International Journal of Bio-resource and Stress Management

https://ojs.pphouse.org/index.php/IJBSM

Crossref

IJBSM May 2025, 16(5): 01-11

Article AR6014

Review Article

Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2025.6014

Artificial Reefs: Solution for Restoration of Marine Ecosystem and Improving Community Resilience

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ABSTRACT

Pollution and global warming have become a threat to the environment and sustenance of life existing on earth. It has led to climate change causing a shift in habitat and ecology of species residing over. Effect of climate change is immense on marine life and it has affected the aquatic flora and faunas, adversely. Therefore, there has been increasing interest in marine restoration. Artificial reefs implementation is one approach being used as a measure for marine ecosystem restoration that has been damaged due to coral reefs destruction by anthropogenic activities like pollution, overfishing, destructive fishing using cyanide or dynamite, collecting live corals for aquarium market, etc. Artificial reefs are modeled by sinking oil rigs, scuttling ships, or shipwrecks that help in preservation of the ocean floor by mimicking with natural reefs. They may be built of polyvinyl chloride or concrete to provide substratum for attachment of algae and invertebrates such as barnacles, corals, and oysters which in turn provides intricate structures and food for assemblages of fish. In addition, they provide livelihoods to millions of people and serve as barrier against the worst impact of cyclones, protecting the coastal communities. These reefs cater to the needs of recreational fishermen and tourists so that the natural reefs can be completely conserved and relieved of fishing pressure. Henceforth, this comprehensive literature review on artificial reefs is carried out to understand its role in marine ecosystem restoration and fisheries management, alongwith the study of its design, material characteristics, application, effectiveness and management.

KEYWORDS: Artificial reefs, fisheries, ecosystem, coral, biodiversity, coastal, protection

***Citation* (VANCOUVER):** Rani et al., Artificial Reefs: Solution for Restoration of Marine Ecosystem and Improving Community Resilience. *International Journal of Bio-resource and Stress Management,* 2025; 16(5), 01-11. HTTPS://DOI.ORG/10.23910/1.2025.6014.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 20th December 2024 RECEIVED in revised form on 24th April 2025 ACCEPTED in final form on 07th May 2025 PUBLISHED on 19th May 2025

1. INTRODUCTION

Throughout globe, coastal community faces problem of coastal erosion that affects their livelihood (Dong et al., 2024). Factors responsible for this are natural processes such as wave action, tidal forces, currents, sediment deficit, natural hazards and anthropogenic activities like excessive sand mining, pollution, overfishing and coastal engineering works (Delgadillo-Calzadilla et al., 2014; Mentaschi et al., 2018). Marine scientists and Coastal Engineers have been working to find solutions to combat this issue through conventional/hard and soft measures (Lokesha et al., 2013; Williams et al., 2018). Hard measures including seawalls, breakwaters, groins and gabions are short-term, expensive, non-eco-friendly measures. Now coastal zone management including coastal erosion mitigation and protection has shifted towards a new trend of incorporating soft and novel environment friendly solutions (Lokesha et al., 2013; Neide et al., 2023). With decline of natural rock in certain geographical regions, alternative materials and solutions for coastal protection, marine management and reef restoration is essential (Hylkema et al., 2021; Higgins et al., 2022; Thierry, 2022). Reef balls, aqua-reef, prefabricated units, and geo-systems (geo-bags, geo-tubes, geo-containers, geo-grids, etc.) are used to control beach erosion and can be easily placed and are cost-effective and eco-friendly (Alvarez et al., 2007; Lokesha et al., 2013). Reef scientists have done enormous studies to assess ways to protect habitat destruction by trawling and beach erosion, promote nature conservation, and assess ideal materials for artificial reefs construction (Vivier et al., 2021; Nguyen et al., 2022).

The hidden genetic biodiversity can prepare ecosystem to adapt to climate change. However, anthropogenic and some natural causes have harmed natural reefs directly or indirectly affecting the inhabitants. Therefore, to overcome these losses, artificial reef (AR) is an option to re-establish a similar habitat as natural coral reef (Miller and Hobbs, 2007; Becker et al., 2018; Lemoine et al., 2019). They are human-made structures that are either deliberately or unintentionally submerged underwater (Jensen et al., 2000; Perkol-Finkel et al., 2006) to establish habitats and provide shelter to fishes and other aquatic organisms for promotion of marine life and fisheries (Thierry, 1988; Grossman et al., 1997; Stolk et al., 2007; Claisse et al., 2014; Paxton et al., 2017) and to promote marine life in areas of generally featureless bottom or where existing coral reefs have been destroyed and threatened greatly by anthropogenic activities and global climate-related pressures (Pickering et al., 1999; Baine, 2001; Graham and Nash, 2013). It improves hydrodynamics for surfing or to control beach erosion (Escudero et al., 2021). Multipurpose artificial surfing reefs are being adopted for advantages like marine life and fisheries promotion, coastal rehabilitation and protection by reducing wave energy, protection from forced trawling, creation of nursery and breeding grounds, recreational purposes (surfing, fishing, and diving), genetic biodiversity support by providing natural habitat for marine organisms and improvement in socioeconomic prosperity (Ranasinghe et al., 2006; Mead et al., 2010; Mendonca et al., 2012). McGurrin et al. (1989) provided an elaborate summary of the history of artificial reef development in the United States. Although real knowledge of ARs came after viewing sunken vessels and planes as a result of World War II in 1940s (Polovina, 1991). The first artificial reef in US constructed using log huts was documented off South Carolina in1830s (Lukens and Selberg, 2004). These reefs cater to the needs of recreational fishermen and tourists so that natural reefs can be completely conserved and relieved of fishing pressure. Henceforth, this comprehensive literature review on artificial reefs is carried out to understand its role in marine ecosystem restoration and fisheries management, alongwith the study of its design, material characteristics, application, effectiveness and management.

2. ARTIFICIAL REEFS AS FISH AGGREGATING DEVICES

Experienced fishermen knew that the fish aggregates near submerged objects such as rocks or sunken shipwrecks on which marine plants and animals grow or provide shelter for some fish and invertebrates. The same principle is used in the construction of artificial reefs using two possible approaches. First being the deployment of natural materials such as logs or any locally available material where funding is a constraint (Alevizon and Gorham, 1989). The second approach is to fabricate specially designed structures to submerge purposefully for attracting the fish flocks. While in most cases ARs are meant to serve as fish attracting or aggregating devices but in some cases they are installed to prevent trawling and destruction of bottom habitat (Polovina, 1991). The oldest reports of installing artificial reefs are from the end of the 18th century, when Japanese fisherman purposely sank bamboo structures with leaves to form fishing sites and discovered that fish catches were more productive in waters around sunken wrecks (Thierry, 1988; Ito, 2011; Lee et al., 2018). This led to the deliberate deployment of wooden materials, including designed structures weighted down with the help of ropes, which enables fishermen to choose the areas where improved fish catches were desired (Bohnsack, 1989). This approach of deploying structures made out of long-lasting materials that is sunk to the bottom of the ocean to create a foundation for coral reef is called artificial reefs (Einbinder et al., 2006) which are being made using a variety of materials, techniques, and configurations and spread worldwide while it is in extensive use in many coastal countries. It can either be a boon or bane, depending upon circumstances. The use of artificial reefs has been extensive in the Philippines (Balgos, 1995). These supplementary structures allow coral polyps to settle, grow, and regenerate to form large calcium carbonate structures that they are supposed to be (Gleason and Hofmann, 2011).

3. BENEFITS OF ARTIFICIAL REEFS/ FISH AGGREGATING DEVICES (AR/FAD)

Artificial reefs are beneficial to promote the growth of marine benthic communities of flora and fauna, as it creates natural environment to encourage fish aggregations and provide breeding and feeding opportunities (Zhang et al., 2024). Despite being successful in simulating marine habitats and boosting fish catches in, there are concerns about the long-term ecological impacts, such as potential pollution and invasive species proliferation. Over the time artificial reefs proved to be an excellent tool for a variety of purpose, such as fisheries resource management and protection, maintaining coastal habitats, proliferating marine resources, improving marine environment (You and Zhang, 2020; Pan et al., 2022), study area for researchers, tourist attraction for divers, rehabilitation of naturally destroyed areas, creates a breeding and nursery ground, beneficial use of solid waste like old boats, tyres, and automobile wastes, etc. and conservation of biodiversity (Bombace, 1989; Gomez-Buckley and Haroun, 1994; Gallaway et al., 2009; Love et al., 2012; Seixas et al., 2013; Davies et al., 2014; Tessier et al., 2015). The aim of this technology is to countermand the detrimental impacts that climate change is having on coral reefs which is one of our most important and productive aquatic ecosystems (Baine, 2001; Hoegh-Guldberg, 2011). Today, artificial reefs created with distinct aims in mind (e.g. species attraction and ecosystem restoration) may have both positive and negative environmental impacts (Brickhill et al., 2005, Firth et al., 2016). Economic returns from these reefs are excellent leading to improved socio-economic condition of the fishermen community. Artificial reef is a great intervention for better conservation of marine resources as it will facilitate biological attraction, improve water quality and promote ecosystem restoration in general and fishery resources in particular (Paxton et al., 2020).

4. FUNCTION-SPECIFIC CRITERIA

ARs are divided into three categories based on their specific functions: i) those whose primary function is to enhance biodiversity or productivity (for fisheries or ecological purposes); ii) reefs which are constructed to protect biological resources; and iii) reefs intended to promote recreation and tourism.

5. ARTIFICIAL REEFS (AR) CONSTRUCTION MATERIAL

The choice of the materials to be used as artificial reefs and their configuration are further important planning considerations. They can be made of materials that are inexpensive and readily available. Materials used in the creation of ARs include rocks, tires, wood, concrete and/ or metal structures, industrial material and even oil and natural gas platforms (Pickering, 1996; Baine, 2001; Love and York, 2005; Biesinger et al., 2013; Kulaw et al., 2017; Streich et al., 2018). From the ancient times, artificial reefs made of different materials have been used in many countries with the aim of attracting fishes (Polovina, 1991; Olivia, 2012). AR materials are selected based on certain characteristics of the particular material, i.e., function, durability, compatibility and stability (Macreadie et al., 2011; Classie et al., 2014). Material quality also ensures its compatibility with the aquatic environment. Used car tires have become extremely popular because of their easy availability, durability, and cost-effectiveness. The use of concrete structure, although more expensive, is also widespread. But waste material that contains toxic chemicals (old refrigerators and air conditioners containing CFCs) should be forbidden because of their polluting impacts on the marine environments. Materials to be deployed must be exercised in preventing the creation of a solid waste dumpsite for unwanted waste materials (Alevizon and Gorham, 1989). Geo-systems such as geo-bags, geo-containers, geo-curtains, geo-tubes, geo-grids, etc. and other systems such as reef balls, aqua-reef, prefabricated units, and beach drainage have gained popularity in the recent years because of their ease of placement, cost-efficiency and less adverse effect on the environment (Lokesha et al., 2013)

6. TYPES OF ARTIFICIAL REEF MATERIAL

6.1. Vessels

It functions as a safe habitat for various fishes and invertebrate communities. It also provides a suitable site for scuba divers to explore and dynamic habitat for fishermen to fish.

6.2. Pipe

Different shape and size of damaged or dug up pipe are used as structure of the reef. It can stack easily to provide profile, and the hollow area of pipes provides a hiding place for fishes and other aquatic organisms.

6.3. Concrete castings

Different types of prefabricated structures like culverts, junction boxes, etc., are used as artificial reef structure. These are essential reef structures as they provide more surface area for fish to hide.

6.4. Reefballs

These are ball-like structures with many holes leading to a hollow interior cavity which helps fish to evade predators. They provide enough surface area for the attachment of invertebrates.

The comparisons of materials that can be used in the development of artificial reefs (Carr and Hixon, 1997), alongwith their benefits and drawbacks have been discussed in Table 1.

Artificial reefs are also being built through biorock technology and placed on the seabed in freshwater or saltwater environments. Biorock technology or mineral accretion technology is an innovative method invented by the late architect Professor Wolf Hilbertz in 1976 to produce natural building materials in the sea. In biorock technology, a low-voltage electrical current is passed through the water using electrodes placed near a steel structure. This current acts like a magnet, thus attracts dissolved minerals, particularly calcium and bicarbonate ions, forming a calcium carbonate layer similar to natural coral reefs (Hilbertz, 1979; Carre et al., 2020). These reefs form hard substratum to which algae, barnacles, corals, and oysters can firmly attach, creating habitats for them and also absorb carbon dioxide as well as benefit local communities (Goreau and Trench, 2012). Biorock materials are the only material employed for marine construction that grow and get stronger with time. Wolf named it Mineral Accretion Technology™, Seacrete™, or Seament™. Biogeochemist Dr. Tom Goreau had once invited Dr. Wolf Hilbertz to Jamaica to work together for developing technology to restore coral reefs, and they named it Biorock ™ technology, as it grew hard limestone rock for structural purposes and increased corals growth along with other marine organisms (Goreau and Prong, 2017). Together they founded the Global Coral Reef Alliance to pursue research and development of Biorock™ Technology. This method creates ideal habitat for restoring damaged fisheries, especially on barren sand, mud or rock, where there are no reefs or seagrass to provide nursery habitat for baby fishes to hide (Goreau, 2014).

Table 1: Comparison of materials used in the construction of artificial reefs

Material type	Benefits	Drawbacks
Concrete	Highly durable and stable. It can be casted into many forms. It provides settlement and attachment surface for growth of encrusting organisms. It is cost-effective and it's highly compatible to the marine environment. (Baine, 2001; Chen et al., 2015; Georges et al., 2021; Guo et al., 2021)	Highly weighted (Kizhakudan et al., 2023)
Steel hulled vessels	Creates attractive diving location and provide economic benefit to coastal communities. It also provides surface for epibenthic colonization, etc. (Subcommittees et al., 2004; Kizhakudan et al., 2023)	Less stable during hurricanes (Bell and Hall, 1994; Hylkema et al., 2021)
Gas and oil platforms	Easily available, more durable, and stable. It serves as habitat for various species (Van Elden et al., 2019; Vona et al., 2022)	It can attract invasive species, and also cause an obstruction in navigation. (Vidal et al., 2022)
Natural materials (e.g. rock, Biogenic materials like oyster shells, wood, etc.)	Easy availability, leaches calcium hydroxide into the water, which can act as a settlement cue for calcifying organisms, particularly bivalves and barnacles (Dodds et al., 2022), wood – low cost, less toxic, compatible with marine environment (Guo et al., 2021)	Short-term stability and life span can cause loss to the terrestrial environment (Guo et al., 2021)
Automobiles	Easy availability and easy to handle	Less durable, requires more effort in preparation prior to deployment (Madiedo et al., 2024), Toxicity of leachate from automobile tires to aquatic biota (de Oliveira et al., 2021)
Tires	Easy availability, easy to handle, cost-effectiveness, long life (Lew, 2023)	Leaching of toxicants like petrochemicals and heavy metals, unstable (Collins, 2021).

7. DEPLOYMENT

The use of artificial reefs is gaining popularity because of its fish aggregating function (Alevizon and Gorham, 1989). Artificial reefs, as a habitat enhancement, too, increase the productivity of barren sea floors by providing shelter and eventually sources of food (Chong et al., 2023). Site selection is one of the most important aspects of the success of these reefs. Placing one in an already rich reef flat may cause more damage than good because the artificial reef would compete with the natural reef as an aggregating habitat and may physically damage the existing reefs (Teena Jayakumar and Sarkar, 2024). Hence, they should be sited in locations that have already been denuded or that support very little marine life (Clarks and Edwards, 1999). These are placed on the bottom, but another innovation of fish aggregating device is used near the surface of the sea (Bohnsack, 1989, Pickering et al., 1999). When setting up an artificial reef program, the agency or country must first critically examine the need for such structures and they must further specify an exact role as these are intended to fulfill. The establishments of artificial reefs in Brunei Darussalam and Singapore, which have limited coral reef resources, are good examples (John et al., 2023). These reefs cater to the needs of recreational fishermen and tourists so that the natural reefs can be completely conserved and relieved of fishing pressure. But these are not a panacea and should be viewed as only a part of a larger fishery management program. A definite limit exists on the number of fishermen who can participate if sustainable benefits are to be achieved. What appears to be lacking in many cases is a master plan to ensure that these reefs can serve as an effective ecological and economical tool. Experience in the developed country has shown that benefits are possible when an artificial reef program is carefully planned, managed and maintained. If not, artificial reefs will begin to be used as excuses for the dumping of waste materials or the overexploitation of fish and other marine life. Artificial reef design and construction require a professional approach (Kizhakudan et al., 2023). An unskilled person attempting reef placement can cause trouble, as in Curacao, Netherland where the local decided to sink a wreck in the nearby water at Seaquarium beach (also known as Sea aquarium beach). The result was that the ship, being improperly secured, slipped into the deep, leaving behind only a much-damaged reef and a sea bottom littered with remnants of the ship (Neely, 2008).

8. LOCATION FOR INSTALLATION OF ARS

ARs construction and installation should only be undertaken after thorough understanding of the local environment, including waves and tidal currents, water and sediment quality, biological communities, sediment transport, the seabed, and other beneficial uses (Barber et al., 2009). They should be installed in such a way as to ensure that the structures are not displaced by force of towed gears/ trawlers, waves, tidal current forces or erosion processes. It should not be constructed in areas prone to hurricanes or cyclones. All groups and individuals who may be affected or interested should be informed on the characteristics of the AR as well as on its location and depth of installation prior to its placement (Baine, 2001).

9. EFFECTIVENESS OF ARS

Artificial reef use can be cost-effective to enhance near shore reef fish populations, increase fishermen net income, and demonstrate sound fishery management principles (Sreekanth et al., 2019). Their abuse can be wastefully expensive, contribute to greater overfishing and sustain bad resource management practices. Success or failure, for the immediate use and for the coastal fishery as a whole, depends on how artificial reefs are used in the existing fishery situation. They attract fish, particularly fingerlings from surrounding waters. Their aggregating power appears to be strong as they have been reported to support up to seven times the fish biomass of natural reefs (Costa et al., 2022; Hylkema et al., 2023). ARs with relatively high relief (rising 2 meters from the bottom) typically support several fish populations such as groupers and moray eels, mobile bottom feeders (grunts, goatfish, rabbit fish, and snappers) including other residents living within the reef structure such as corals, lobsters, clams, seahorses, sponges, sea turtles, etc. which range over larger areas as they move from one reef module to another within a cluster and between clusters, schooling plankton feeders (fusiliers and sturgeons) which use the water column above the general reef area (Pondella et al., 2022). In addition, visiting schools of travelers often linger over the reefs. Where the artificial reef is displaced into adjacent areas of high conservation/ productive value, it may cause damage to the ecosystems, e.g. sea grass or corals. Artificial reef or its components displacement may affect other activities in the area for example, navigation, when its position on nautical charts is no longer correct and therefore it becomes a risk to navigating vessels. Fragments of the reef may also contribute to the marine debris problem leading to aquatic pollution. So to mitigate this, ARs should be anchored to avoid displacement.

10. ARTIFICIAL REEFS FOR FUTURE AQUA LIFE SUSTENANCE

The application of artificial reefs may result in one or more impacts on marine resources such as the biomass that is currently exploited gets redistributed from natural habitat to artificial reef and biomass that is currently not being exploited is attracted to the artificial reef to increase the total available exploitation (Polovina, 1991; Smith et al, 2015). Also, high relief habitat (2 meters from the bottom) is increased by artificial reef structures, and stocks that are limited by high relief habitat can increase (Rilov and Benayahu, 2002). It can be useful in closing areas to trawling (bottom obstructions), protecting juveniles in shallow nursery grounds, and providing fishing sites for artisanal fishermen using that they can capture the older fish (Fabi et al., 2015; Kizhakudan et al., 2023). They can substantially reduce travel and research time for artisanal fishermen and improve the catchability of their gear as they can easily locate the area where the artificial reefs are deployed (Polovina, 1991). The artificial reef has proven particularly effective for artisanal applications in which fishing effort is relatively low (Becker et al., 2018). Where fishing effort is controlled, these reefs may result in over-fishing. Therefore, the structures may not be appropriate except in situations where fishing mortality is controlled (Pondella et al., 2022; Hylkema et al., 2023).

11. FISHING METHODS IN ARTIFICIAL REEFS

Artificial reefs can show rapid increase in local fish population rehabilitation/ restoration (Rilov and Benayahu, 2000, Hylkema et al., 2023), coral reef and algal growth. The fishing methods that are carried out in artificial reefs include hooks and lines, gill nets, trammel nets and seine nets. Mainly three types of hooks and lines are used in the reefs (Philipose, 2013). They are long lines, mid-water hand lines, bottom hand jigging. Long lines are used for commercial fishing especially in a technique called longlining. It is used to catch flat needlefish *Abelennes* spp., *Snappers, Groupers, Carangoides* spp., *Rachycendron canadum*, etc. Mid water hand lines are used to catch small sized mid water fishes like scads, mackerels, small tunas, etc. Bottom hand jigging is exclusively used for catching cuttlefishes. Gill net is a rectangular piece of netting with large mesh size. In water the net acts like a barrier and while the fishes, without noticing the barrier, tries to pass through it gets entangled in the gills (gilling). Trammel nets are triple layered fishing nets with the outer layer having bigger mesh size of 250 mm approximately and the middle layer having a smaller mesh size of 50mm which is used for catching prawns, skates, rays and flat fishes. Seine nets have wings and towing wraps in the front and a bag in the rear end (Barnette, 2001; Philipose, 2013; He et al., 2021; Montgomerie, 2022). As the boat moves forward, the wings direct the fishes to the bag. This gear is mostly used for pelagic fishes like anchovies, squids, etc. (Philipose, 2013).

12. ARTIFICIAL REEFS OF INDIA

In India, the idea was initially adopted by the traditional fishermen. For the very first time, three artificial reefs were established in some villages of the Trivandrum and Kanyakumari coast in the late 80s and early 90s. The artificial reef was in the form of triangular concrete modules as well as bamboo modules and was led at a depth of 12–14 fathoms (John, 1996). These establishments of artificial reefs were supported technically and financially by Trivandrum based program for community organization (PCO). Between the years 1988 to 1994, various artificial reefs were led in many villages in Trivandrum-Mariana, Thumba, Kannanthura, Valiathura, Adimalathura, Puthiyathura, Paruthiyoor, and Kollemcode. In Kanyakumari, despite the coastline having a number of rock outcrops, fishermen have been laying artificial reefs (Kurien, 1995). In Mulloorthara and Enayam, reefs have been created with the financial and technical assistance from South Indian Federation of Fishermen Societies (SIFFS), an NGO that also played a major role in laying reefs with common ownership in the Trivandrum area (Lakshmi et al., 2010). The AR project off the coast of Thoothukudi district, in the Gulf of Mannar, was initiated in 2007 with multiple objectives of reviving corals and coastal habitats, preventing 21 islands from sinking due to sea level rise that is one of the major manifestations of the climate change, reducing trawling as well as protecting the livelihood of traditional fishermen (Jain, 2020).

India's second-ever artificial reefs installation to boost marine life was deployed in the Arabian Sea near Worli, Koliwada, Mumbai, Maharashtra in May, 2024 (Doshi, 2024). The first artificial reefs were deployed in Pondicherry (Bose, 2024). About 210 reef units constructed from recycled concrete and steel are installed 500 meters offshore, expected to show initial signs of a thriving ecosystem sometime after installation. While the first sign of transformation may start reflecting after few months, with the artificial reefs becoming a harbour for small and large native species. It will act as a carbon sink as well as boost the livelihood of coastal communities (Edi et al., 2017; Shu et al., 2022).The 210 reef units included three different types of modules including triangular reef fish modules, groupers fish modules and well ring modules. Once installed, the wheels of the transformation set into motion when a bacterial biofilm start forming on the structure, followed by micro and macro algae (Bose, 2024). Like a natural sea surface, these reefs after 90 days become home as well as a breeding ground for small ornamental and benthic fishes, while after six months, large fishes, having significant commercial value also start visiting the reefs in search of food (Clark and Edwards, 1999, Costa et al., 2022, Kizhakudan et al., 2023, Bose, 2024).

The government of India is promoting the use of artificial reefs as an initiative for the country, under the Prime Minister's Matsya Sampada Yojana (PMMSY) scheme. In August 2023, the Union Department of Fisheries announced the deployment of artificial reefs across 3,477 fishing villages throughout India, including in Maharashtra in the upcoming years. Under this nation-wide initiative led by the Central Marine Fisheries Research Institute (CMFRI), headquartered in Kochi, Kerala the reef installation programme is ongoing and it intends to promote sustainable fisheries and livelihoods. (Anonymous, 2023; Doshi, 2024).

"We need artificial reefs not just to grow the fish population in our waters but also to mitigate the growing number of cyclones and typhoons caused by climate change," says Hussain Mohammad Kasim, former principal scientist of CMFRI and one of the pioneers of the artificial reef project in India (Doshi, 2024)

13. LARGEST ARTIFICIAL REEF IN THE WORLD

The Great Barrier Reef, Australia is the world's largest coral reef, and the world's largest artificial reef is the Ex-USS Oriskany, known as Mighty-O, Florida, United States. Ex-USS Oriskany initially was the naval vessel USS Oriskany which was turned to an artificial reef later on. The vessel was built in 1945 and commissioned in 1950. It served in Korea and Vietnam and got retirement in 2006. After retirement, the 44,000 ton aircraft carrier was purposefully sunk by the navy, off the coast of Pensacola, Florida, in 2006 (Morgan et al., 2009) under a pilot program to convert decommissioned vessels into artificial reefs (Baine, 2001). By far it is the largest vessel ever sunk to make a reef. This reef is often referred to as the "Everest of diving" because divers can explore it in the depth range of 80–212'. It is also sometimes referred as the "Great Carrier Reef" (Gabriel, 2016). The second-largest artificial reef will be the USNS Hoyt S. Vandenberg, a former World War II era troop transport that served as a spacecraft tracking ship after the war (Partner, 2023).

14. CONCLUSION

Artificial Reefs are alternative to combat losses due to anthropogenic and natural causes. Pradhan Mantri Matsya Sampada Yojana, an initiative by government of India, is actively promoting their installation across the coastal states to enhance marine biodiversity, rejuvenate coastal fisheries, and rebuild fish stocks, ultimately aiming for sustainable fisheries conservation and improved livelihoods. This review focuses on bringing awareness so that ARs projects may be developed in various coastal states of the country.

15. ACKNOWLEDGEMENT

The author would like to thank The Dean, College of Fisheries, Kishanganj for his guidance and support to complete this research review.

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