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Artificial coastal defence structures – A surrogate of natural rocky structure to enhance coastal biodiversity

J Prince Prakash Jebakumar[1,*], G Nandhagopal[1], S Ragumaran[1], Vijaya Ravichandran[1] and C M Ramakritinan[2]

[1]*Coastal Environmental Engineering Division, National Institute of Ocean Technology, Pallikaranai, Chennai, India.*
[2]*Department of Marine and Coastal Studies, Madurai Kamaraj University, Madurai, India.*
**Corresponding author. e-mail: prince@niot.res.in*

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The world's 40% of the population lives in coastal areas (<150 km from the sea), and this is set to increase in upcoming years. This urban sprawl leads to the proliferation of artificial coastal defence structures along the coasts to save the populace from coastal erosion, storms, and hurricanes. Deployment of artificial coastal defence structures has direct or indirect impacts on the local and global scenario, but the ecology of artificial habitats was studied poorly. Therefore, the current study aimed to focus on the role of artificial coastal defence structures in enhancing the coastal biodiversity. A total of 228 epibiotic species associated with the artificial coastal defence structures were identified. The study recorded high species richness and diversity of epibenthos in artificial habitats compared to natural habitats. Among various types of artificial habitats, assemblage pattern of epibiotic species in sandstone surfaces differs from non-sandstone surfaces. Apart from the structure surface, local epibenthic biodiversity also plays a significant role in determining the artificial structure assemblages. The length, vertical height, and age of the structures are the major deciding factors in species composition of the structures. The overall study concluded that the artificial coastal defence structures could act as a surrogate surface for epibiotic assemblages. The input of coastal biodiversity component while designing the artificial coastal defence structures can be an added advantage.

Keywords. Urban sprawl; coastal biodiversity; artificial habitats; natural habitats; epibiotic species.

1. Introduction

The marine ecosystem is providing an immense range of essential services to the human populace (Peterson and Lubchenco 1997; Holmlund and Hammer 1999; Nandhagopal *et al.* 2020). Due to this huge availability of marine resources, the coastal area was attracted by humans for the revenue source. Currently over 40% of the world's population survive in and around the >150 km range from the sea (Cohen *et al.* 1997; Nicholls *et al.* 2007). These coastal populace are often

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subjected to various pressure due to the pervasive global climate change, which impacts at regional and local scales (Thompson *et al.* 2002; Firth and Hawkins 2011). The increasing urbanization along the coastal area and the threat due to the coastal erosion and flooding, proliferating the artificial coastal defence structures (Chapman and Underwood 2011; Firth *et al.* 2013a). The artificial coastal defence structures seawalls, jetties, breakwaters, groynes, dykes are the common structure built in marine coastal habitats worldwide at the expense of natural habitats. In many locations, the artificial coastal defence structures replaced partially or completely the natural shores (Airoldi *et al.* 2005; Moschella *et al.* 2005).

The primary purpose of the artificial coastal defence structures is to prevent or reduce coastal erosion, flooding, stabilizing, and retaining beaches (Firth *et al.* 2013b). More than 50% coast of Europe, USA, Australia, and Asia has been modified with hard engineering structures (Bacchiocchi and Airoldi 2003; Moschella *et al.* 2005; Vaselli *et al.* 2008; Firth *et al.* 2013b). Though the artificial coastal defence structures become the common member of the natural shorelines, still the ecology of the artificial coastal defence structures are known very little (Connell and Glasby 1999; Bacchiocchi and Airoldi 2003; Chapman and Bulleri 2003). The impact of artificial coastal defence structures on the marine environment can be of: (i) direct physical disturbance from the addition of materials during construction, (ii) alteration of connectivity between habitats and species isolation, (iii) indirect physical disturbance, through changes in sediment transportation pattern and altered turbidity, (iv) noise and light pollution (Dafforn *et al.* 2015). Regardless of a nuisance to the shoreline by artificial coastal defence structures, still, it is a part of the resource to the coastal biotic assemblage by providing a novel habitat (Jebakumar *et al.* 2015).

Apart from the primary purpose of the artificial coastal defence structures like protecting the assets from erosion and flooding, it is inevitably colonized by the marine epibenthic organisms such as barnacles, mussels, bryozoans, sponges, hydroids and macroalgae and acts as a simplified surrogate for natural rocky habitats (Southward and Orton 1954; Thompson *et al.* 2002; Martin *et al.* 2005; Branch *et al.* 2008), which in turn create biogenic habitats for additional fauna of mobile species such as crustaceans, fish and cephalopods (Coleman and Connell 2006; Wilhelmsson *et al.* 2006; Clynick *et al.* 2007). However, many studies suggest that these artificial coastal defence structures are known to support less diverse compared to the natural rocky structures (Chapman and Bulleri 2003; Bulleri and Chapman 2004; Gacia *et al.* 2007; Vaselli *et al.* 2008; Pister 2009) and support more non-native species than natural habitats (Airoldi and Bulleri 2011; Mineur *et al.* 2012). The diversity deficits on the artificial coastal defence structures compared to natural rocky structures may be due to higher disturbance regimes caused by wave energy and sand scouring (Moschella *et al.* 2005). Because mostly these structures are often constructed in high energy and erosive soft sediment environments. Along with this, the intermittent maintenance activities are also responsible for the loss of diversity (Airoldi and Bulleri 2011). Still, after a prolonged period of immersion in the marine environment, the artificial coastal defence structures are able to support high species diversity and richness compared to adjacent natural rocky structures (Evans *et al.* 2016).

The ecology of the artificial coastal defence structures compared to natural rocky structures are always questionable when it comes to debate. The main reason was due to the less knowledge on the ecology of the artificial coastal defence structures. The ecological studies of epibiota associated with the artificial coastal defence structures are still at the preliminary level globally. Fewer studies exist in the ecology of epibiota associated with the artificial coastal defence structures (Moschella *et al.* 2005; Glasby *et al.* 2007; Evans *et al.* 2016). In India, scanty studies are available on the diversity of the epibiotic species associated with artificial coastal defence structures (Ravinesh and Bijukumar 2013), though most part of the Indian coastline was occupied with the artificial coastal defence structures. As an initiative, the current study was aimed to understand and study the biotic assemblage on artificial coastal defence structures deployed along the shorelines of Tamil Nadu coast and this type of studies was not prevalent in India. In this study, an extensive survey was conducted along the coast of Tamil Nadu for the search of artificial coastal defence structures and to identify each and every associated epibiotic species based on the structure types. The study also aimed to identify the efficiency of the artificial coastal defence structures to act as a surrogate natural rocky structure.

2. Materials and methods

A 1076 km coastal stretch of Tamil Nadu, located at the south-eastern part of the Indian peninsula, forms the Coromandel Coast upon the Bay of Bengal and the Indian Ocean. This vast stretch of coastal corridor comprises 15 marinas and harbours. Further, it has numerous artificial structures, and protective groins that provide habitat for a wide variety of epibiota (Jebarathanam *et al.* 2019) along with few natural rocky shores (hereafter natural habitats). Based on the texture, the artificial coastal defence structures (hereafter artificial habitats) are classified as sandstone and non-sandstone habitats (figure 1).

A one time extensive field survey was conducted during the year 2018 along the 1076 km coastal stretch of Tamil Nadu (southeast coast of India) to study the distribution and diversity of epibiotic species associated with artificial and natural habitats. A total of 84 locations were sampled during low tide of each day. All the 84 sites were divided and classified under seven zones based on their geographic locations and orientation of the coastline (Abhishek Tavva *et al.* 2017) (see supplementary data). Series of field surveys were conducted through SCUBA diving and Snorkelling at low tide, depths ranging from 1 to 5 m (Jebakumar *et al.* 2015) at seven sampling zones during 2018. Each zone includes 8–18 sampling stations (total of 84), mainly along the Tamil Nadu coast (figure 2). Investigations resulted in a wide variety of artificial habitats such as boulder piles, sea walls, groins, harbour break waters (sand stone) caissons, tetrapods, fishery jetties and pipeline trestles (non-sandstone) (Connell and Glasby 2006) along the shoreline of Tamil Nadu. Handtools were employed to remove animals from solid surfaces of the artificial and natural structures. The diversity of the samples were analyzed in each sampling site using a 10-m belt transect method. A total of two to three transects were laid along the submerged portion of the artificial coastal defence structures depending on the length of the structures, and three to five quadrates (1 × 1 m) were laid per transect (Megina *et al.* 2013).

The epibiotic samples were collected and coded for identification in the laboratory. They were brought in clean sample containers (one sample per container). Then the specimens were photographed immediately after transportation as well as onsite. Further, to determine the specimens species level, individual samples were preserved in 90% alcohol (Vinod *et al.* 2014). The World Register for Marine species (WORMS 2014), Records by Zoological Survey of India, has been used as a reference for up-to-date taxonomical identification. The lists of species displayed the currently accepted name. The cluster analysis based on the Bray–Cutis similarity matrices of root transformed species diversity was used to analyze the species diversity differences

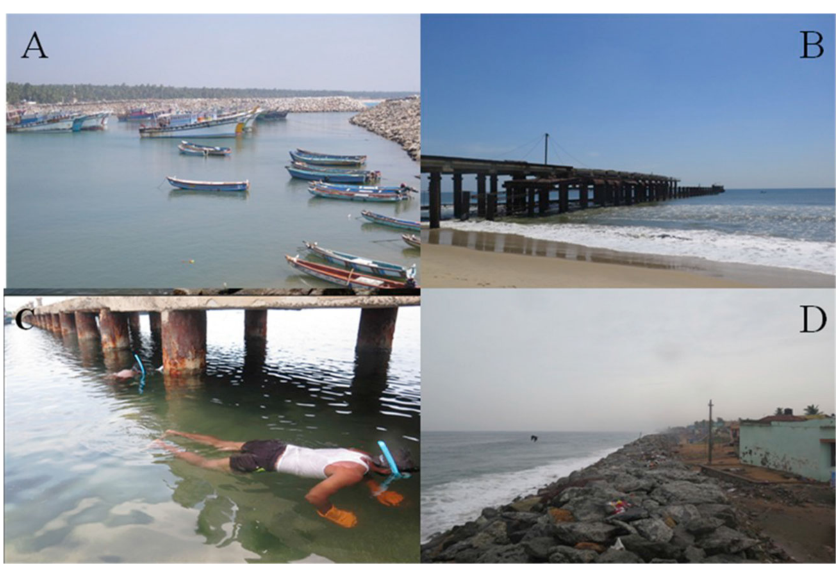

Figure 1. Depicting various types of coastal defence structure (**A** and **D**): sandstone and (**B** and **C**): non-sandstone surveyed along Tamil Nadu coast.

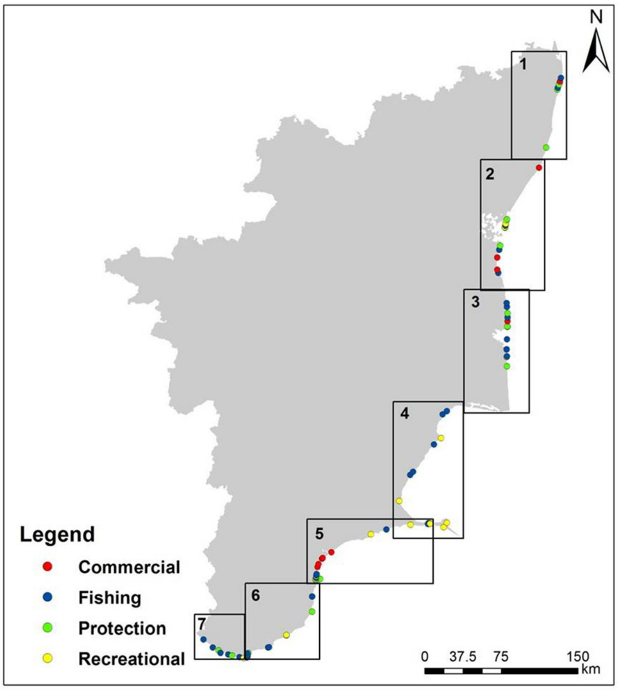

Figure 2. The study area: The Tamil Nadu coast in southern India; grey squares indicate the seven sampling zones where the 84 sampling stations were placed (see supplementary table S1 for coordinates).

between the zones. The Primer v7 was utilized to perform this analysis.

3. Results and discussion

The extensive survey along the entire stretch of Tamil Nadu coast (artificial habitats) identified a total of 228 species that belongs to the three kingdoms, 13 phyla, 23 class, 70 order, and 116 families. Among these 228 species, the Gastropoda was the dominant class, with 71 species followed by seaweed with 45 species. Along with these species, some of the dominant groups are Ascidians (26 species), Sponges (20 species), Echinoderms (16 species), Arthropods (16 species) and Annelids (10 species) and the remaining minor representative groups are classified under other categories and comprised a total of 24 species. The survey along the natural habitats that are nearby to the artificial habitats recorded a total of 53 species belong to three kingdoms, nine phyla, 12 class, 27 order, and 27 families. In the natural habitats, the seaweed was the dominant group with 22 species followed by Gastropods 17 species and the remaining groups were represented by few species. In case of natural habitats, very few existed in Zone 1 and no natural habitats was found in Zone 2–6, whereas only in Zone 7 decent number of natural and artificial habitats were present adjacently. Therefore the natural and artificial habitats present in Zone 7 alone were compared. The difference between the natural habitats and artificial habitats in taxon-wise was represented in figure 3. There was a significant difference in the total species richness between the natural and artificial habitats (ANOVA, $P \leq 0.05$). All the recorded species of natural habitats were recorded in the artificial habitats too, but some of the species are unique only to the artificial habitats. It is well known, that the natural habitats are more rich and diverse than the artificial habitats (Chapman and Bulleri 2003; Moschella *et al.* 2005; Pister 2009; Evans *et al.* 2016; Firth *et al.* 2016).

In contrast, the current study reported high species richness and diversity in artificial habitats than the natural habitats. The cluster of natural habitats at the southern tip of Tamil Nadu coast where three seas meet together (junction of the Bay of Bengal, Indian Ocean and Arabian Sea) intend to have unique physical forces (Moschella *et al.* 2005; Kaliraj *et al.* 2014), which might not have been encouraged biotic settlement at natural habitats. However, the existing artificial structures may provide shelters and protection from prevailing physical oceanographic effects at this area and supported biotic assemblage. It indicates that most of the artificial habitats are able to provide ample amount of space and shelter to many of the seaweeds, juveniles, filter feeders, and predators compared to natural habitats. The majority of artificial habitats have steep vertical faces, whereas natural shores had shallow sloping gradients. Apart from that, the age of artificial habitats will be long enough to support diverse species in many of the locations, because Evans *et al.* (2016) stated that the sustainable habitat provided by the artificial structures after a prolonged period enhanced to support high species richness than the natural adjacent rocky pools. The similar studies of different locations also proved that the intertidal and shallow boulders known to support wide variety of biodiversity and rare species (Kangas and Shepard 1984; Chapman 2005). It is also evident that the increase in the number of microhabitats complexity in artificial habitats will considerably increase the biodiversity than the adjacent natural habitats and viably act as a surrogate natural habitat (Martins *et al.* 2010; Firth *et al.* 2014). These cumulative effects may sustainably increase the species richness in artificial habitats compared to the natural habitats. However, indepth studies are

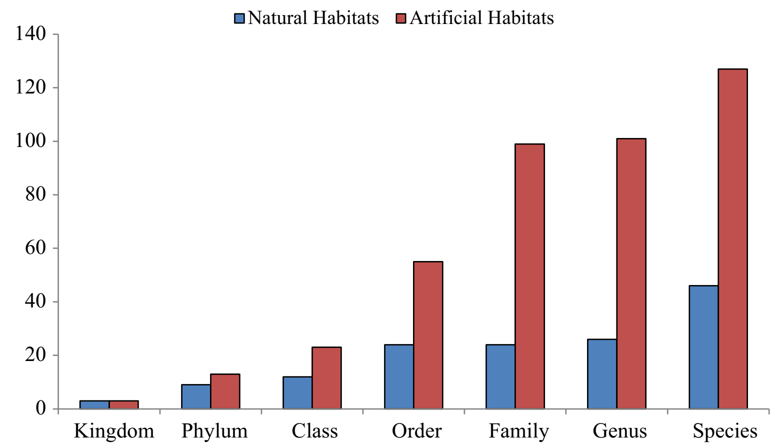

Figure 3. Difference in taxon class between artificial habitats and natural habitats of Tamil Nadu coastal region (Zone 7).

warranted towards the impact of physical oceanographic forces like a wave and current on biotic assemblage pattern on natural as well as artificial structures.

Among the artificial structures deployed along the Tamil Nadu coast has been divided into sandstone (natural rocky boulders) and non-sandstone (concrete structures) surface habitats. The sandstone surface habitats supported 34 species on an average, whereas the non-sandstone surface habitats were able to support only 17 species on an average to each structure. The non-sandstone surface habitats also lacked key species like seaweed and crustaceans compared to sandstone surface habitats. The smooth surface and high vertical slope, which hinder the settlement of species in the non-sandstone surface, lead to lower diversity (Chapman 2006). The non-sandstone surface habitats are also known for the settlement of fouler compared to sandstone surface habitats (Nakono and Strayer 2014). Connell and Glasby (1999) proved in their study that the sandstone surface habiats are almost similar in species richness and diversity. From the study, it was also clear that the surface texture and mineralogy are also essential factors in determining the species recruitment and community composition (Caffey 1982; Holmes *et al.* 1997; Herbert and Hawkins 2006). Apart fom that, many studies proved that the intertidal and shallow boulders known to support wide variety of biodiversity and rare species (Kangas and Shepard 1984; Chapman 2005). It is evident that the use of artificial habitats (sandstone) than the non-sandstone surface structures will be the better option to enhance the marine biodiversity.

The artificial habitats along the Tamil Nadu coast have been divided under seven zones based on geographical location and orientation of coastline. The epibiotic species abundance based on zones revealed that Zone 7 have higher species abundance followed by Zone 5, Zone 6 and Zone 4 (figure 4). Zones 1 and 2 represented lower species abundance, while the lowest was noticed in Zone 3. The study also revealed that there was a significant difference between species diversity and zones ($P \leq 0.05$). The cluster analysis forms three groups among the zones (figure 5), whereas Zone 7 alone separated from the rest of the zones. The abundance of epibiotic species spread in different zones varied based on the locations. In general, Zones 4–7 exhibited high species abundance and diversity compared to other zones. The reason for high diversity in artificial habitats located in these zones was the species abundance, diversity and richness that already existed in that particular zone. These four zones are located along the Plak Bay and Gulf of Mannar region, which are well known for the rich biodiversity (Venkataraman and Waffer 2005). The richness of species diversity in these zones provides the source to the artificial habitats deployed. The Bary–Curtis similarity index also confirmed the differentiation in species diversity and abundance between zones through clustering. The Ocean current speed, pattern and proximity between artificial habitats were also the prime reasons for the high diversity in Zones 4–7. In general, the current directions are usually southwards (Brewer *et al.* 2015), and northward currents are slow compared with southward (Gordon and Claudia 2018). Therefore, the quantity of larval movement will be mostly towards the south than the north. The Palk Bay and Gulf of Mannar regions are shallow and partially, a land-locked area which may also be one of the reasons for the

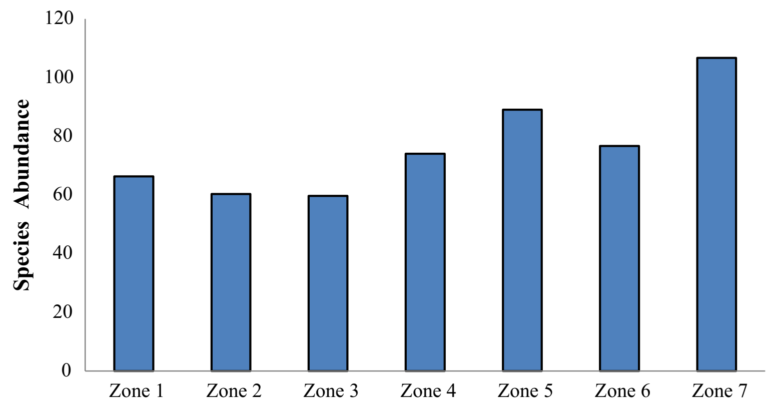

Figure 4. Species abundance of different zones during the study along the artificial coastal defence structures.

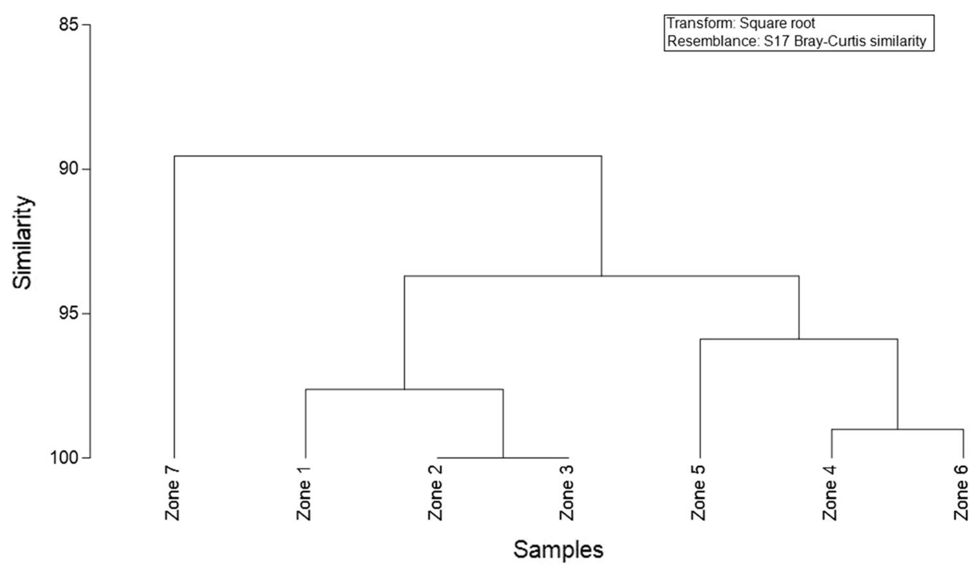

Figure 5. Cluster analysis between the zones using Bray–Curtis similarities from $\sqrt{}$-transformed species abundance data.

species movement restrictions towards north (Jayaraman 1954; Krishnamoorthy and Subramanian 1999). The proximity between the artificial habitats in Zones 4–7 are less compared to Zones 1–3, as its non-proximity to larval spread span may restrict the species exchange. These combined factors are responsible for the high species richness in Zones 4–6 compared to Zones 1–3.

During this study, the natural habitats located in southern part of Tamil Nadu recorded the highest species diversity ($n = 27$) compared to other natural structures. Similarly, the artificial habitats located in these regions also recorded high species diversity ($n = 74$) than that of the other artificial habitats. In the case of northern Tamil Nadu region, both artificial and natural habitats recorded very little diversity. The artificial and natural habitats in the southern region occupied with unique endemic, endangered, and rare species like hydrozoan, sponges, corals, and sea cucumber. However, the artificial and natural habitats present in the northern part of Tamil Nadu (Zones 1–4) mostly occupied with fouling organisms such as Barnacles, Serpulid worms, and ascidians. This study explains that the deployment of artificial habitat proximity to source population shall be one of the significant factors that can literally affect biodiversity (Nandhagopal *et al.* 2020). However, each region has its own coastal processes, including tides and physical processes such as sediment transport (Motyka and Brampton 1993). These regions may also differ in biology as variation in hydrodynamic conditions could alter the larval supply within the region, which in turn affect the community. In the southern region of Tamil Nadu, the Gulf of Mannar Biosphere Reserve may be the larval supplier to the ACDSs of these areas, whereas the absence of such biosphere reserve in the northern part may be a significant reason for lower diversity and rare species settlement.

4. Conclusion

The present study concludes that artificial habitats can be employed in the protection of the coast as well as to enhance the local biodiversity. The overall research revealed that the diversity and richness of species on the artificial habitats purely depend on the diversity patterns of the existing locations. The artificial habitats deployed in and around the Gulf of Mannar Marine National Park recorded wide diversity of species as well as rich in species abundance compared to other artificial habitats. Apart from the locations, the length, surface texture, age, structure types also influence the diversity and abundance of the species. The study also concluded that the species richness dramatically depends on the current pattern, dispersal of larvae than geographical proximity between two zones. In general, artificial habitats are less diverse compared to natural habitats, but the current study contradictorily recorded high species richness and diversity in artificial habitats than natural habitats. Overall, the current study concludes that the artificial coastal defense structures can act as a surrogate of natural rocky structure to enhance coastal biodiversity. The maturity of artificial substrate for a prolonged period might create scares of biota settlement by community succession due to dynamicity of ecosystem enhance biota settlement and mimicked the natural substrates. However, the insertion of microhabitats like cervices and holes to improve the water-retaining features of artificial habitats are need to be considered while designing and planning in order to fully function the artificial habitats equivalent to natural habitats.

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Author statement

Prince Prakash Jebakumar: Conception and design of study. G Nandhagopal: Acquisition, analysis and interpretation of data. S Ragumaran: Acquisition of data. Vijaya Ravichandran: Design of study and drafting the manuscript. C M Ramakritinan: Drafting and revising the manuscript.

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