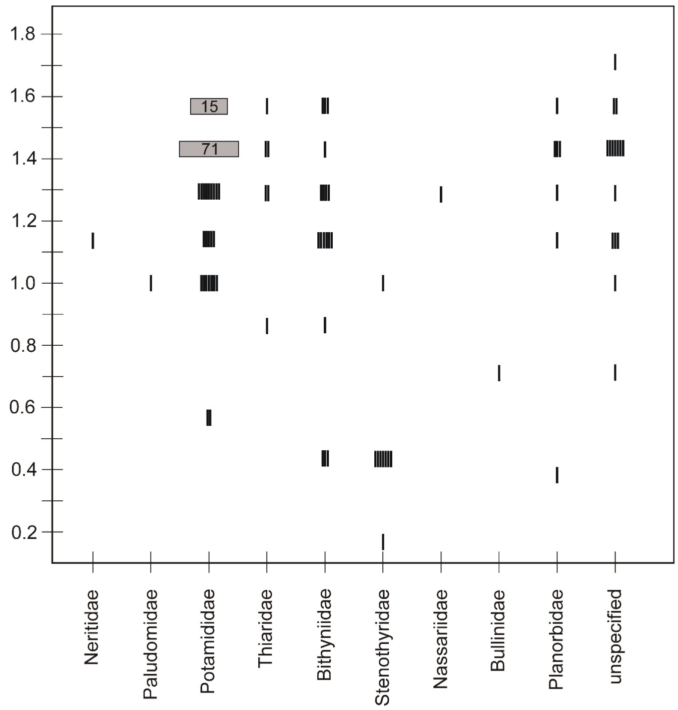

Fig 4. Compositetaphonomic grades of specimens of different gastropod families and the group of unspecified specimens observed in sediments of Adyar and Cooum rivers as well as in the Muttukadu backwaters.

3.3 Discussion of distribution and preservation of gastropod shells

The high number of shell specimens obtained in the limited volume of geoslicer samples proves the applicability of this tool for reconnaissance sampling and attests to the relatively high abundance of gastropod shells and shell fragments in the sediments. As this study aims at providing a first overview of the gastropod shell inventory in river and backwater sediments characteristic of the larger Chennai area, sampling was not carried out to distinguish or delineate gastropod habitats. Nevertheless, the suite of specimens allows to distinguish two different groups of gastropods. The species *Mieniplotia scabra, Melanoides tuberculata, Indoplanorbis exustus, Bithynia sp. and Gyraulus sp.* are considered as one group and associated, because they occur in the same rural as well as urban sample sites of the Chennai Metropolitan Area (e.g. *I. exustus, Bithynia sp., M. tuberculata, Gyraulus sp.* in A6, AD8, C3). They can also occur in closely adjacent sampling sites (e.g. *M. scabra*, *M. tuberculata* in A3 and AD10, (Table 1Figure 1). None of these species occurs in association with those of the other group, which consists of the *Pirenella* species (*P. cingulata, P. incisa), Stenothyra blanfordiana, Nassarius sp. and Clithon sp.*. They are exclusively observed in the Muttukadu backwaters and in the Adyar sampling sites AD11, 12 and 15, which are located in the estuarine mouth region close to the coast (Table 1Figure 1). All species of the first group are characteristic of freshwater habitats, such as slow to fast moving or temporary rivers and irrigation ditches as well as stagnant ponds, lakes or paddy fields. Only *M. tuberculata* is reported to extend into brackish water[(13,14)]. In contrast, the species of the second group prefer brackish to hypersaline conditions (e.g. *Pirenella species,*[(10)]) in shallow intertidal estuarine or deeper marine environments (*Nassariidae, Stenothyridae,*[(12)]). Only representatives of the genus *Clithon,* which is common between intertidal rocks and mangrove swamps of India, are reported to occur in freshwater as well[(13,14)]. The dominance of freshwater preference in the first and of brackish water preference in the second group is a clear indication that salinity is a major factor controlling gastropod distribution.

Within the group of the freshwater gastropods, either rural or urban character of the environment are not reflected by the occurrence of individual species in the sediment, since *Bithynia sp., Gyraulus sp*. and *M. tuberculata* are found in both environments. As *P. tanschauricus* and *I. exustus* are each only observed in one site, environmental preferences cannot be discussed. The presence of *Bithynia sp.* shells with closed operculum in sedimentary layers down to 10 cm depth is remarkable. The shells were sampled in the rural segment of Cooum river, which is seasonally affected by dryness, and probably these individuals reached their position in an attempt to escape from the surface. Hence, the shells may not be deposited contemporaneously with the sediment in which they were found.

All of the freshwater gastropods represented in the sediments are at least in part reported from lakes, ponds and paddy fields of SE India (i.e. Porur Lake, Chennai, [7]; Kanchipuram district, [5]; Pondicherry, [4]). However, all of these studies also describe species that are not present in the river and backwater sediment samples of Chennai. These are *Radix* or *Lymnaea luteola, Lymnaeidae*, now accepted as *Racesina luteola* (Lamarck 1822), *Pila globosa* (Swainson 1822), *Ampullariidae and Bellamya sp., Viviparidae,* now accepted as *Filopaludina sp*. [14]. Their abundance varies between 24.0 and 90.6% in the respective study areas. Although all studies considered here are based on different amounts of samples and under different condition, which renders an accurate comparison difficult, the lack of shells representing these families in the Adyar and Cooum river sediments investigated in the present study is considered as a remarkable difference. This is on one hand most probably due to their preferred habitats, since *Racesina sp., Filopaludina sp. and Pila sp.* live in permanent or temporary water bodies, domestic pools or ponds [13] and not in river settings. On the other hand, the lack of such shells may also show that preservation conditions of larger gastropod shells that are all thin as well as globose are bad in clastic sediments. This is in line with the observation of this study that apertures and body whorls are among the first shell areas that are lost in sedimentary processes. The role of size for preservation is also highlighted by the group of gastropods from the brackish environment. Here, the small shells of *Stenothyra blanfordiana* show best preservation, which is also underlined by generally low composite taphonomic grades, despite of their globose character (Figure 2 l, Figure 4).

The dominance of *Pirenella* species and in particular of *P. cingulata* among the association of gastropods from brackish water may reflect its robustness with respect to mechanical destruction. But it certainly also reflects its' high abundance in the estuarine and backwater environments as well as habitat preference. While *P. incisa* prefers shaded mangrove vegetation, *P. cingulata* mainly occurs on open sand and mud flats [10]. In such environments *P. cingulata* can reach high densities along the Indian and SE Asian coast ranging from several 100 individuals/m^2 over 1000/m^2 even in densely populated areas like Singapore ([20] in [10]) up to 12,000/m^2 reported by [21] for the Vellar estuary at the coast of Tamil Nadu. Despite of doubts expressed by [10], because this population may also contain individuals of *P. incisa*, it underlines the extreme potential abundance of *P. cingulata* in tidal flats. During high tides and particularly during flood or storm events these environments are highly affected by mobilization of sediment and therefore shells of *P. cingulata* may also show a high abundance in sedimentary deposits of the estuarine system.

4 Conclusions

Sediments of the Adyar and Cooum rivers as well as the Muttukadu backwaters show a rich inventory of gastropod shells. The specimens represent the following families and species with markedly contrasting abundance: *Potamididae* (63.7%, *Pirenella cingulata, P. incisa), Bithyniidae* (10.5%, *Bithynia sp.*), *Stenothyridae* (5.3%, *Stenothyra blanfordiana*), *Planorbidae* (4.1%, *Gyraulus sp.*), Thiaridae (3.5%, *Mieniplotia scabra*, Melanoides tuberculata). The families *Paludomidae (Paludomus tanschauricus), Bullinidae* (*Indoplanorbis exustus*), *Neritidae* (C*lithon sp.*), *Nassariidae* (*Nassarius sp.*) are each only represented by one specimen. A fraction of 10.5% of all specimens could not be taxonomically identified. Two major and non-overlapping groups can be observed. These are on one hand, (i) *M. scabra, M. tuberculata, I. exustus, P. tanschauricus, Gyraulus sp., Bithynia sp.*, which exclusively occur in rural and urban river sediments and the other hand, (ii) the *Pirenella species, S. blanfordiana* as well as *Clithon sp. and Nassarius sp.*. The latter are only found in sediments of the estuarine mouth of the Adyar river and in sediments of the Muttukadu backwaters that are both characterized by brackish conditions. This invokes salinity as a major factor controlling gastropod distribution. While all of the gastropods of the Adyar and Cooum sediments are common in freshwater habitats of South India other gastropods that are frequently observed, such as *Racesina luteola, Pila sp. or Filupalodina sp.*, are not represented in the sediment bound shell inventory. This may be due to preference of stagnant water bodies relative to riverine habitats but probably also shows that gastropods characterized by larger and globose shells are hardly preserved in sedimentary processes. The predominance of *Pirenella cingulata* among the shells found in sediments of brackish environments probably reflects robustness with respect to mechanical destruction as well as its extreme abundance in tidal flats. Due to post-mortem destruction most shells are incomplete. Roughly 25% of all specimens are almost complete shells not only showing spire and body whorl but at least in part also apex and/or aperture and outer lip. More than 50% represent spires or combinations of apex and spire. Several taphonomic features (i.e. exfoliation, external luster, cracking, fragmentation, edge preservation, bioerosion, encrustation) reflecting different destructive post-mortem processes were observed, individually ranked and averaged in a composite taphonomic grade for each specimen. Grades for gastropod families represented by several specimens and the group of unspecified shells and fragments show a large range and reach high values. Lowest grades, indicative of best preservation, are observed for *Stenothyra blanfordiana* and *Bithynia sp.*.

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