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Assessment of non-degradable litter and its impact on the benthic community of selected mangrove ecosystems of Kerala, India

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Original Article

Abstract

Inadequate management of non-degradable litter in coastal areas can lead to its accumulation in mangrove forest, affecting its ecosystem services. Abundance and distribution of marine litter and its impact on benthic organisms in mangrove ecosystems are far less investigated in India. Thirteen mangrove ecosystems distributed in Ernakulum District, Kerala were selected for the study and evaluated for plastic pollution. The identified litter particles were categorized according to particle type, colour, size and composition. The abundance of plastics estimated was classified according to its source of origin. The abundance of benthic organism in the study stations was also estimated. The density of micro (<5 mm) and meso (5-25 mm) plastics ranged between 29 and 36 Nos/kg with the highest concentration found in mangrove sediments of Kumbalangi and the lowest in protected area like Mangalavanam. Plastics accounted 73 to 96% of total macro litter. The major polymer types identified were polyethylene, polypropylene, polyethylene terephthalate and polyvinyl chloride by Fourier Transform Infrared (ATR–FTIR) spectroscopy. The simulation experiment showed a progressive reduction in total benthic community when smothered with thick plastic sheets. This study is an eye opener concerning plastic litter problem in mangroves of the Vembanad Lake ecosystem, which can be well explained as due to anthropogenic impact.

Keywords: *Assessment, non degradable litter, impact, anthropogenic, benthic community*

Introduction

Mangrove forests are highly productive system located at the transitional interface between marine and terrestrial environment, restricted to tropical and subtropical regions (Kathiresan and Bingham, 2001). Mangroves are rich in biodiversity and play a key role as provider of important ecosystem services, including carbon sequestration, storm protection, wave dissipation, shore line stabilization and habitat for marine life (Hutchison *et al*., 2014; Menendez *et al*., 2018; Friess *et al*., 2019; Spalding and Parrett, 2019). But, they are considered to be one of the most fragile ecosystems in coastal areas.

In India, mangroves are distributed along the estuaries and coasts of nine maritime states and four union territories. Once the mangrove cover in the country was 6740 km^2 (Krishnamurthy *et al*., 1987) and it has now declined to 4975 km^2, due to excessive human interventions (FSI, 2019). Living at the interface between land and sea, the mangroves can tolerate natural stressors (Polidoro *et al.*, 2010), but they may be sensitive to disturbances like those created by human activities (Kathiresan and Bingham, 2001). Hence, the mangroves are disappearing at an alarming rate and have lost much of their areas across the world. Mangroves of Kerala State have drastically shrunk to 9 km^2 by 2019 (FSI, 2019) from about 700 km^2 in 1975 (George *et al.*, 2019), due to habitat conversion. Mangroves in Ernakulam District declined when Cochin became the industrial capital of the state. Several thick mangrove areas such as Panangad, Vallarpadam, and Vypin possess only small patches as a result of urbanisation (Vidyasagaran and Madhusoodanan, 2014).

Apart from the identified threats, large plastic materials, upon reaching this sensitive habitat get entrapped there, resulting in smothering and scouring which can ultimately damage the ecosystem. (Donohue *et al.*, 2001; Smith, 2012). It can disturb the ecosystem processes and the biodiversity as plastic trapped by mangrove pneumatophores and prop roots may constitute a physical impediment affecting both the tree itself and the associated fauna, which prevents gas exchange, thereby proving harmful to the benthic community and releasing toxic chemicals absorbed by or industrially added to plastic materials (Cole *et al.*, 2011; Martin *et al.*, 2019; Ivar do sul *et al.,* 2014). It can even ruin the aesthetic look, especially in places of considerable recreational importance. Bio-accumulation, bio-magnification and bio-transformation of microplastics in to the food chain, dissolution of microplastic materials in to the ecosystem, swallowing of plastics by birds and other terrestrial as well as aquatic animals misunderstanding them as prey, traps the seeds of mangrove plants and making them unfit for germination are the noted adverse effects due to plastic litter pollution in mangrove forests (Moulitharan *et al.*, 2017). However, the accumulation and impact of non-degradable litter in the mangrove ecosystems are far less studied in India till date and hence the present study was undertaken on selected mangrove areas of the Ernakulam District with the objectives (i) To assess the abundance and distribution of plastic litter pollution (ii)To estimate the sources of litter pollution (iii) To study the impact of plastic litter on benthic organism and (iv) To suggest management measures for reducing the accumulation of litter in mangrove ecosystem.

Material and methods

The mangrove ecosystem along the belt of the Vembanad Lake, the largest estuarine system in the south west coast of India, located between latitudes 9°30'-10°28'N and longitudes 76°13'-76°31'E was studied for the extent of plastic litter pollution during the month of April 2019.

Study area

The mangrove habitats selected for the study were located along the Cochin Backwaters in and around the district of Ernakulam, which support a luxurious patch of mangroves along the banks.

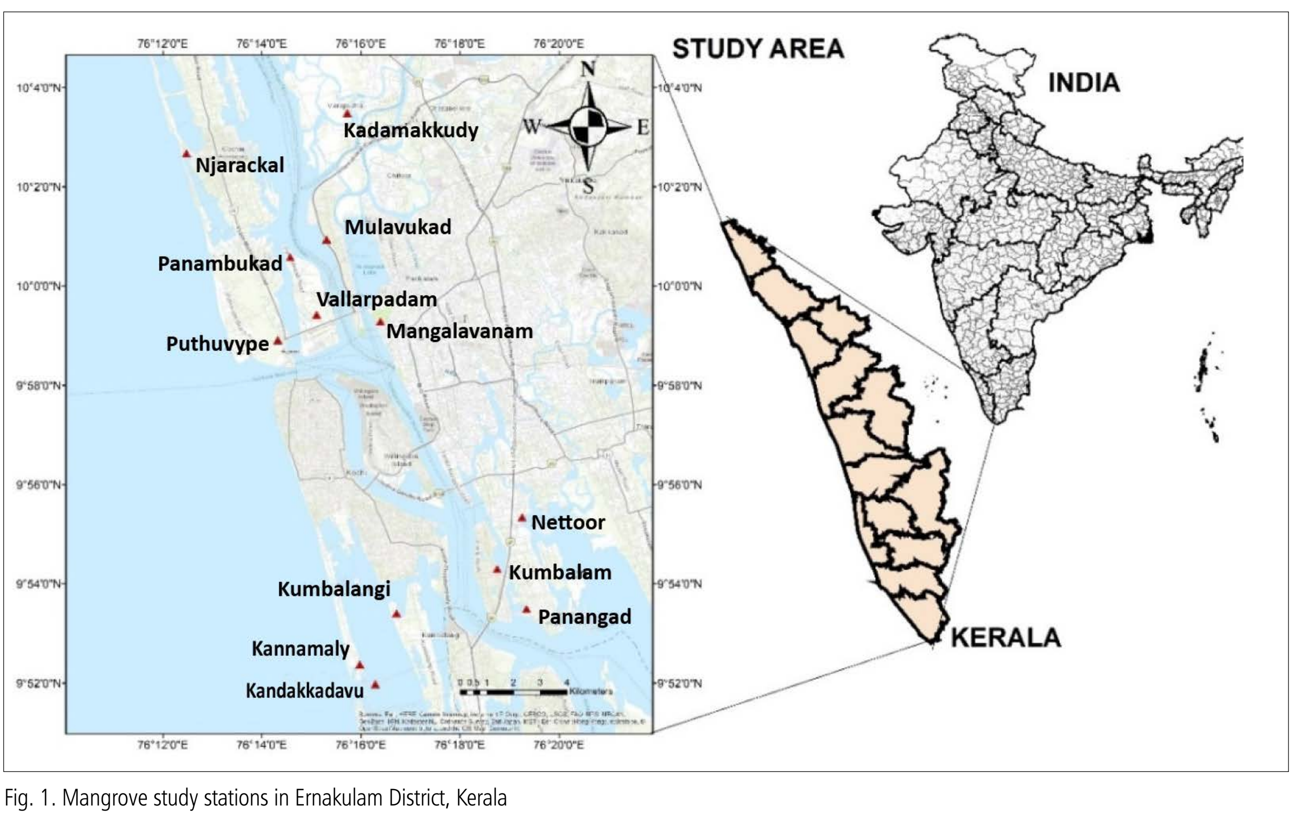

Fig. 1. Mangrove study stations in Ernakulam District, Kerala

Intense and large scale constructional activities, reclamation and aquaculture farming and other anthropogenic interferences resulted in massive destruction of mangroves in this area. Thirteen stations were fixed as per variations in habitet degradation by visual observation as indicated in the location map drawn using Arc GIS version 10.5, making use of Google Earth imageries and delineating the micro-level boundaries (Fig.1). Six stations namely Kandakkadavu, Kannamaly, Kumbalangi, Panangad, Kumbalam and Nettoor, which fall under the southern side of Cochin Estuary (Lat.09°52'15"–09˚55'31" N and Long. 76°16'03.74"- 76˚ 19'20.93"E) were grouped under the first zone while the second zone comprised of seven stations Mangalavanam, Vallarpadam, Puthuvype, Panambukad, Mulavukad and Kadamakkudy which spread on the northern stretch of Cochin Estuary (Lat.09˚59'18.41"-10˚02'29.87" N and Long.76˚16'21.58"-76˚ 12'26.33"E). Few of the mangrove sampling locations are shown in Figs. 2(a-d).

Sediment analysis

Sediment samples from the selected 13 mangrove stations were taken in triplicates with a scoop (approximately1 kg) and transferred to laboratory in air tight self-lock polyethylene bags. The exact location of each site was recorded using a portable GPS.

In the laboratory, samples were sieved using a stacked sieve (2, 0.5 and 0.1 mm). Any plastic material visually observed in the sieve was removed using a metallic forceps and collected in separate bottle. The material retained was processed further following the protocol of NOAA (Masura *et al.*, 2015) with required alterations (Imhof *et al.*, 2012). The sieved sediment fraction was transferred to a one litre beaker and a concentrated 11M $ZnCl_2$ solution (d=1.5gm/ml) was added double the volume of the sediment and stirred using magnetic stirrer for 10 minutes. Following this, samples were allowed to settle for 5 min. Floating plastic particles were collected using forceps and supernatants were vacuum filtered using 1.2 μm filter paper. The samples retained in a beaker were treated with Hydrogen peroxide (30%) until the degradation of all organic contents in it. The supernatant formed was again filtered using a 0.4 μm filter paper. The process was repeated for complete extraction. The filter papers were dried and microplastic particles were observed under the stereozoom microscope (Leica S8APO (40×) with

Fig. 2. (a-d). Few of the mangrove sampling locations (a) Abandoned helmets entrapped in pneumatophores in Kumbalangi (b) Entrapped bottle in Panambukad mangroves (c) Accumulated litter in Nettoor (d) Submerged litter on the banks on canals cleaning in Njarackal mangrove area

DFC 295 camera). Photomicrography of individual plastic particles were done, and they were sorted, enumerated, size fractionised and categorised, as per the shape/type and colour (Hidalgo-Ruz *et al.*, 2012; Lusher *et al.*, 2017). Particles < 5 mm were categorised as microplastic litter, 5-25 mm as meso and > 25 mm as macroplastics (Masura *et al.*, 2015) and the average abundance was expressed as numbers/ kg sediment.

Extraction efficiency

The extraction efficiency of the method was tested, before starting the actual analysis. Four types of microplastic polymers such as Polyethylene (PE), Polypropylene (PP), Polyvinylchloride (PVC) and Polyethylene Terephthalate (PET) varying in shape, size and colour and a representative array of microscopic plastic debris present in marine ecosystems were sourced for extraction efficiency. A known quantity (by number) of different plastic commodities comprising of the above mentioned polymers were cut in to small pieces (less than 5 mm in size),mixed with know quantities of sediments and spiked with $ZnCl_2$ solution. It was found that around 90-95% extraction efficiency could be achieved throughout the analysis carried out.

Polymer identification

Attenuated Total Reflectance–Fourier Transform Infrared (ATR–FTIR) spectroscopy (Perkin Elmer Spectrum Two Universal) was used to collect spectra from 4000 to 400 cm^{-1} with a data interval of 1 cm^{-1}. Resolution was set at 4 cm^{-1}. Absorption bands identified using a peak height algorithm were compared to those of each polymer reported in the literature (Jung *et al.*, 2018) with more than 70% similarity. Required measures to avoid contamination were adopted while handling and processing samples in the laboratory (Woodall *et al.*, 2014).

Macroplastic abundance

Macro litter sampling, was done with a 1x1 m^2 quadrat and the items present were counted, material codes and remote litter classes were attributed as per the guidelines of UNEP/IOC (2009).

Litter codes were assigned to each items depending on their material composition namely Plastic (PL), Foam plastic (FP), Metal (ME), Rubber (RB), Glass and ceramic (GC), Paper and card board (PC), Cloth (CL), Wood (WD), and items that cannot be grouped into this as, Others (OT). In addition, remote litter classes (RLC) were given based on their form (eg: sheet, bottle, fishing net etc.) The items under these classes were thus categorised into bottles, carry bags, sheets, thermocol, food containers and others to have more understanding about their sources of origin. Thus the percentage distributions of items such as domestic, recreational, industrial, fishery, and e-waste were estimated. Based on the locational abundance of micro, meso and macroplastic, an ecosystem ranking was made out as "Very high'', ''High'', ''Moderate'', and ''Low". Maps delineating the ecosystem ranks were drawn by using Arc GIS ,10.5.

Macrobenthos estimation

Sediment samples for macrobenthos estimation were sieved through a 0.5 mm mesh sieve and preserved in 4–7% neutral buffered formaldehyde. In the laboratory the sample was further analysed for macrobenthic abundance (Holme and McIntyre, 1984; Eleftheriou and McIntyre, 2005; APHA, 2005). For quantitative enumeration, each sample was examined under a stereozoom (Leica S8APO) microscope. The organisms were separated into different taxonomic groups and then enumerated and expressed as individuals/m^2.

Simulation study

The impact of smothering by plastic litter on benthic community was assessed by designing a simulation experiment in two selected mangrove sites, one in Mangalavanam and the other one in Njarackal (Fig. 3. a, b). Double layered woven plastic sheets of size 2m x 2m were laid above the substratum in triplicates, in both the locations, with proper mooring, simulating a situation similar to smothering and settling of macroplastic in mangrove area. Sediment sampling was done consecutively every third month for a period of one year starting from day 0 to days 90, 180, 270 and 360 for assessing the impact of plastics on benthic abundance. Controls were also kept in the two stations to observe and compare changes.

Statistical analysis

Shapiro-Wilk test of normality and Leven's test of homogeneity of variance was conducted to check the assumptions of normal distribution of data and test of homogeneity of variances ($p>0.05$) to conduct Analysis of Variance. The difference in the distribution of micro, meso and macroplastic was tested for significance using one-way ANOVA with sampling locations and zones as factors with 95% level of significance. A confirmatory post hoc Tukey HSD was run for multiple comparisons. A chi-square cross-tabulation test of independence was conducted to study and evaluate the trend in distribution of composition of variables along the surveyed locations. A regression analysis was conducted with a linear fit to evaluate the relationship of benthic communities with the total plastic abundance. In order to understand the distribution of benthic communities and plastic litter along the surveyed sites and their interactions in a two dimensional plane, a principal component analysis (PCA) was conducted using the FactomineR (Le *et al.*, 2008)

Fig. 3. (a ,b) Laying of plastic sheet in mangrove site

and Factoextra packages (Kassambara and Mundt, 2017). Based on the score and factor loadings, a biplot was generated to understand the interaction of studied variables across the survey locations. All statistical analysis was done using the statistical program R version 4.0. All the scientific plots were made in synergy using R, sigmaplot 12.0 and inkscape 0.92.2.

Contamination prevention

In order to avoid airborne contamination, utmost care was taken during the entire period of analysis. The samples were analysed inside a laminar hood, by wearing a white cotton lab coat and nitrile gloves. All the glassware was thoroughly washed with Milli Q water before use.

Results and discussion

Abundance of litter

Micro and mesoplastics were found to occur in all the 13 mangrove stations studied. The overall average abundance of microplastics estimated from the Cochin mangrove ecosystems were 5.01±5.66 Nos/kg with the maximum of 29 Nos/kg sediment in Kumbalangi mangroves. A similar trend was also observed for meso particles with the average abundance of 2.75±4.2 Nos/kg with the maximum of 36 Nos/kg. The average concentration of macro litter observed was 3.4±3.8 items/m^2 ranging from 0-17 items/m^2. One-way ANOVA performed revealed significant difference in micro, meso and macroplastic contamination ($p<0.05$) in the 13 mangrove stations studied and a multiple comparison was done with Tukey post-hoc HSD with 95% level of significance to understand specific difference in plastic litter distribution across different locations.

Mangroves acts as a reservoir for microplastics due to its ability to retain the accumulated particles by entrapping it between the seedlings and pneumatophores (Li *et al.*, 2018; Nor and Obbard., 2014; Sutton *et al.*, 2016; Weinstein *et al.*, 2016). They act as sinks for marine plastic litter as well as a barrier for anthropogenic debris before they are dispersed in the marine environment (Martin *et al.*, 2019). Sampling activities in mangrove areas are practically very difficult and there are only few studies related to the quantification of the abundance of marine litter on mangrove soil (Graces-Ordonez *et al.*, 2019).

Nor and Obbard (2014) have reported a maximum average concentration of 62.7 ± 27.2 items/kg of dry sediment from the mangroves of Singapore coastal mangrove ecosystem. Naji *et al.* (2017) have found the maximum average concentration of 19.5-34.5 items/kg of dry sediment from two mangrove stations in the Persian Gulf of Iran. The maximum concentration of 42.9±26.8 items/kg of dry sediment inside the mangroves of Qinzhou Bay in China was reported by Li *et al.* (2018). On the other hand, the microplastic density estimated by Graces-Ordonez *et al.* (2019) was 31 and 2,863 items/kg, the highest concentrations in mangroves. All these results are on the higher side of the present estimate, which may be due to the greater population density in the city areas and the influence of ocean currents. But it is always challenging to have a comparison, as there exist variations in reporting units and differences in sample types (Nor and Obbard, 2014).

The spatial distribution of micro and mesoplastic litter showed that the ecosystems in Zone 1, which is on the southern side of the Cochin Estuary, had higher average abundance than Zone 2. The ecosystems where the two size classes namely micro and mesoplastic abundance were high, also evidenced more density of macroplastic litter. The entrapped particles undergo degradation due to physical, chemical and mechanical actions and get fragmented to meso and further to microplastic particles (Andrady *et al.,* 1993; Song *et al.*, 2017; Julienne *et al.*, 2019). The ecosystem acts as a sink for it to remain there and the process of accumulation over the years results in the increase in concentration of its small fractions (Ivar do sul *et al.*, 2014; Martin *et al.*, 2019).

Cordero and Costa (2010) have assessed the average abundance of marine macro litter in mangroves of the San Vicente Estuary, Brazil as 1.33 items/m^2, with most dominance of plastics (63%) while Smith (2012) found a wide variation in the average abundance of marine litter, between 1.2 and 78.3 items/m^2 in the mangroves of Motupore Island in Papua New Guinea, where 89.7% were plastics. The macroplastic density was 540$\pm$137 and 31$\pm$23 items/ha near and away from populated centres respectively and plastic items constitute 73 to 96% of litter in the Colombian Caribbean mangroves (Graces-Ordonez *et al.*, 2019). The surface macro litter estimated by Riascos *et al.* (2019) in Buenaventura (Colombia) ranged from 0.22 to 35.5 items/m^2 with dominance of synthetic polymers (86.86%). They also observed a higher litter density on the landward side than the seaward of the mangrove ecosystem studied. Also, Martin *et al.* (2019) observed low abundance of marine litter (0.66 items/m^2) in a newly planted mangrove forest, and comparatively higher numbers (3.7 items/ m^2) in a mature natural forest along the coast of Yanbu, Saudi Arabia with predominance of plastics (92.2%). This result is comparable with the present investigation, where an average macro litter abundance of 3-4 items/m^2 were observed among the mangroves of Ernakulam District.

These results are in concordance with the type of water body, lentic system and high state of mangroves disturbance which facilitate plastics fragmentation, generating microplastics (Weinstein *et al.*, 2016). Differences in geographic locations, different sampling methodology, extraction efficiency and other factors can bring wide variability in micro plastic abundance which restricts an unbiased comparison among the studies. Lack of standardised units of quantification for measuring the abundance of microplastics leads to unreliable comparison among different studies (Duis and Coors, 2016; Naji *et al.*, 2017). Nonetheless, a harmonisation and standardisation of techniques and protocols for the extraction and identification of microplastics is urgently needed (Naji *et al.*, 2019).

Ecosystem grading

An ecosystem grading based on the abundance of plastic litter showed that Kumbalangi had the maximum micro and mesoplastic abundance and ranked 'Very high' (Fig.4a, b). Similarly, for macroplastic distribution Kumbalangi, Kumbalam and Nettoor stations ranked "Very high". Plastic carry bags, disposable plates and cups, abandoned helmets, house hold items, broken buckets, tarpaulin sheets, tyre, used flex sheets and many more were lying entrapped between the pneumatophores and seedlings. The survey area of Kumbalangi was an eco-tourism spot where anthropogenic impact appeared high. At Nettoor the mangrove area surveyed was adjacent to the International vegetable market, enormously used by customers every day. A similar trend could be observed in other locations where illegitimate dumping seemed to be the major reason for the accumulation of non-degradable litter, which persists at the same site, once entrapped. This was followed by a 'high' abundance in the stations of Kannamaly, in

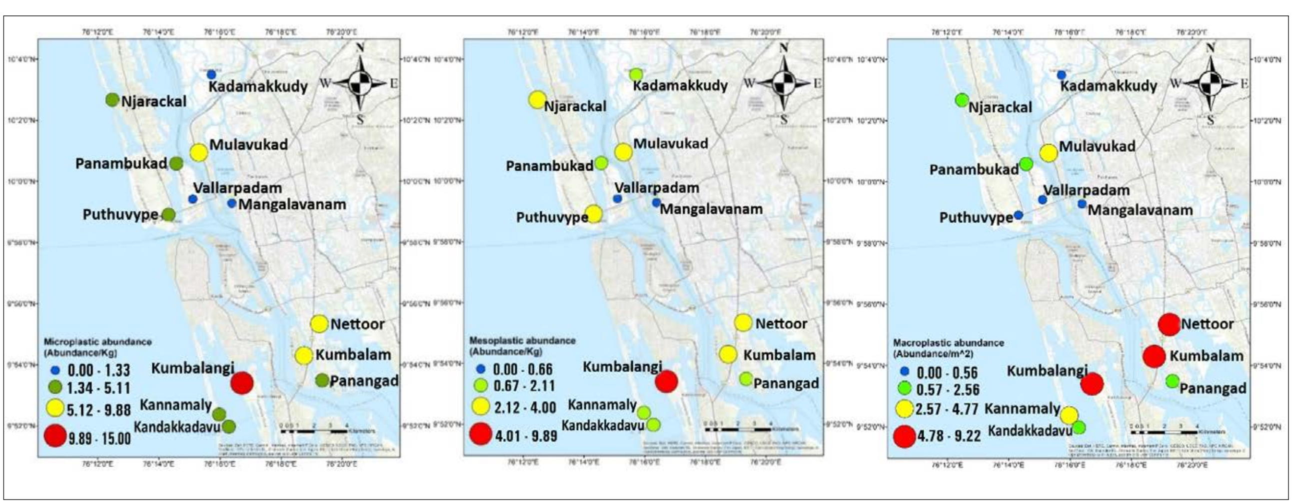

Fig. 4(a-c). Map showing the mangrove ecosystem grading based on the abundance of plastic litter

Zone 1 and Mulavukad in Zone 2. Kandakkadau and Panangad in Zone1 and Panambukad and Njarackal in Zone 2 fell under the 'Moderate' category of macro litter abundance (Fig. 4c). Domestic solid waste bundled in plastic carry bags were seen frequently irrespective of the locations. All these stations were in close proximity to public roads where people deliberately throw waste, leading to illegitimate dumping. More over the tidal force and amplitude were not strong enough to wash off these to the open flowing waters. This leads to accumulation of intentionally dumped and accidently trapped litter in the mangroves. Among the stations surveyed, three stations which had few regulations on dumping of litter by Authorities, like Mangalavanam, Vallarpadam and Puthuvype, were comparatively clean with low abundance of microplastics and ranked 'Low' while other stations fell under 'High' to 'Moderate' ranks.

According to Li et al. (2020) human interventions act as the major reason for the enhancement of non-degradable litter density in the mangrove forests of Beibu Gulf, Guangxi Province, China, where the litter density at a site adjacent to areas of human population was relatively higher (95.6 ± 5.0 items/kg) than the same collected from an industrial area (49 ± 12 items/kg).

Characteristics of mangrove litter

Composition of litter

Micro and macro litter composition varied from pieces of degraded plastic carry bags to thick plastic sheet, degraded garbage bag to food packaging cover, hard plastics, plastic thread (sack), fishing net/rope piece, flex piece, nylon and foam sponges (Figs.5a and 6a). Presence of rubber, paint, thermocol, broken glass, cloth, aluminium foil and broken ceramic were also noted during the survey. The chi-square test of independence, performed to compare the distribution of microplastic types across different locations showed significant difference in its availability across the stations ($p<0.05$).

On an average, 57% of the micro litter composition consisted of fragmented plastic carry bag/kit pieces and many were in its degraded form (Fig. 5b). A similar observation has been made by Graces-Ordonez *et al.* (2019) in the mangrove soils of Cieenaga. Grande de Santa Marta, Colombian Caribbean where 73-96% of the items collected were plastics with the most abundance of carry bags and packaging covers.

Fragmented pieces of plastic items accounted for 'hard plastics' which was present in almost all stations with an average estimate of 13.72% followed by food packaging cover. For the macro litter category, out of the identified litter items, 53.2% contributed to plastics and 8.24% formed plastics, comprising a total of 61.4%. Rest of the items collected were cloth (11.12%), glass and ceramic (5.9%), metal (4.53%) and rubber (6.59%) as shown in Fig. 6 (b). Other items such as bundled solid waste, sanitary napkins, medical and e-wastes etc. contributed to 9.06%.

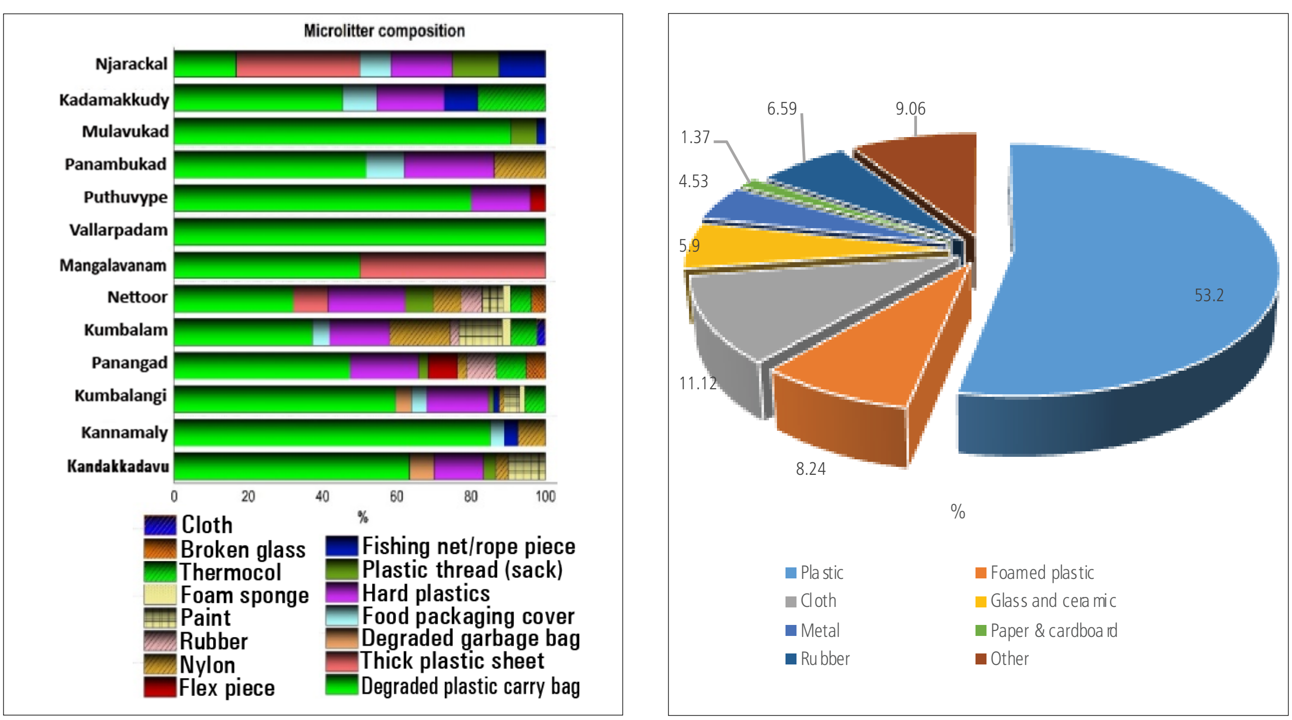

Fig. 5(a). Micro litter composition in different mangrove survey stations and (b) Average percentage composition of micro litter.

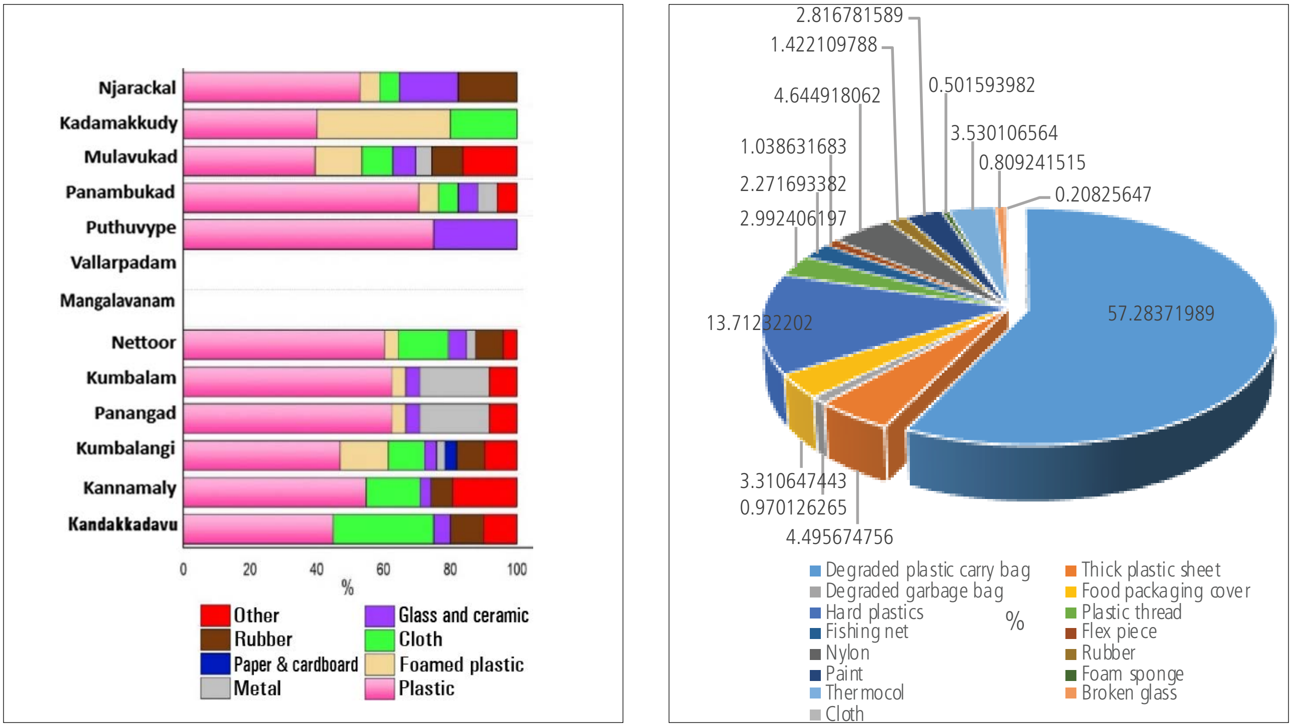

Fig. 6(a). Macro litter composition in different mangrove survey stations (b) Average percentage composition of macro litter.

Among the diversified array of litter categories, plastic carry bags (PL07, RL25) (62 counts), water bottle (PL02, RL02) (53 count), plastic sheet/garbage bag/grow bag (PL16, RL16) (41 count) were observed during the present survey. Accumulation of plastic cups (FP02, RL09), broken buckets (PL03, RL03), food packaging containers (PL 06, RL19) and fishing rope (PL19, RL08) were also noted.

Medical wastes such as syringes (PL12, RL18) and gloves (RB03, RL25) were seen entrapped among the root system of mangroves. Thermocol (FP05, RL13) was another item present in many locations. Abandoned helmets (ME10, RL23) (6 counts) were found lying among the pneumatophores landlocked. Discarded tube light (GC05, RL21), bulbs (GC05, RL21), glass bottles (GC02, RL02) mainly contributed to glass items. Rubber materials comprised of tyre (RB04, RL28), cycle tube (RB05, RL28), balls (RB01, RL27), gloves, (RB03, RL25) and foot wear (CL01, RL25). Improper disposal of single use plastics like cups & plates (PC03, RL09) and sanitary diapers (OT02, RL18) were also noticed. Used and degraded flex pieces (CL 03, RL25) were another item visible in most stations. In the sampling area, greater accumulation was found adjacent to public roads, and maximum was observed within the first 10 m area from the edge of the road and diminishing towards the interior. Household solid wastes bundled in plastic carry bags (OT05, RL23), illicitly thrown in many mangrove swamps by the local people was a common observation throughout the survey. From the 13 mangrove locations surveyed, 46 numbers of such bundles were counted. A total count of 408 items of different material compositions were observed from the study stations during the one-time survey.

Source wise classification of macro litter

Collected plastic litter were grouped to different sources and found that 70% of the waste was domestic in nature implying, anthropogenic impact. Among these 21% was plastic carry bag and 18% drinking water bottle. Garbage bags and other plastic sheets contributed to 14%. Another 13% accounted for bundled solid waste. Recreational items (12%) > industrial (6.4%) > medical (3%) > commercial (3%) e-waste and (3%) > fishery (1.2%) were the other source wise distribution in the study stations. Disposable cups and plates were grouped under recreational and large numbers of such items could be counted from many stations especially in tourism spots.

The potential impact of microplastics on the ecosystem is most influenced by the size of this contaminant (Aliabad *et al.*, 2019). The adsorption capacity of microplastics in the sediment can increase with the decrease in their size, likely due to the increase in surface area (Velzeboer *et al.*, 2014). Overall size of the detected microplastics measured on its longest axis ranged from 0.08 to 5 mm and the mesoplastic measurement had a dimension of 5.1 to 24.6 mm in the sediments inside the mangrove ecosystems studied Fig. 7a & b.

The size range of microplastics plays a significant role as it determines the potential for ingestion of these contaminants by the biota (Nor and Obbard, 2014; Moore *et al.*, 2000). All the collected particles were secondary in nature as they appeared as degraded forms of several items. High temperatures and strong solar ultraviolet light associated with tropical climate can accelerate the degradation of large plastic debris in supratidal zones (Lambert *et al.*, 2018)

Types of litter

Micro and mesoplastics collected were categorised (Fig.7a, b) into four groups according to their types as Films, Fragments, Fibre and Round. Film was the dominant category followed by Fragments>Fibre>Round and is similar to other observation across continents (Cordeiro and Costa, 2010; Ivar do sul *et al.*, 2014; Martin *et al.*, 2019; Graces-Ordonez *et al.*, 2019).

Colour fraction of litter

The colour fractions observed were White> Blue> Green>Red> Transparent>Black>Orange >Yellow (Fig. 8a, b). In fact, colour is one of the most important factors often considered to influence the ingestion of microplastics by marine organisms, as specific colours might attract predators when they resemble the colour of their prey (Kuhn *et al.*, 2015; Abayomi *et al.*, 2017). Previous studies have demonstrated that most microplastics collected from sediments of mangroves and sandy beaches were white or transparent (Corcoran *et al.*, 2015; Veerasingam *et al.*, 2016, Li *et al.*, 2018), which is in agreement with the present study.

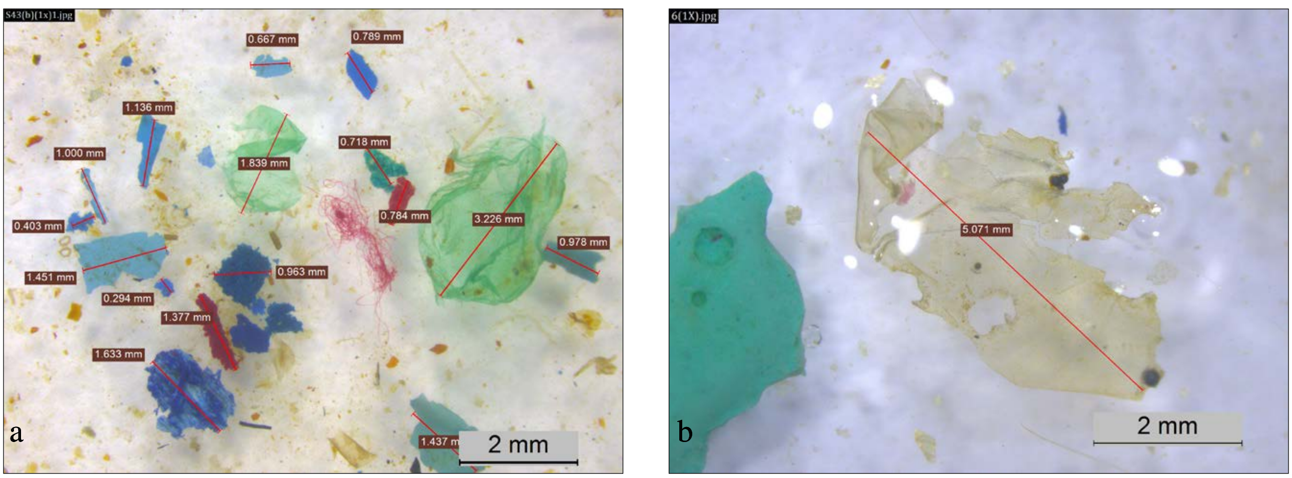

Fig. 7. Size fractions of (a) micro and (b) mesoplastic litter

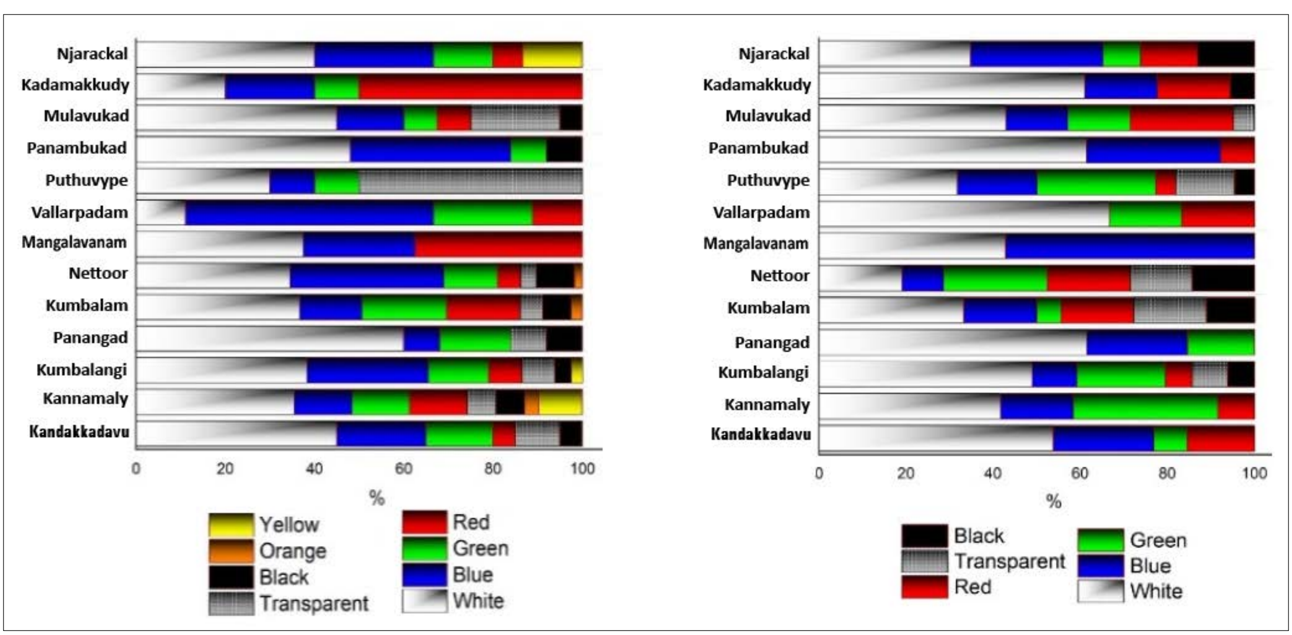

Fig. 8. Percentage colour fractions of(a) micro and (b) mesoplastic

However, there are other observations with blue (Peng *et al.*, 2020) and black (Naji *et al.,* 2019) as dominant colours.

Polymer identification

The confirmation on the polymer type of microplastic was done with a sub sample of the collected plastics using a FTIR (PerkinElmer Spectrum 2, Version 10.6.0) with wave length ranging from 400-4000 nm^{-1} and the data analysis was done using Spectrum IR. Software. 50 % of the analysed samples were of Polyethylene (HDPE/LDPE) in nature followed by > PP > PETE

Relationship between benthos and plastic abundance

When plastic sheets form a layer over the substratum, it can degrade benthic habitats due to smothering which can lead to hypoxic/anoxic condition, and cause changes in sediment permeability due to buried plastics (Carson *et al.*, 2011).

As evidenced from the PCA biplot (Fig. 9) there is a significant reduction in benthic community in the regions with high micro and macroplastic abundance and the overall availability of microplastic and mesoplastic materials is significantly influenced by the abundance of macroplastics.

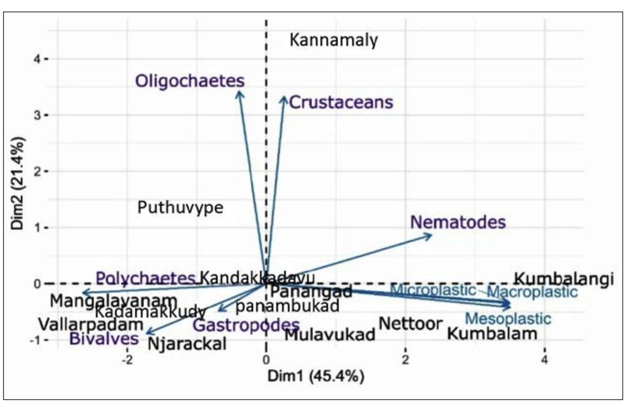

Fig. 9. PCA biplot showing the relationship of Plastic with benthos

Simulation experiment

Simulating a smothering effect revealed that the abundance of benthic communities at the control and the treatment sites were not significantly different during the initial period of the experiment ($p>0.05$). But after 90 days of the experiment significant changes could be observed between the control and the treatment and the trend continued on the 180th, 270th and 360th day of observations, clearly indicating negative impact. (Fig.10a, b).

The decrease in benthic abundance over the period of time was drastic (44.4%) from day 0 to day 90, and a further decline on day 180 (68.92%), on day 270 (91.47 %) and on day 360 (96.12%). This clearly indicates that even short term smothering is harmful to the underlying organisms and such sheets should be removed periodically. Among the group of benthos observed, polychaetes showed maximum abundance in control as well as treatments. The percentage decline of individual organisms, noticed in treatment sediments was 26.37% on day 90, 51.9% on day 180, 83.07% on day 270 and 92.31% on day 360. Another change recorded was in the abundance of crustaceans, which showed a declining trend of 50, 75 and 100% from the start of the experiment to day 360. Nematode abundance also showed a declining trend from 32.69% reduction on day 90 to complete absence in subsequent sampling. A decline of oligochaetes was also visible under the sheet mulched soil during the period of observation.

The reduction in benthic faunal abundance can be explained by the smothering effect of plastic in the substratum which simulates an anoxic condition. Plastic litter covers the pneumatophores and roots of the plants that acts as a litter trap and negatively impact the benthic habitat existing in the area (Ivar do sul *et al.*, 2014; Martin *et al.*, 2019). Specific

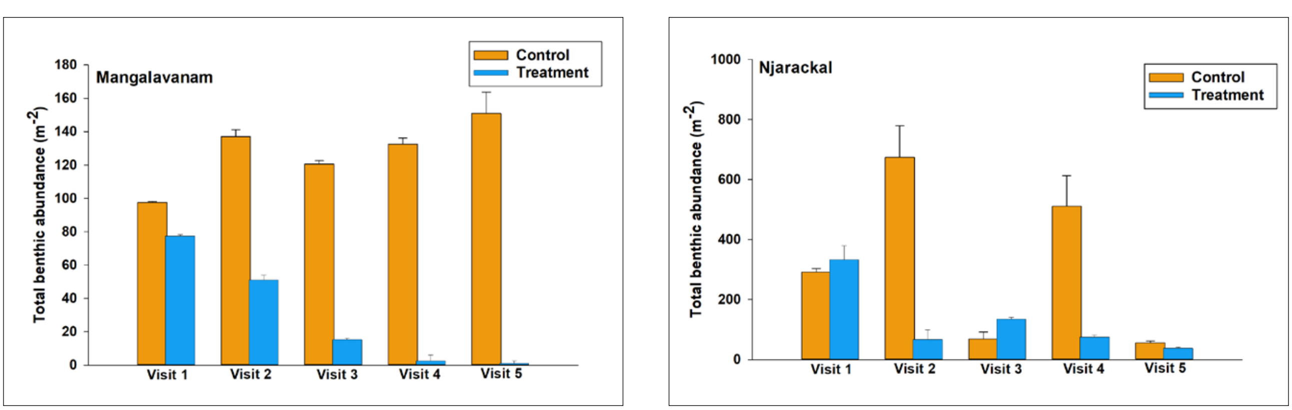

Fig.10.Total benthic abundance in the two mangrove locations (a) Mangalavanam (b) Njarackal

biotic assemblages colonize marine litter according to their position in the mangrove forests and their stiffness (Riascos *et al.*, 2019). Biological assemblages are also affected by the orientation of litter materials and the exposure time in the marine environment (Czarnecka *et al.*, 2009).

The polychaete worm *Arenicola marina* (lug worm) showed reduced feeding activity, longer gut residence time of ingested plastics and inflammation leading to depleted energy reserve upon a chronic treatment with PVC (Wright *et al.*, 2013). These depleted energy reserves could decrease lipid reserve and compromise somatic maintenance and growth, maturity and reproduction in organisms (Wright *et al.*, 2013)

The study points to the fact, that human intervention plays a significant role in polluting and degrading mangrove habitats affecting its ecosystem services and hampering its aesthetic value. The establishment and survival of mangrove seedlings are affected by marine litter causing physical damage, loss of foliage, crushing and death, situations that need to be investigated.

This study was designed to investigate the characteristics of plastic pollution in the mangrove ecosystem of Ernakulam District. Kerala, India. By conducting a detailed survey and sampling in 13 mangrove locations situated around the area, it was understood that some parts of the mangrove forests are under serious threat of litter pollution. The major reason investigated was anthropogenic intervention, and reducing human activities could aid remediation in the intensity of pollution in these areas. Anthropogenic interference could not only affect ecosystem health, but result in fragmentation and area reduction.

This work has established a database of litter pollution in mangroves which is far less studied so far. Hence these findings are important for informing researchers in future studies to design management tools for the prevention, reduction and control of these emergent pollutants. The simulation study with plastic sheets laid in two mangrove locations to understand the impact of plastic smothering on benthic community showed that there is a strong negative impact which increases with time. The benthic abundance declined from 53.3% in 90 days of smothering to 93.8% in 360 days.

More detailed studies are further required to provide a healthy valuable ecosystem and improve the quality of life. Based on the present study the following five-point recommendation is suggested for better management of marine litter and protection of mangroves from the threat.

Filter screens should be provided at the inlet area of the water channel to prevent entry of marine litter from open waters to the mangrove ecosystem.

Periodic cleaning of the mangrove habitats by removing the macroplastics and other litter should be made mandatory by the local governing bodies and provisions for inspecting this should be made.

Awareness should be created through visual and print media among the coastal communities about the harmful effects of litter on mangrove ecosystems and the need to conserve the health of this critical habitat.

Dumping of bundled domestic and other solid waste should be prohibited by law and made punishable.

In areas where mangrove tourism is promoted, a strict ban on use of plastics and careless discarding of waste should be enforced. Provisions for collection of waste generated by tourists should be made, with arrangements for further disposal and solid waste management.

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