Summary
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The creation and deployment of man made structures to enhance marine resources is the basis of specialized branch of marine technology known as “Artificial reef development” through which biodiversity, including fishery production could be enhanced within smaller areas, by offering suitable substrate and an increased food supply.

The Tuticorin coast of Southeast coast of India is being threatened due to various factors particularly unsustainable fishing and coral mining. Artificial reefs have become a viable option to rehabilitate the damaged environment, to enhance biological resources, to restrict trawling and push net fishing.

A total of 105 nos. of triangle shaped ferro cement modules were deployed in the present study in a three different sites with depths (FC site-1, 5.6m, FC site-2, 6.2m and FC site-3, 6 m) at the outside area of Vaan and Koswari islands in Tuticorin coast. Also, a total of 55 cube shaped flyash artificial reef modules were deployed at outside the Harbour mainland patch reef area of Tuticorin Coast with a depth of 8.3 m (FA site-4). Two control sites were selected, one at outside the islands and another at outside of the Harbour patch reef area.

The main objective of the study was enhancement of biodiversity including fishery production through the development of artificial reef. The effect on the physico-chemical parameters, plankton population, benthic faunal assemblages and catch per unit effort were studied. The study also investigated
the effects of habitat structural complexity on recruitment of fin and shellfishes diversity and the feasibility of using fly-ash waste products constructively in the marine environment as artificial reefs in Tuticorin coast, Southeastern India.

The physico chemical parameters such as air and water temperature, salinity, dissolved oxygen, pH, water transparency, calcium, magnesium, inorganic phosphates, nitrates and nitrites of surface and bottom waters were monitored on monthly intervals. Air temperature values at all study sites showed a well defined seasonal pattern from 26.5 to 32.6°C, while the water temperature values fluctuated between 24.2 and 32.6 °C during the entire study periods at all study sites. The salinity generally fluctuated between 30% and 36% during the entire study period. The dissolved oxygen ranged between 3.6 ml/l and 6.2 ml/l, which is known to decide the suitability of aquatic ecosystems to support the survival and growth of aquatic organisms at the artificial reef and control sites. The pH at the study sites showed a wide range between 7 and 8.2. The major ions such as calcium and magnesium at the study sites showed a significant correlation between surface and bottom water, where the bottom water value was slightly higher than that of surface water. The mean value of phosphate ranged from 0.50μg/l to 1.28μg/l, which were within normal ranges. Nitrates for the study sites showed seasonal pattern fluctuations within the mean range from 0.23 to 0.63μg/l, while nitrite values ranged between 007μg/l to 0.02μg/l. The physico-chemical parameters recorded during the present study at the artificial reef and control sites were favourable to the development of various biological resources.
The seasonal variation in population density of plankton, species composition and biomass at the artificial reef sites were compared to the control sites. A total number of 65 species were recorded for both artificial reef and control sites, of which 29 species were phytoplankton and 36 species zooplankton. But the abundance and biomass of plankton at the artificial reef was higher when compared to the control sites. It was observed that the percentage composition of dinoflagellates was dominant at the artificial reef sites (42.86%) when compared to the control sites (33.33%). Similarly, zooplankton percentage composition was also high in the artificial reef sites (86.11%) when compared to the control sites (61.11%). The highest phytoplankton density for FC and FA sites were recorded as 10214 and 8386 respectively, while for the control sites 1 and 2, it was recorded as 4364 and 5408 respectively. The highest zooplankton density for FC and FA site was recorded as 3850 and 2347 respectively, while for the control 1 and 2 sites, it was recorded as 1693 and 2247 respectively.

The present study revealed that the plankton abundance at the artificial reef sites was higher when compared to the control sites. The mean and standard deviation of plankton-wet weight at artificial reef sites were higher than the control sites. The maximum 4.6 g wet weight was recorded at FC site and 3.19 g for FA site, while for control sites, it was recorded as 1.9 g. The increase in plankton abundance becomes the foundation of a food chain in the artificial reef area, leading ultimately to an increase in the fishery resources.

The distributions of benthic community in the seabed at the artificial reef and control sites were studied, in which six major groups were
encountered, i.e., gastropods, bivalves, echinoderms, crustaceans, polychaetes and scaphopods. Compared to all study sites, the highest population density was recorded at FA site and the population density fluctuated from 199 individuals m\(^{-2}\) to 287 individuals m\(^{-2}\). For FC sites, the population density fluctuated from 166 individuals m\(^{-2}\) to 243 individuals m\(^{-2}\), while for control site, population density fluctuated from 67 individuals m\(^{-2}\) to 114 individuals m\(^{-2}\). The benthic macro fauna mean species diversity, species richness in and outside the reef area was high when compared to the control sites. It was inferred that the artificial reef modules have altered the surrounding seabed, favouring siltation and accumulation of organic matter inside the reef area, which influenced the soft bottom community and their abundance on the surrounding benthic ecosystem.

The sediment texture and the organic carbon were also estimated. The sediments present in the study area were heterogeneous mixture mainly composed of quartz sand, biogenic carbonate derived from coral reef and shell fragments. At FC sites, mostly silty sand type was observed during 2002 and it changed to equal proportion of sand, silt and clay during 2003, but for Control 1, silty sand type was mainly observed throughout the entire study period. Similarly, silty sand sediment type was observed for FA and Control 2 sites. The organic carbon values for the study area ranged from 0.03 to 2.33%. It was found that the percentage of clay and organic carbon values seem to get increased in the artificial reef sites, which greatly influenced the enhancement of benthic population.
The study on the recruitment of epibenthic organisms on artificial reef modules was carried out using ferro cement and fly ash panels. The biofilm bacterial count on the ferro cement panels had a bacterial density of 19, 48 and \(213 \times 10^2\) CFU/cm\(^2\) and on fly-ash panels, the bacterial density of 8, 52 and \(249 \times 10^2\) CFU/cm\(^2\) for the 1\(^{st}\), 2\(^{nd}\) and 3\(^{rd}\) day respectively. The recruitment of epibenthic organisms such as hydroids, ascidians, sponges, encrusting organisms (molluscs, barnacles) and echinoderms began to colonize rapidly on both panels. Rapid growth of barnacles was seen on both panels after one month of the deployment and the percentage composition of barnacle was also higher for both panels when compared to other fouling community through out the study period. Sponges started appearing on both panels from third month of deployment. It was clear that the concrete and fly ash panels did not show any signs of preventing the settlement of epibenthic organisms and hence, both appear to be a good material for the construction of artificial reefs.

The results of the habitat structural complexity of artificial reef modules on fish assemblages revealed that the degree of structural complexity of the artificial reefs had significant effects on the composition of family distribution, species diversity and species richness. The modules at FC site 3 were 100% closely deployed followed by FC site 1, and FA site 4 where the modules were 75% and 70% closely deployed respectively. At FC site 2, the modules were deployed widely forming a straight line. A total of 52 species belonging to 33 families were observed during visual survey in entire study period and the value of mean species diversity and richness were high at FA site 4 (1.31 and 23.73), followed by FC site (1.14 and 17.0), FC site 3 (1.01 and 12.87) and FC.
site 2 (0.86 and 8.33). A highest similarity value of 77.08% was observed between FC site 1 and 3. The study clearly shows that the arrangement of modules is one of the key factors for the development of potential artificial reef and this could also be considered in the future artificial reef development programmes if any, for the better enhancement and conservation of the resources.

The study on the catch rate of commercially important fishery resources such as finfish, shellfish and echinoderm was carried out to find out whether the artificial reef structures had any impact. In total 62 species were caught during the entire study period in which, 36 species of fin fishes equal to 58.06%, 10 species of crustacean (16.12%), 6 species of echinoderms (9.67%) and 10 species of mollusks (16.12%) were recorded. The overall catch data showed that the fishing yield, species distribution and overall weight percentage composition was higher at artificial reef sites than the control sites. It was observed in the present study that the mean catch rate at artificial reef sites was two times higher than that of control sites. The mean catch of 6.32 kg was recorded at FC site and for control site it was 2.60 kg. At FA site, the mean catch rate was 4.82 kg and for the control site it was 2.7 kg. The average mean species diversity and species richness were also higher at artificial reef sites than control sites. There was an increase of 11.95 % fin fishes, 8.35% crustaceans, 10.77% echinoderms and 10.60% mollusks at artificial reef sites when compared to control sites. The total biomass at the artificial reef sites was 80.18% while for control sites, it was 38.9%, and this supports the higher fishery production at the artificial reef sites. The study revealed that the
The deployment of artificial reefs enhanced the fishing yield and increased the mean catches of fishes, crustaceans, echinoderms and molluscs.

The present study revealed that the physico-chemical parameters of the selected study sites were favourable to the development of various biological resources. The increase of plankton biomass wet weight (4.6 g) at the artificial reef sites ultimately enhances fishery resources. The artificial reef habitats also favoured the increase of diversity of the macro organisms in and around its vicinity. In addition, the percentage of clay particles and the organic carbon ratio were observed to be more at the artificial reef areas, which greatly influenced the settlement of benthic assemblages. Both ferro cement and fly ash panels were appeared to be a good material for the construction of artificial reefs modules and the arrangement of modules also played an important role in the fish assemblages. It is concluded that the deployment of artificial reef modules provided a suitable and favourable substrate for epibenthic organism and habitat for the enhancement of pelagic, demersal, migratory and residential fishes, which increase the fishing yield of fin fishes (11.95 %), crustaceans (8.35%), echinoderms (10.77%) and mollusks (10.60%). The results of the present study clearly reveal that the artificial reefs could be used for the increase of biodiversity as well the enhancement of fishery resources at any degraded coastal area.