EPIBIOTIC ASSEMBLAGE AND TAXONOMICAL IDENTIFICATION OF MARINE ORGANISMS ASSOCIATED WITH THE ARTIFICIAL COASTAL DEFENCE STRUCTURES ALONG THE TAMILNADU COAST, INDIA

Synopsis submitted to Madurai Kamaraj University forthe award of the degree of Doctorof Philosophy in MARINE BIOLOGY

By

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SYNOPSIS

Currently over 40% of the world population lives in coastal areas (<150 km from the sea) and this is set to increase in the upcoming years (Cohen, 1997; Nicholls *et al*., 2007; Firth *et al*., 2016). The coastal population coupled with the impacts of climate change such as sea level rise and increased storm frequency, the number of coastal artificial structures are proliferating around the world (Pethick, 2001; Wang *et al*., 2012; Hinkel*et al*., 2014).Throughout the history, it has been estimated that >70%of natural habitats in the habitable portion of the planet has been severely modified or exploited by humans (Hannah *et al*., 1994). This leads to the extinction of 5–20% of the species in many groups of organisms. Over 50% of coastlines of Europe, USA, Australia and Asia have been modified by hard engineering which has predominantly been for coastal defence structures such as seawalls, breakwaters and groynes (BacchiocchiandAiroldi, 2003; Moschella*et al*., 2005; Firth *et al*., 2013). The awareness in conserving the marine and coastal environmentwas relatively recent, and it is lesser compared to the conservation measures made on land. Developments in terrestrial conservation have occurred at a quicker rate compared to marine and coastal conservation owing to legislation to influence landowners to conserve wildlife, habitats and landscapes. In contrast, marine conservation is incompatible to conserve area based than the sector based management regimes (Cole-King, 1995).

The man-made artificial structures are typically designed and constructed to perform a specific purpose(Mineur*et al*., 2012). The various forms of artificial structures result in change to substrate type, surface texture and complexity which can create a range of novel habitats within the marine environment(Moschella*et al*. 2005; Coombes *et al*. 2015).The Impacts of artificial structures on the marine environment can be i) direct physical disturbance from the addition of materials during construction, ii) addition of artificial habitat, altering the connectivity of structures and habitat composition, iii) indirect physical disturbance, through changes in sediment transportation and altered turbidity, iv) noise and light pollution (Dafforn*et al*., 2015), but still the need of the ACDSs are inevitable.

The strong physical impact on the urbanised coastal areas due to the high wave exposure, hurricane and storms, making them vulnerable to the damages. The rising sea levels, tides and currents combine with the potentially destructive forces of waves are responsible for the coastal erosion and flooding (Dafforn*et al*., 2015).Coastal assets often need defending from destructive forces of high impact waves. To avoid all these damages due to erosion and storm, it is important to reduce the force of the waves, particularly storm waves by intercepting them which are approaching the shores (Asif and Muneer 2007).In these cases hard structures such as detached nearshore breakwaters and seawalls are widely used.However artificial structures often develop species assemblages that are similar in many ways to nearby natural rocky shore environments (Moschella*et al*., 2005; Firth *et al*., 2013). Though they mimic the natural rocky structures, but generally support less diverse assemblages (Moschella*et al*., 2005; Mineur*et al*., 2012) with higher numbers of non-native species (Vaselli*et al*., 2008), but lower abundances of mobile fauna (Firth *et al*., 2016).

The humans greatly depend on the marine ecosystem for the variety of resources to fulfill their needs, which leads to the settlement of populace along the coasts are increasing alarmingly. In the current scenario, more than 40% of the world's population and 60% of the world's largest cities are in and around the 100 km radius of the coast (Tibbetts, 2002). The proportion of the world’s population living around the coastline is set to increase further. An increase in the human population growth along the coasts and the associated offshore development leads to increase in the marine and coastal environments that are dominated by the artificial coastal defense structures (Firth *et al*., 2016). Along with the increasing human population, the rise in the sea level, higher storm frequency and hurricanes are aggravated the use of the artificial coastal defence structures (Wang *et al*., 2012).

The artificial coastal defence structures deployed in the marine environment are always colonized by sessile species such as barnacles, mussels, bryozoans, hydroids and macroalgae (Mineur*et al*., 2012), which in turn creates biogenic habitats for additional fauna including mobile species such as crustaceans, fish and cephalopods (Clynick*et al*., 2007). But, in general, there was a concept that the benthic intertidal assemblages of sessile species associated with artificial structures found to be less diverse than the natural rocky shore communities (Firth *et al*., 2013). A few studies carried out on ACDSs in Indian waters (Bhave and Apte, 2012; Ravinesh and Bijukumar, 2013), but still tere was no systematic studies related to the ACDSs. To date, no specific studies have investigated the ecology of the epibiota related to the artificial coastal defence structures and their ecological role in the marine environment, especially in India. Therefore the present research was aimed to investigate the distribution and ecology of the epibiota associated with the artificial costal defence structures.

Objectives

- Assemblages of epibiotic species associated with the artificial coastal defence structures (ACDSs) at seven zones along the coast of Tamil Nadu.
- Assemblages of associated epibiotic species based on the types of the artificial coastal defence structures (Fishing Harbour, Protection, Commercial and Recreational) at seven zones along the coast of Tamil Nadu.
- Species richness based on the seasonal comparison of epibiota assemblages from ACDSs and Natural structures.
- Assemblages of Non -native species with ACDSs along the coast of Tamil Nadu.
- Impact of artificial coastal defence structures on the coastal Biodiversity.

Materials and Methods

Study Site

The Tamil Nadu coast located in the south-eastern part of the Indian Peninsula is occupied by numerous artificial structures and protective groynes that provides habitat for a wide variety of marine organisms. Along the coast of Tamil Nadu, 84 locations from Chennai to Thengapatinam in Kanyakumari district which are occupied by the artificial coastal defence structures were selected for the present study. These 84 locations were selected, divided under seven zones (Zone 1 to 7) and monitored for two years i.e., 2016 and 2017 seasonally to identify the epibiota associated with the artificial coastal defence structures.

Field Sampling

All the 84 artificial structure sampling locations were surveyed for the period of two years-2016 and 2017 and at seasonally representing the summer (May), Rainy (September) and Winter season (January). The survey was conducted in all the sampling locations during the low tide period for the better and accurate collection of epibiotic samples and also to avoid the roughness of the sea. Before the sampling, the tides of each site was observed for the collection. This protocol was carried out to provide accurate data about the ecology of the structures.

Series of field surveys were conducted through SCUBA diving and Snorkelling at low tide, depths ranging from 1 to 5 m (Prince *et al*. 2015) at sampling stations during Winter (January), Summer (May), and Rainy (September) season of 2016 and 2017. The studied habitats comprised artificial substrates such as boulder piles, groynes, caissons, tetrapods, fishery jetties, pipeline trestles, and harbour breakwaters along the entire shoreline of Tamil Nadu, India. Hand tools were employed to remove animals from the solid surfaces of the artificial structures.

The epibiota was quantified using a 10 m belt quadrate method. The 10 m transects were placed randomly parallel to the structures, and 1 m^2 quadrate was placed between the transects to quantify the animals (Megina*et al*. 2013). A total of 3 to 5 transects were placed along the structures depending on the length of the structure, and 4 to 6 quadrates were placed in each transect for quantification of the epibiota. A vertical transect was employed for the concrete structures, and 25 cm^2 quadrate was used for the quantification, as the structure was limited. The epibiotic species were photographed *in-situ* before the collection of the reference samples. The collected reference samples were preserved in the formalin (5%) and also ethyl alcohol (90%) separately, then they were stored in the icebox and transported to the laboratory for the later identification process. Most of the epibiotic species were identified in the field itself to avoid ecological disturbances. The World Register for Marine species (WORMS) has been used as a reference for up to date taxonomy. The lists of species collected in the present study displayed the currently accepted name.

Data Analysis

The statistical tools such as ANOVA, Similarity Index, Kruskal Wallis test, and Cluster analysis were performedbetween the artificial coastal defence structures and natural rocky structures. The ONE Way and TWO Way ANOVA were performed using the Microsoft Excel tool to prove the significance between the Zones and between the seasons. The lowest sample numbers per data set for Zones were considered sufficient to provide analysis using ANOVA. The Kruskal Wallis test was performed using the PAST 3 software.

The ordination of species was performed on the species abundance data recorded on each Zone, which were square root transformed, characterised numerically and displayed graphically as non-multidimensional scaling (nMDS) and as a cluster diagram. The distance between each sample represents similarity and dissimilarity, where the samples close to each other were more similar. To complement the ordination plot, the grouping of assemblages of species was also displayed in a cluster diagram. The nMDS plot and Bray-Curtis Similarity index was analysed using the software PRIMER v7.0 (Clarke *et al.*, 2014). Additionally, the

Diversity indices was also performed using the software PAST 3 (Hammer *et al.*, 2001).

CHAPTER I

GENERAL INTRODUCTION

This chapter deals with the general introduction to the Artificial Coastal Defene Structures (ACDSs) and its role against the natural disasters from protecting the coastal populace and coastal infrastructures. It also states that how the ACDSs can enhance the local marine organisms by providing habitat to the epibiota as well as to the non-native species. This chapter finally ellobrates about the factors that are affecting the marie communities developing by associating with the ACDSs and how the ACDSs can utilize to support biodiversity.

CHAPTER II

EPIBIOTA ASSOCIATED WITH THE ARTIFICIAL COASTAL DEFENCE STRUCTURES

In this chapter, the detailed knowledge regarding the ecology of ACDSs was presented. A total of 84 locations was selected along the Tamil Nadu coast from Chennai to Thengapatinam of Kanyakumari district and studied seasonally for two years i.e., 2016 and 2017 to identify the epibiota associated with the ACDSs. These 84 stations were divided under seven zones based on the coastal orientation. During the study, a total of 228 epibiotic speciesbelong to the153 genera, 116 families, 70 orders, 23 classes,13 phyla and3 kingdoms. The high diversity was attributed to the class Gastropoda with 61 species, followed by Ascidiacea (26 species), Ulvophyceae (21 species), Demospongiae (20 species) and Florideophyceae (16 species.). The epibiotic species abundance based on the Zones revealed that the Zone 7 found higher species diversity followed by the Zone 5 and Zone 6. The Zones 1and 2 represented the lower species diversity while the lowest diversity was noticed in the Zone 3. The n-MDS among the season formed four separate groups based on the diversity.The study based on the season stated that the rainy season recorded high abundance followed by winter and summer seasons. But overall the two year study stated that the rainy and winter season are more over similar in diversity of species compared to summer season. The Two-Way ANOVA was performed between the species abundance of different taxa and different seasons. A significant difference as shown between the season and species abundance of the different taxa ($P < 0.05$).The diversity indices like Shannon, Simpson and Dominance was high during the winter or rainby compare to summer. The overall results stated that the summer season recorded lowest diversity and the temperature prevailing over the ACDSs was the major reason(Kupper*et al*., 2018). The ACDSs belongs to fishing structure type recorded high species diversity in all the seasons.The high diversity and abundance around the fishing type structures was high because of frequent vessel movement,supply of source larvae, protection to the animals against the tidal force, desiccation and enormous food providing by the breakwaters (Fishing structures) was the major reason for the high diversity and abundance around the fishing type structures (Murray *et al*., 2012; Sussanna*et al*., 2015).My observation on the existing ACDSs evident that the ACDSs can act as a better surrogate to the natural rocky structures. Furthermore, that the species diversity and richness of the ACDSs are based on the physical environment and biodiversity existing in the local environment. This chapter also clearly states that the proper utilization of the ACDSs can greatly help in enhancing the local biodiversity and also acts as a protection barriers for the juveniles.

CHAPTER III

EPIBIOTA ASSOCIATED WITH THE ARTIFICIAL COASTAL DEFENCE STRUCTURES IN COMPARISON WITH NATURAL ROCKY STRUCTURES

This chapter compared the species diversity between the different types of ACDSs against the natural rocky structures. The studied ACDSs was divided under four category based on their purposes. It is well knbown that any hard substrate deployed in the sea will be colonized whether natural or artificial (Southward and Orton, 1954).In the present study a total of 53 epibiota was recorded in the natural structures, whereas the ACDSs recorded 228 epibiotic species. In general overall taxon wise distribution between the artificial coastal defence structures against the natural rocky structures was statistically insignificant, which was confirmed by the ANOVA ($P > 0.05$). The current observation from the study revealed that the Breakwaters are rich in species diversity and richness even compared to the natural structures. In all the seasons during the two study years(2016 and 2017) the Breakwater recorded a maximum species diversity compared to other structure types. Compared to other structure types, the seawater immersion period and the quantity of drench area footprint is high in fishing harbour structures leads to be the primary reason for the rich epibiotic diversity. Further, the number of crevices, vertical height, length of the structure, shaded areas availability, and free from predation were also found to be the reasons. The Simper analysis among the different ACDSs revealed that the overall average dissimilarity between the ACDSs was 31.39 percent. The results of the current study also emphasized that the structure types plays a major role in determining the species composition of the ACDSs and the dissimilarity between the ACDSs). The community structures between the structure types was alsoanalyzedusing the ANOSIM and,the results revealedthat there were significant difference in the community structure between structure types (ANOSIM, R=0.9978, P=0.0001). This chapter clearly explained that the difference in artificial structure length, size, orientation, surface texture and position of artificial structureswill alter the species diversity and richness. The study also stated that the seasonal fluctuations also affect the diversity of ACDSs.Along with the above, the age and maintenance frequency of the ACDSs also an important factor in determining the species composition.

CHAPTER IV

ROLE OF ACDSs IN SPREADING OF NON-NATIVE SPECIES

The chapter IV deals with the role of the ACDSs in supporting and spreading the non-native species. The ACDSs are known to support the growth of the epibiotic species, but it is also well known to support the growth of non-native species. The current study also reported a total of 20 non-native species, out of these, almost 18 species belonged to the ascidians (Fig. 1), 1 species belonged to the bryozoan and 1 species belonged to the gastropod. The abundance and dissimilarity of the non-native species settled study for the years 2016 and 2017 associated with the ACDSs were compared between the study Zones. There were no significant differences in the abundance and species diversity between the years 2016 and 2017 (Kruskal Wallis test, P = 0.4404). In the artificial coastal defence structures, the cryptogenic species were highly abundant (n=15) than the invasive (n=3) species. There were no major variations in the settlement of non-native species due to the seasonal fluctuations. Among the four different structure types that the Breakwater-Fishing recorded a high number of non-native species. It is obvious and well known factor that the vessel traffic will be the major reason for this dominance over non-native species.The study also reported that the structure type and geographic distances between the structures are the major influences over the spreading of non-native species locally. The permutational analysis was done by considering the geographical location (zone wise), and structure types (Fishing, Armor, Commercial and Recreational), and the result showed a significant effect of both factors on the non-native community structures ($P < 0.05$). Among the identified non-native organisms, ascidians are the dominated ones. The wide range of tolerance, easy brooding and adaptation to all the substrate made the ascidians a dominant group in spreading. During the studythe non-native gastropod *Eualetes tulipa,* and the ascidians *Polyclinum isipingense* and *Diplosoma variostigmatum* are reported first time in the Indian coastal waters. The in-depth studies on physiology, life spawn, larval settlement pattern, prey-predation and fouling efficiency would help to prepare a proper management plan for the artificial coastal defence structures along the coastal waters of Tamil Nadu, India.

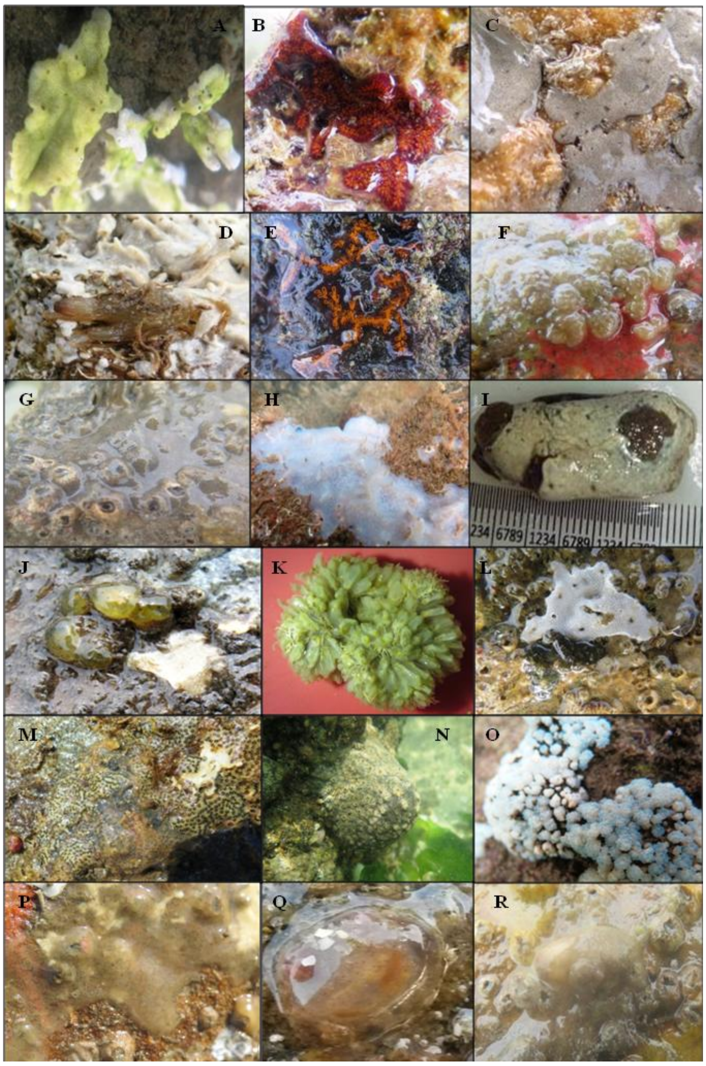

Figure 1. Depicting the various Ascidian species collected during the survey along the Tamil Nadu Coast from the study periods 2016 & 2017

(A) *Trididemnum miniatum* (Kott, 1997), (B) *Botrylloides nigrum* (Herdman, 1886), (C) *Didemnum psammathodes* (Sluiter, 1895), (D) *Herdmania momus* (Savigny, 1816), (E) *Botrylloides sp.* (Herdman, 1886), (F) *Eudistoma sluiteri* (Hartmeyer, 1909), (G) *Diplosoma variostigmatum* (Hirose and Oka, 2008), (H) *Aplidium multiplictatum* (Sluiter, 1909), (I) *Polyclinum isipingense*(Sluiter, 1898), (J) *Eudistoma tumidum* (Kott, 1990), (K) *Ecteinascidia venui* (Meenakshi, 2000), (L) *Lissoclinum fragile* (Van Name, 1902), (M) *Symplegma oceania* (Tokioka, 1961), (N) *Polyclinum indicum* (Sebastian, 1954), (O) *Aplidium sp*. (Sluiter, 1909), (P) *Synoicum sp.* (Phipps, 1774), (Q) *Corella eumyota* (Traustedt, 1882), (R) *Styela canopus* (Savigny, 1816)

CHAPTER V

MARINE BIODIVERSITY OF NUTRITIONAL AND MARKET VALUES EPIBIOTA OF ACDSs

In this chapter, the role of the ACDSs in developing the ecological as well as economical value of the country through marine biodiversity enhancement was presented. The ACDSs are known to support non-native species, but the current chapter states that the ACDSs are alsosupporting the epibiotic species which are considered to be economically and ecologically important. In this study a total of 25 economic valued species and 3 endangered species (*Favia sp.*, *Montipora sp.* and *Holothuria spinifera*) was reported. There were no variation in the ecologically and economically important species diversity over season wise (Winter, Summer and Rainy) or year wise (2016 and 2017). In general the rainy season recorded little high diversity compare to other seasons in both the study years. This minor dissimilarity between the Zones and the seasons of year was also confirmed by the ANOSIM analysis (R= 1, P= 0.0001). For the both study years the overall average dissimilarity was 10.14 percent based on the SIMPER analysis between the Zones and Species diversity. Among the Zones the Zone 5, 6 and 7 recorded high ecologically and economically important species compared to other zones. The existence of these zones in the biodiversity rich area was the major reason for this high diversity in these Zones. The study also clearly stated that the ACDSs are comfortably supporting the life for the endangered species like corals and seacucumbers. Through this support the ACDSs can acts as a better ground to enhance endangered species. The ACDSs are able to provide better solution in supporting the economic as well as ecological growth of the particular region. The report of ecological and economical species associated with the ACDSs throughout the year will sustainably support the local economy. It has been established that the ACDSs are known to support less diverse than the natural rocky structures, but this study recorded high diversity of species in some of the ACDSs compared to the adjacent natural rocky structures.

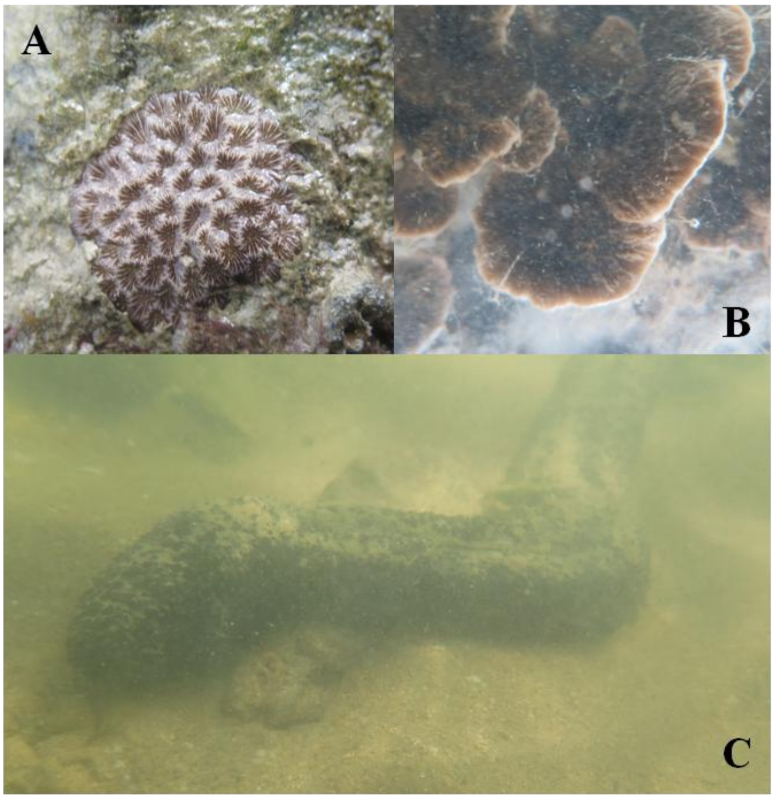

Figure 2. Endangered species recorded during the survey along the Tamil Nadu Coast from the study periods 2016 & 2017 (A- *Favia* sp., B- *Montipora* sp. and C- *Holothuria spinifera*)

CHAPTER VI

GENERAL DISCUSSION

This chpater presents the general discussion regarding the overall study. In general the ACDSs are known to support less diverse than natural rocky structures (Moschella *et al*., 2005; Firth *et al*., 2013), contrary to this hypothesis, in our study the ACDSs recorded high diverse compared to natural rocky structures. Based on the observation from this study, it is clearly visualized that the artificial coastal defence structures can acts as a better surrogate to the natural rocky structures. Apart from that, the rock pools, surface heterogeneity, slope, orientation and shade provide habitat for the settlement and survival of many epibiotic marine species, which are not already present in that environment. It is an added advantage to the local biodiversity enhancements. Many ecologically and economically important marine species have been reported only in the artificial coastal defence structures than the natural rocky structures. One of the major findings in this study was that the artificial coastal defence structures can support diverse of species if the artificial coastal defence structures exists in the biodiversity rich areas. The main reason for this was the artificial coastal defence structures depend the natural system for larval supply (Nandhagopal *et al.*, 2019). After a first line diversity settlement like biofilm, macroalgae, and filter feeders, the artificial coastal defence structures have known to attract further species which may facilitate the survival of future colonisers through the provision of food and/or shelter. The study also clearly mentioned that the ACDSs records the non-native species compared to the natural structures (Daffron *et al.*, 2015; Firth *et al.*, 2016), but it can be eliminated with the proper management plan. Therefore the consideration of ecological value when designing the ACDSs will lead to a higher species diversity of the structures with reduced non-native species. This present study also stated that the ACDSs supporting wide range of ecologically and economically important species. Through this support the ACDSs can acts as a survival tool in the economy of locals. In the current situation, the ACDSs are the unavoidable member along the coastline, therefore the present study provided a better knowledge in understanding the ecology of the ACDSs inorder to utilize it in the betterment of the biodiversity.

CONCLUSION AND RECOMMENDATION

The present study provided the detailed understanding of the ecology of the ACDSs and also concluded that the ACDSs can asts as surrogate to the natural structures by considering the proper construction and management plan. The study also concluded that the structure types are also an important factor while considering the ACDSs to enhance biodiversity. The results will help the practitioners in the management of current structures and in the construction of future projects. The consideration of following recommendation will be an added advantage to the ACDSs;

- Complex and heterogeneous structures should be created where possible in order to encourage and maintain biodiversity both on and around artificial coastal defence structures.
- Engineering enhancement in the artificial coastal defense structures can be carried out during the construction stage or retrospectively for the better biodiversity.
- Retrofitted low cost options such as the holes and grooves in ACDSs could be the potential towards the benefits of ecological enhancement without high amount of financial investment.

- In order to upscale the ecological enhancement techniques through ACDSs on a large scale, there is a need for acceptance by the coastal managers, coastal engineers and policy makers.

- Future marine coastal planning needs to involve collaborations between scientists, policy makers and practitioners in order to combine the research, expertise and knowledge on the marine environment as a whole and work together to provide ecologically enhanced marine infrastructures.

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