CMFRI Training Manual Series No.32/2023

TRAINING OF TRAINERS FROM THE DEPARTMENT OF FISHERIES OF ALL MARITIME STATES AND UT'S AND FSI, CIFNET.

'FUNDAMENTALS OF ARTIFICIAL REEFS FOR IMPROVING MARINE FISHERIES IN INDIA'

18-20 JAN 2023; 30,31 JAN -1 FEB 2023

COURSE MANUAL

FUNDED BY THE PMMSY-NFDB, GOI

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Ministry of Agriculture and Farmers' Welfare, Govt. of India
Post Box No. 1603, Ernakulam North P.O.
Kochi- 682 018, Kerala, India

COURSE MANUAL ON

FUNDAMENTALS OF ARTIFICIAL REEFS FOR IMPROVING MARINE FISHERIES IN INDIA

Edited by

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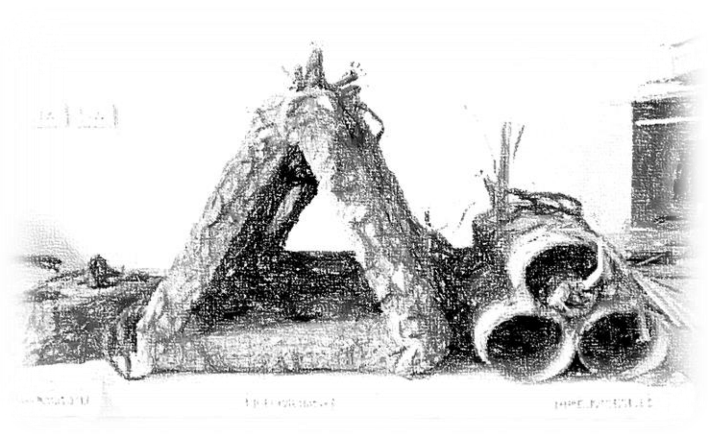

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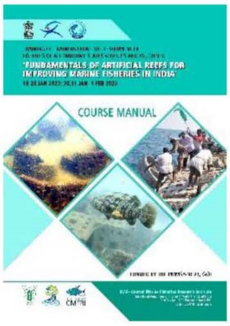

Course Manual on Fundamentals of Artificial Reefs for Improving Marine Fisheries in India

CMFRI Training Manual Series No.32/2023

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Publication, Production & Coordination: Arun Surendran, Library & Documentation Centre, ICAR-CMFRI, Kochi

Printed at: Shri Vignesh Prints, Chennai

Suggested Citation:
Kizhakudan, Joe K., Kizhakudan, Shoba Joe and Remya, L. (Eds.) 2023. Course Manual on Fundamentals of Artificial Reefs for Improving Marine Fisheries in India. ICAR-Central Marine Fisheries Research Institute, Kochi, 126p.

Contents

Foreword

Artificial reefs are set on the seabed to enhance the growth of marine floral and faunal benthic communities which simulate natural settings for promoting fish aggregations and provide the base for the propagation of resident populations within sheltered structures. They are being used in several parts of the world to promote habitat recovery and enhance reef-dependant resources. The advantage of artificial reefs is in developing fishing grounds close to shore, easily accessible to traditional and non-destructive fishing methods, ensuring the sustainability of both, the habitat, and the resources therein.

Since 1980, ICAR-CMFRI has been working on habitat enhancement and improvement of coastal productivity and livelihoods, through FADs, artificial reefs and fish stock revival and restorations, with early trials in Lakshadweep, Tamil Nadu and Kerala. Since the turn of the 21st century, ICAR-CMFRI, through its Madras Regional Station in Chennai, joined hands with the Government of Tamil Nadu in deploying artificial reefs in nearly 150 sites in the coastal waters of the state. The Institute has, over the years, evolved standard protocols for site selection, design, fabrication, deployment and impact assessment of artificial reefs. In 2020, ICAR-CMFRI was granted a patent for three designs of artificial reefs (Patent 197/CHE/2012).

The results from the various deployments in Tamil Nadu, Kerala, Andhra Pradesh and Gujarat have developed more interest in AR deployments towards coastal fishery and habitat enhancements. There is a huge demand from the traditional fisher community in Tamil Nadu for deploying more reefs for the promotion of livelihood. Following the developments in AR applications towards coastal productivity the Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying (DoF, MoFAH&D) New Delhi organized a National webinar on 29.08.2022 and subsequently on 24.11.2022 in which a team of scientists and experts from CMFRI led by Dr. Joe K. Kizhakudan, PI & PS presented the research findings and impacts and highlighted the increasing needs for habitat enhancements, restoration of fish resources as a commitment to achieving SDG goals of the United Nations. The DoF, MoFAH&D subsequently released an OM F.No.J-26001/6/2022-DoF(E-20799) dated 10.10.2022 proposing to create 1200 AR sites by 2022-23 in 13 states/UTs along the coastline “Promotion of sustainable fisheries and livelihoods through Artificial Reefs and/or Sea ranching”.

The DoF, MoFAH&D intends to assist the States/UTs under the Pradhan Mantri Matsya Sampada Yojana (PMMSY) scheme for the installation of AR and for undertaking sea ranching activities in their coastal waters as a sub-activity under the activity “Integrated Modern Coastal Fishing Village” of the centrally sponsored scheme (CSS) component of PMMSY. The Technical and scientific expertise of ICAR-CMFRI in this area have been recognized and we have been identified to impart the training and technical assistance to the officials of departments of fisheries of the respective states/UTs, FSI, CICEF, CIFNET and Sagar Mitras.

We are grateful to the National Fisheries Development Board (NFDB) for extending support for conducting two 3-days Trainers Training program (ToT) on “The Fundamentals of Artificial Reefs for Improving Marine Fisheries in India” during 18-20 Jan. 2023 and 30,31 Jan. and 01 Feb. 2023 and publish course manuals in Tamil, English and Hindi for the benefits of the officials and trainees.

This Trainer’s Training program on artificial reefs is the first of its kind to be conducted in India. I congratulate the Madras Regional Station of ICAR-CMFRI for successfully spearheading artificial reef programs in the state. I hope the training program and this course manual will be of immense help to the potential trainers identified from different government agencies to take forward the artificial reef program on a national scale as envisaged under the PMMSY.

A. Gopalakrishnan
Director

Abbreviations

AFH	Artificial Fish Habitat
AR	Artificial Reefs
CARAH	International Conference on Artificial Reefs and Related Aquatic Habitats
CMFRI	Central Marine Fisheries Research Institute
DoF	Department of Fisheries
FAO	Food And Agriculture Organization of The United Nations
GFCM	General Fisheries Commission for The Mediterranean
GFM	Grouper Fish Module
ICAR	Indian Council of Agricultural Research
IFAD	International Fund for Agricultural Development
IPIMAR	Fisheries And Marine Research Institute of Portugal
MAP	Mediterranean Action Plan
MoA&FW	Ministry of Agriculture & Farmer’s Welfare
MoFAH&D	Ministry of Fisheries, Animal Husbandry & Dairying
NFDB	National Fisheries Development Board
OSPAR	Oslo and Paris Conventions
OECM	Other (area-based) Effective Conservation Measures
PMMSY	Pradhan Mantri Matsya Sampadana Yojana
PTSLP	Post-Tsunami Sustainable Livelihood Programme
RFM	Reef Fish Module
SCMEE	Sub-Committee on The Marine Environment and Ecosystem
TNCDW	Tamil Nadu Corporation for Development of Women
UNCLOS	United Nations Convention on The Law of The Sea
UNEP	United Nations Environment Programme
WRM	Well Ring Module

Acknowledgements

- Dr A Gopalakrishnan for permission, approval, and encouragement to carry out the Institute research project on the designs, impact assessment and post-deployment evaluation studies on artificial reefs in Tamil Nadu.
- Dr G Syda Rao and Prof. Dr Mohan Joseph Modayil, former Directors, ICAR-CMFRI for the encouragement and support extended during the early initiatives in artificial reef programs in Tamil Nadu.
- Department of Fisheries, Tamil Nadu and the Post Tsunami Sustainable Livelihood Programme (PTSLP) of the International Funding for Agricultural Development (IFAD) through the Tamil Nadu Corporation for Development of Women (TNCDW) for the vision and faith expressed by them while entrusting the MRS of ICAR-CMFRI with the execution of the various artificial reef projects under consultancy and extension services mode, and assisting in developing the concept to a broader perspective for coastal productivity and livelihoods.
- Dr E Vivekanandan, Dr H Mohamad Kasim and Dr G Mohanraj, Principal Scientists (retd.) and former Scientists-in-charge, Madras RS of ICAR-CMFRI, Dr KK Philipose, Dr Rajamani and Dr I Jagadish Principal Scientists (retd.), ICAR-CMFRI, who have spearheaded the program of extending consultancy services in artificial reefs and conducted the primary test trials.
- Shri Ahmad Kamal Basha, Shri P. Poovanan and Shri S. Mohan, Technical Officers (Retd.) at Madras RS of ICAR-CMFRI and the SCUBA diving teams at ICAR-CMFRI, Tuticorin and at other research stations of ICAR-CMFRI.
- Dr N K Sanil, Chair, Consultancy Cell, PME, Cell of ICAR-CMFRI and all the members of the Consultancy Cell, and Shri Anilkumar of the Consultancy Processing Cell, PME cell who have given all the necessary technical guidance and support in the processing of MOUs and correspondence regarding the projects.
- Dr KK Apukuttan, Dr M Rajagopal, Late Dr Grace Mathew and Dr V. Kripa, Former Chairpersons, Consultancy processing Cell, ICAR-CMFRI.
- Dr Boby Ignatius, Scientist-in-charge, PME Cell, ICAR-CMFRI for timely support in processing all matters related to the project correspondence and initiation.
- Administrative and Accounts & auditing staff of ICAR-CMFRI for the smooth conduct of the projects.
- All the Scientists-in-charge of MRS of ICAR-CMFRI, Chennai since the time of inception of artificial reef projects by the Centre, for constant support and facilitating the conduct of all the programmes.
- All the traditional and small-scale fishers and families and village heads, Panchayat leaders and members of the progressive fishing villages of Tami Nadu, who are the main partners in the whole progress of the introduction of scientific procedures in artificial reefing.

- SCUBA experts like Shri Aravind SB (Temple Adventures), Shri Venkatesh Pakkiri (Ocean Delight), Shri Govind, Shri Arjun Motha (Tuticorin) and Shri Jehaan (Quest academy, Ramnad) for the assistance rendered in underwater assessments.
- Fisher divers team guided by Shri Venkatesh Pakkiri from Kovalam along with Rahul S., Rahul Govind and Vargese V. from Mahaballipuram and Chandru D. from Periya Neelangarai for the help rendered in the sampling and siting studies and deployment works of all the projects all along the coast of Tamil Nadu.
- Indian Council of Agricultural Research (ICAR), New Delhi for the continued support and guidance extended in the execution of the various consultancy programs in the state of Tamil Nadu for the last 15 years.
- National Fisheries Development Board-Pradhan Mantri Matsya Sampadha Yojana, Hyderabad for the financial support extended towards the conduct of the two Three-days Training for Trainers programme (Jan-Feb 2023) for the benefit of the Fisheries Officials from all maritime states and UTs, and FSI and CIFNET and other coastal R&D Institutions/Agencies, and for the preparation and release of this course manual in three languages during the programme.

Artificial reefs - definition, history and status in India

Joe K Kizhakudan, Shoba Joe Kizhakudan, Divu D, Sreenath R, Mohamed Koya K, Loveson Edward, Vivekanandan E, Mohamad Kasim H, KK Philipose, Rajamani M, Mohanraj G, Rajagopalan M and Remya L.

Introduction

World fisheries today face threats from several quarters, including non-judicious fishing practices influenced by irrational growth in demand, destruction of aquatic habitats through pollution and destructive fishing methods, rupture of trophic food webs by increased exploitation of particular fishery resources, increased incidences of natural disasters and the impacts of climate change. With increasing concern over global marine fish production, and the scenario being not very different in India, there is an urgent need to evolve resource-, area-, and habitat-specific management tools to revive, sustain or improve Indian marine fisheries and marine ecosystems. The immediate and primary objective of a management strategy would ideally look towards enhancing fish catches.

Fig. 1. Mechanized fishing vessels docked at Kasimedu, Chennai

Fisheries in many parts of the world have undergone drastic changes, with onsiderable reduction in the mean sizes of common, commercially exploited resources, increase in catches of smaller, low-value resources and bycatch, and massive collapses caused by rapidly growing fisheries often unforeseen by our assessment methods, leading to disastrous social and economic consequences. The slow and steady depletion of high-value demersal resources (Garcia and Newton, 1997) is also a matter of great concern, as this is usually directly linked to the degradation of benthic habitats.

Sustainability is a deceptive goal because human harvesting of fish leads to a progressive simplification of the ecosystem in favour of smaller, high turnover, low trophic-level fish species that are adapted to withstand disturbances and habitat degradation, and present fisheries management is unable to reverse this trend. Some questions to ponder are –

- What has happened to our coastal waters?

  Increased exploitation and investments and pro-development installations, increasing discharges and inputs (thermal / saline/nutrients /debris).
- What is happening to our traditional fishers?

  Severely stressed
- Are we fishing down the food chain?

  Yes, it has already begun a few decades back
- Are we seeing the end of top predators and welcoming foragers?

  Yes, several fisheries and catch compositions have changed and large predators declined.
- Do we call it size reduction or the emergence of smaller varieties as a substitution?

  It is a combination of both and at times it is existential.
- How has the traditional fisher or the majority of fishers adapted to these changes?

  Shifted to capital intensive efforts with reduced CPUE and thus affecting livelihoods.
- Is sustainability meant to be showing higher catches of multiple species and changed compositions?

  No, sustaining the composition, balance of numbers and trophic levels and prey-predator ratios, retaining the primal states is.
- Where are we going with the continued harvest, increased efforts and hungry mouths?

  Reduced fish stocks and catches, overexploitation, very less fish to catch and feed.
- Is the competition bringing the survival instincts of best efficient techniques, faster, bigger nets, smaller mesh, better echo locatory supports and capital investments.

  Yes, more investments for better capture rates and efficiencies and value additions, but reducing margins and the artisanal fishers get handicapped.
- What happens to the marginalized and weaker fisher and most of all the surviving fishes?

  Increasingly vulnerable, and they live in stress and misery.

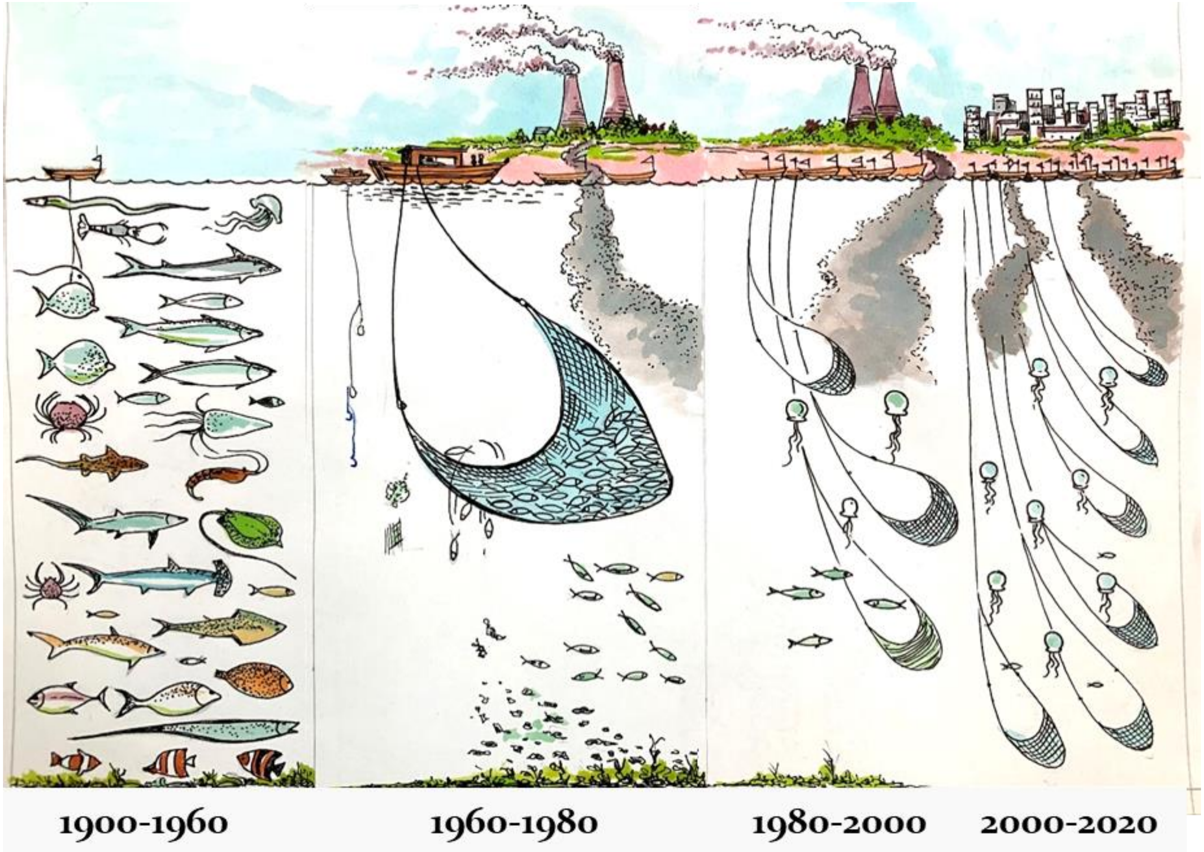


Fig. 2. Illustration of changes in the fishing scenario in coastal waters from 1900-1960 to 2000-2020 based on fishers' perception

- Have we compromised biodiversity and future economic options?

  Yes, the non-selective gears bring in several non-targeted species and in multitudes this has altered the ecosystem and habitat functioning and thus the balance and resilience within are shaken.
- Would the food fish deficit and high prices lead to long term local over exploitation?

  Yes, only to the extent of availability and economic feasibility.
- Does all these lead to the last resort of the landless poor (Pauly 1994)

  Yes
- Why do we need artificial reefs?

  We need more fish habitats, which are lost, restore the balance of fish diversity, populations, production and revive fishing and increase fish resilience towards increasing climate change.

Fig. 3. Fishing boats used at Kovalam, Tamil Nadu and Sassoon Dock, Mumbai and hooks used in hook & line fishery in Mumbai

Artificial Reefs

Artificial reefs are structures set on the sea bed to enhance the growth of marine floral and faunal benthic communities which simulate natural settings for promoting fish aggregations in terms of attracting migrant populations for breeding/feeding opportunities and also provide the base for the propagation of resident populations within sheltered structures. Artificial reefs promote habitat recovery/enhancement and boost aquatic biota. Artificial reefs are submerged (or partly exposed to tides) structures deliberately placed on the seabed to mimic some functions of a natural reef, such as protecting, regenerating, concentrating and/or enhancing populations of living marine resources. This includes the protection and regeneration of habitats. They serve as habitats that function as part of the natural ecosystem while doing “no harm.”

There is often a misunderstanding on the use of Fish Aggregating Devices (FAD)/Artificial Fish Habitats (AFH) and Artificial Reefs (AR). While FADs and AFHs are temporary aids to aggregate certain varieties or species mostly in surface or mid-water realms, ARs are more long-term habitat reconstruction programs to protect, produce and process a near similar natural reef like faunistic community built up and sustain it for several years.

Fish Aggregating Devices are structures or devices deployed in aquatic bodies to lure fish. They may be permanent, semi-permanent or temporary, made of natural or artificial materials. The practice of deploying FADs is rooted in the general knowledge of the tendency of fishes to aggregate under or in the vicinity of floating objects. These devices have been in use for over thousands of years. The earliest known FADs were driftwood, branches of trees and palm fronds etc.

While FADs provide an easy means of attracting fish towards easy exploitation, the deployment and proliferation of FADs have influenced harvesting practices and become the concern of fisheries managers (FAO, 2015). FADs increase the chances of selective fishing from spawning aggregations or juvenile aggregations, causing an eventual recruitment overfishing or growth overfishing. Sasikumar *et al.* (2015) report that the extensive use of FADs for cuttlefish fishing along the Karnataka coast has led to recruitment overfishing of the species in the eastern Arabian Sea, with a reduction in the number of recruits from 93.2 million in 2008 to 35.6 million in 2013. The use of synthetic non-biodegradable material in place of natural plant materials adds to the load of marine debris and pollution in the coastal waters.

Fig. 4. Traditional fish aggregating devices using coconut fronds, palm leaves, *Thespesia* spp. and *Acacia nilotica* tree branches, granite stones, etc.

In coastal marine ecosystems, ARs offer a platform for coral populations and increase the abundance of reef-dependant biota, including fishery resources. Their primary action being on the potential recovery of natural reef habitats that have been, or are on the verge of being affected by a collage of natural and anthropogenic events, artificial reefs can also prove to be a means of expanding favourable habitats through the deployment of coral-implanted reefs. The advantage of this would be developing fishing grounds close to shore, easily accessible to traditional and non-destructive fishing methods.

Artificial reefs exclude FADs, artificial islands, cables, pipelines, platforms, mooring, and structures for coastal defence (eg. breakwaters, dikes, etc.) which are primarily constructed for other purposes. Artificial reefs are management tools, which if applied in the right perspective, can prove to be great promoters of habitat recovery and enhancement and aquatic biota population boosters. Artificial reef technology has been used widely across the globe for both habitat and ecosystem enhancement and commercial fishery enhancement.

Advantages of an Artificial Reef

Artificial reefs provide suitable shelter for several groups of reef dependant fishes, particularly those that aggregate in such habitats for breeding. These structures easily attract smaller organisms which are vital sources of food for different marine species. They also serve as visual reference points for fish that forage away from the reef. A major advantage of fishery development through artificial reefs would be the reduction in scouting time and fuel consumption necessary for the fishermen to locate fish gatherings. These reefs, if properly constructed and properly buoyed, can be used to enhance existing rough bottom habitats and develop quality fishing grounds close to access areas. A well-planned and constructed reef is a mutually beneficial enterprise for both fish and man. The construction of a reef or fish haven can change a barren, relatively unproductive substrate into a dynamic, highly productive environment. Increasing the amount of rough bottom habitat provides immediate shelter and subsequent food for a complex of organisms which may have been otherwise lost in the process of its struggle for existence.

Types of reefs:

Protection: Beach and shoreline protection structures assembled in the sea bed to stall the wave swells and reduce the impacts on the sea shore.

Conservation/sanctuary: Create habitats and reserves for the settlement of select species or ranching select species and develop settlement colonies.

Production: Multimodule assembly of reefs built for the settlement, aggregation and multiplication and fishery sustenance and fisher livelihoods.

Recreation: Modules and deployments designed for fish assemblages for the SCUBA and diving enthusiasts and promote ecotourism**.**

Breeding and nursing /ranching: Specially designed reef modules for the juveniles and seed holding and nursing environment, to promote stocking and population revival.

Fishery and livelihood: Low scale short-term reef installations with simple models and fewer numbers with diversified and natural structures.

Creation of artificial sea mounts: Creation of large piles and dumps specially designed, to make artificial mounts or structures to create eddies and enrichments in the columnar region. These are normally very tall structures deployed on the continental shelf at greater depths.

Upwelling reefs for nutrient mixing: Introducing wall-like structures on the sea bed at the wave-breaking zones to induce a shift of sedentary nutrient mixtures to the surface and water column thus providing base and supplements for the growth and multiplication of primary and secondary producers.

Creation of current shadows/wake region: Developing specifically designed modules to be deployed in areas with more sea currents and flow speeds**.** Assembly of the modules is suited to create more current shadows and wake regions according to the flow directions, which can support plankton colonies.

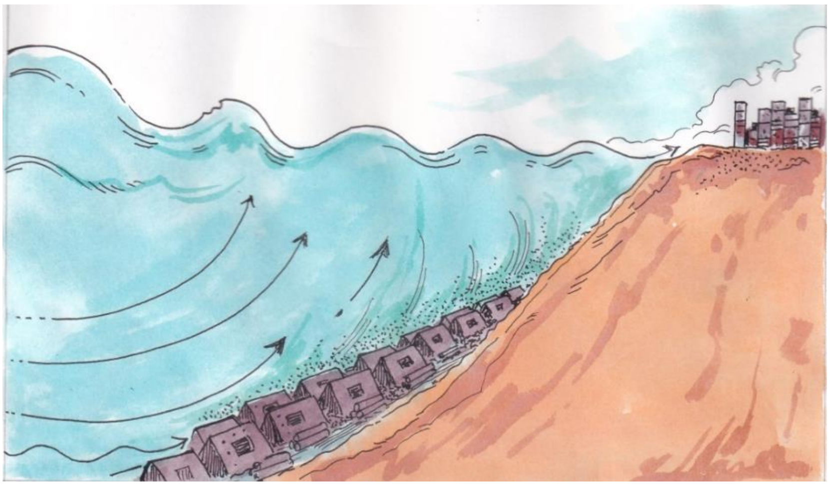
Multiple purposes: A combination of modules aimed to contribute to production, conservation, recreation, or other functions as is desired.

a.

b.

c.

d.



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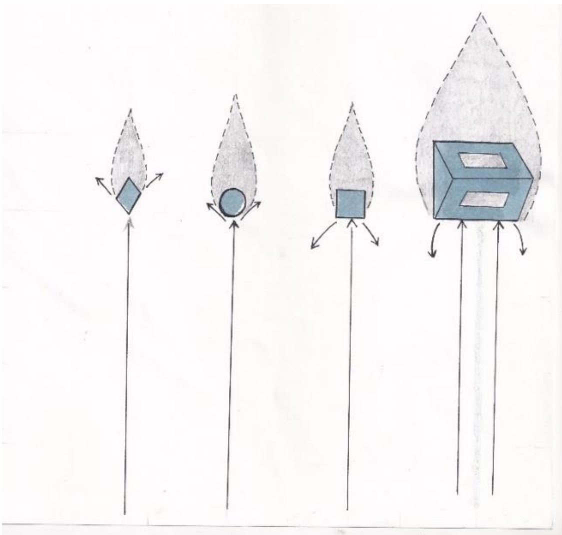

f.

Fig. 5. Artificial reefs deployed for various purposes – [a] ARs for protection [b] ARs in a Marine Protected Area (MPA) [c] ARs for recreation and tourism [d] ARs forming seamounts or cones [e] ARs reefs for upwelling [f] ARs forming shadow/wake regions

Artificial reef R&D and deployment in India

Since its inception in 1947, the Central Marine Fisheries Research Institute (ICAR-CMFRI), has been working on marine living resources, fisheries, sustainability, fisher census and livelihood, mariculture and marine environment. The Institute has produced several methodologies, technologies, products, research findings and publications in these directions.

Over the years, in the coastal states of Tamil Nadu, Gujarat and Maharashtra and many similar states where the commercial fishery has been predominantly supported by large predator fish communities and demersal fish species, increasing fishing intensity particularly focussed on large demersal groups has resulted in a continuous decline of these resources and the emergence of smaller fishes. Eventually, there has been a transition in the dependence of coastal fisheries from larger fishes to smaller ones, causing irreparable changes in the community structure and ecosystem functioning. The increasing pressure on the available fish stocks, anthropogenic inputs, climate change-related stress and increasing sea food demand and nutritional requirement has only aggravated the marine fisheries scenario with increasing pressure on the critical habitats and fisher livelihoods.

Since 1980, ICAR-CMFRI has been working on habitat enhancement and improvement of coastal productivity and livelihoods, through FADs, artificial reefs and fish stock revival and restorations. Initially, several NGO's working in the fisheries sector like the South Indian Federation of Fishermen Societies (SIFFS), Programme for Community Organization (PCO), Trivandrum, Loyola Social Service Center, Trivandrum, Murugappa Chettiar Research Centre (MCRC), Chennai and Centre of Research on New International Economic Order (CRENIO, Chennai) were responsible for mobilising fishermen and launching ARs in a few fishing villages in the south-west and south-east coasts of India. CMFRI initiated R&D works on artificial reefs in the 1990s. An experimental deployment was conducted in Minicoy, Lakshadweep and Tuticorin during the early 1990's by CMFRI. A National Workshop on Artificial reef building technology and farming was conducted at the Trainers Training centre (TTC) at CMFRI, Kochi in 1996.

Two reefs were deployed off Vizhinjam in 1997 by ICAR-CMFRI. Subsequently deployments were conducted with funding support from the Department of Fisheries, Government of Kerala, during the 1999-2003 in Poovar in Trivandrum, Dharmadom in Kannur, Moodady in Kozhikode, Thikkody in Kozhikode, and Muttom in Kannur districts, covering an area of nearly 50,000 sq. m. Different AR structures deployed in the coastal waters south of Chennai in the 2000s demonstrated the potential role of AR in resource enhancement and increased economic benefits. Catches from the deployed sites comprised of high-quality fishes, fetching fishermen better economic returns per unit effort (Vivekanandan *et al.*, 2006). Tamil Nadu has, in recent years, become a major player in the practice of artificial reef deployment in coastal waters, under technical guidance from CMFRI. Since 2006, the Department of Fisheries, Government of Tamil Nadu, has deployed artificial reefs in 125 coastal sites spread across 10 districts along the Tamil Nadu coast, with technical assistance from Madras Regional Station of CMFRI, Chennai. Since 2011, the IFAD-assisted Post

Tsunami Sustainable Livelihoods Programme (PTSLP) of Tamil Nadu Corporation for Development of Women (TNCDW), Government of Tamil Nadu, has also come forward to deploy artificial reefs along the Tamil Nadu coast, with 18 sites completed by CMFRI and 42 sites done by the National Institute of Ocean Technology (NIOT). Other NGOs and agencies have together deployed artificial reefs in another 22 sites in Tamil Nadu during 2000-2020.

CMFRI, in association with NTPC (CSR funding) and State Fisheries Department, deployed artificial reefs at Mutyalammapalem village in Visakhapatnam District Andhra Pradesh. A total of 210 (70 each 3 models) AR modules covering an area of 1000 m^2 were deployed (at 15 m depth) along the Mutyalammapalem coast of Andhra Pradesh in May 2015.The total area covered by 210 units is 1000 m^2 with a surface area of 2781.8 m^2. CMFRI has also undertaken Artificial fish habitat-based marine ecosystem restoration in the inshore areas off Bhadreswar, Kutch District, Gujarat on consultancy mode for Agriculture, Farmers Welfare and Co-operation Department, Government of Gujarat, with the deployment of 225 reef modules in 12 clusters off Bhadreswar.

CMFRI has also been conducting studies to assess the state of maturation of artificial reefs deployed at different sites along the Tamil Nadu coast, and collect information to assess the impact of artificial reefs on the natural habitat and its biodiversity. The team at the Madras Regional Station is conducting focused research and monitoring and evaluating the works on the development of suitable reef designs, structures and densities in the promotion of habitat formation in the near coast, for the past two decades in Tamil Nadu. Several patterns, materials and sites have been studied and site-specific programmes have evolved. Recently, the Institute was awarded patent rights for Patent 197/CHE/2012.

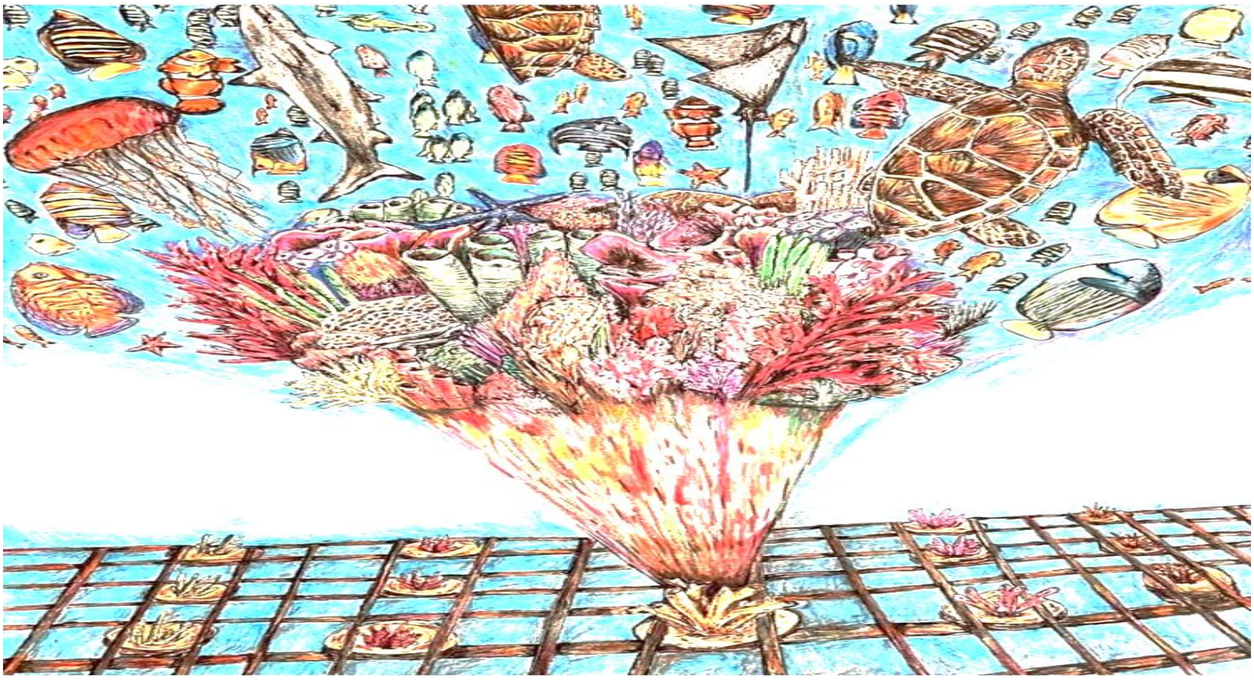

Fig. 6. An artist's view on the production cum conservation impacts from a small habitat restored on the sea floor

Global practices in artificial reefs

Shoba Joe Kizhakudan, Joe K Kizhakudan and Remya L.

Global strides in artificial reef R&D and deployment

Historically, it was well understood by the coastal communities and fisher's world over that the rock patches, sunken ships and vessels and submerged coastal dwellings and reefs supported more life in the coastal waters, and they supported good fisheries. The floating tree trunks, leaves, floating islands in flash floods carried huge sheltering populations of fishes and fauna. The traditional fishers of Kerala and Tamil Nadu in India deployed huge palm trees and thick bushy trees with foliage as anchors in the sea bottom with boulders and sandbags which harboured larger predatory fishes and thus improving catch rates and returns.

The first artificial reefs were inadvertently created in the Mediterranean Sea in the 1500s, when rocks used to anchor tuna fishing nets left on the seabed at the end of each fishing season accumulated over time and created new rocky habitats, inhabited by fish which were subsequently exploited by local fishermen between the tuna fishing seasons (Riggio et al., 2000). Similar practices were employed by artisanal fishermen across the world (Simard, 1995). The modern concept of "artificial reef" evolved in Japan in the 20th century after World War II, and was adopted in the Mediterranean Sea in the second half of 1900s.

The Japanese are the world leaders in artificial reef technology for commercial fishery enhancement and have been creating artificial reefs since the 18thcentury; the materials used are of high quality like concrete, steel and glass-reinforced plastic. In the USA, the artificial reef programs of many maritime states are run for the benefit of recreational sports fishing, (SCUBA) diving, commercial fishing, waste disposal, and environmental mitigation; the materials used are mostly waste, including concrete, rock, construction rubble, scrap tires, cars, railway carriages and ships. Only Japan and the USA have a national development plan. Malaysia and the Philippines use waste tires to build many of their artificial reefs. The central Visayan Islands of the Philippines have been known to use 1600 pyramid bamboo modules. Australian reefs have been built from materials of opportunity such as tires and redundant ships; these reefs are used primarily as a focus for recreational angling, and SCUBA diving. In Taiwan, many fishing vessels (made obsolete by government policy to reduce the size of the fishing fleet) were sunk to provide new habitats. In Europe, artificial reefs were pioneered along the Mediterranean coast in the late 1960's. At present, most reefs are still associated with scientific research. Italy, France, and Spain have been the most active reef-building countries since 1970. Spain is placing more artificial reefs into its coastal waters than other EU countries. In

1991, Italian artificial reef scientists for the first time formed an inter-European reef group to encourage liaison between research groups and other associations of the Mediterranean.

The main purposes of these deployments were to enhance fisheries and improve fisheries management. The increasing interest in artificial reefs has given rise to the organising of the first International Conference on Artificial Reef and Related Aquatic Habitats in Texas, USA in 1974, and subsequently in Brisbane, Australia (1977), California (1983), Florida (1987), California (1991), Tokyo, Japan (1995), San Remo (1999), Mississippi (2005), Curitiba (2009), Turkey (2013), and Malaysia (2017). Several management guidelines have been developed over the last twenty years to support managers and scientists in the placement of artificial reefs in the European seas (OSPAR, 1999; UNEP-MAP, 2005; London Convention and Protocol/UNEP, 2009; OSPAR, 2009). The London Convention 1972, UNCLOS and Basel Convention 1989, Mediterranean Action Plan and the Barcelona Convention 1995 lead to the development of guidelines for the placement of materials at sea other than for mere disposal (construction of artificial reefs) (UNEP-MAP, 2005, 2009). In 2006, the Protocol entered into enforcement. In 2008 specific guidelines for the placement of artificial reefs were within the context of the London Convention and Protocol (London Convention and Protocol/UNEP 2009). No placement of matter in the maritime area for a purpose other than that for which it was originally designed or constructed shall take place without authorisation or regulation by the competent authority of the relevant Contracting Party. OSPAR (O'Sullivan, 2018).

In 2009, FAO General Fisheries Commission for the Mediterranean (GFCM) initiated a debate on the use of artificial reefs in the Mediterranean and Black Seas, especially to enhance and manage fisheries and fishing resources (GFCM, 2010). This issue has been addressed during the annual meetings of the Sub-Committee on the Marine Environment and Ecosystem (SCMEE) that led to an ad hoc workshop in January 2011 (GFCM, 2011, 2012) for developing the guidelines and management practices for artificial reef siting, use, construction, and anchoring in Southeast Florida (Lindberg and Seaman, 2011). These guidelines provide resource users, managers and planners with essential information and guidance on the most effective methods for enhancing and protecting natural resources as well as improving fisheries and aquaculture opportunities.

The objectives of these guidelines were:

1) to update the information reported in the previously prepared guidelines;
2) to assist the countries in the planning and deployment of artificial reefs based on scientific criteria;
3) to avoid pollution or degradation of the aquatic ecosystem due to the deployment of unsuitable materials as well as the dumping of waste;
4) to prevent negative impacts due to the deployment of artificial reefs;
5) to provide information on the different scopes and types of artificial reefs, as well as on their potential effects;

6) to provide technical information on the deployment, monitoring, ongoing management and socio-economic effects of artificial reefs.
7) To provide actual biological advantages in biodiversity improvement, recruitment and fisheries
8) To extend coastal protection against sea bottom surges and swells
9) To provide alternative livelihood options for coastal traditional fishers
10) To extend habitat restoration, reproductive refugia, nursery grounds and protected areas under vulnerable or threatened stages.
11) To extend impetus to sustainability in fishing and improve fisheries governance.

European Programs in the Mediterranean Sea: The Mediterranean region is one of the world's richest biodiversity spots hosting 7.5% of the world's animal taxa of which nearly 28% of them are endemic. Nearly 150 million people live bordering these coastal regions and areas. Historically, the practice of deploying reefs could be dated back to 3000 years in some of the Mediterranean countries. The more recent European Programs in the Mediterranean Sea in countries like Cyprus, France, Greece, Israel, Italy, Spain, Tunisia, Malta, Monaco, and Turkey introduced over the past 50 years were aimed at promoting small-scale fisheries using gill nets, trammels, and traps (Bombace et al., 2000; Pelini et al., 2008; Gianna Fabi et al., 2011) and to deter illegal trawling in coastal areas and other sensitive habitats. As multiple countries are involved in the area, conflict and resolutions led to the evolution of legal frameworks and protocols in the programs. In Monaco, growing corals was the objective while in Malta it was diving. In France alone, nearly 90,000 m^3 of artificial reefs (concrete) have been deployed in 20 sites. Since 2000, ten reefs (concrete) have been developed around the islands of Greece, each covering 8-10 sq.km. Israel deployed reefs basically to promote professional fisheries and recreational activities. Italy has the program developed in over 70 sites with protection, production and a combination purpose to impede trawling as a primary objective. Spain is the leader in the group with over 103 sites completed following "Methodological guidelines for Artificial Reefs Placements" - protection, production and impeding trawling. Tunisia developed programs with the support of the JICA funds for impeding trawling and protecting sea grass beds.

Sustainability of Artisanal fisheries in Portugal in the Gibraltar Strait: The Portuguese Fisheries and Marine Science Lab - IPIMAR deployed artificial reefs in the Southern Portugal-Algarve. Initially, they were deployed for protection in 1990 with tall structures and later production reef modules in smaller sizes were introduced. Nearly 21,500 units in 45 sq.km with an area of influence of 70 sq km. During the 1980's the fishing fleets had drastically reduced by 50% and since the introduction of artificial reefs, traditional fishing and livelihoods were revived. This is perhaps the largest reef deployed in Europe - 8.2 km long and 1.5 km wide. The fish production from the region rose continuously for 15 years.

Mexico -Yucatan Peninsula started artificial reef programs in the seventies with sunken ships and then barrages. Later in Campeche in 1985, modules for fish production were introduced. The fish production rates increased by 10 folds and the species abundance improved from 23 to 49 species.

The Japanese experience: The initial deployments using stones in 1952 saw improved aggregations and ease of fishing in littoral and intertidal zones. In 1974 the Coastal Fishing Ground Improvement and Development Law was introduced and by 2001 they had covered 20,000 sites of deployments with a variety of objectives, which include protection, conservation, production, seaweeds, nursery, littoral marine species, breeding, aquaculture, upwelling, ranching.

Artificial reefs in Virginia Beach, USA: In a recent turn of events, the Chesapeake Bay Foundation was ordered in July 2022, to remove all artificial reef materials from several sites in the Lynnhaven River in Virginia Beach after the reefs were found with prohibited items, such as asphalt and metal wire, sticking out of the water, when the Virginia Marine Resource Commission found that the materials used were in substantial violation of state code. This incident exemplifies the need for caution in the use of the right materials for reef construction, and the need to ascertain that the artificial reef will not have any negative impacts on the ecosystem it is placed in.

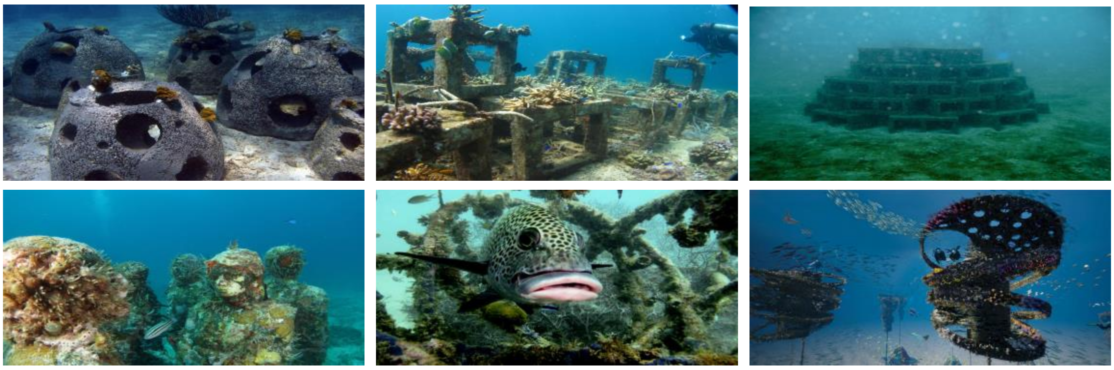

Fig.7. Types of reefs deployed in different countries for different purposes.

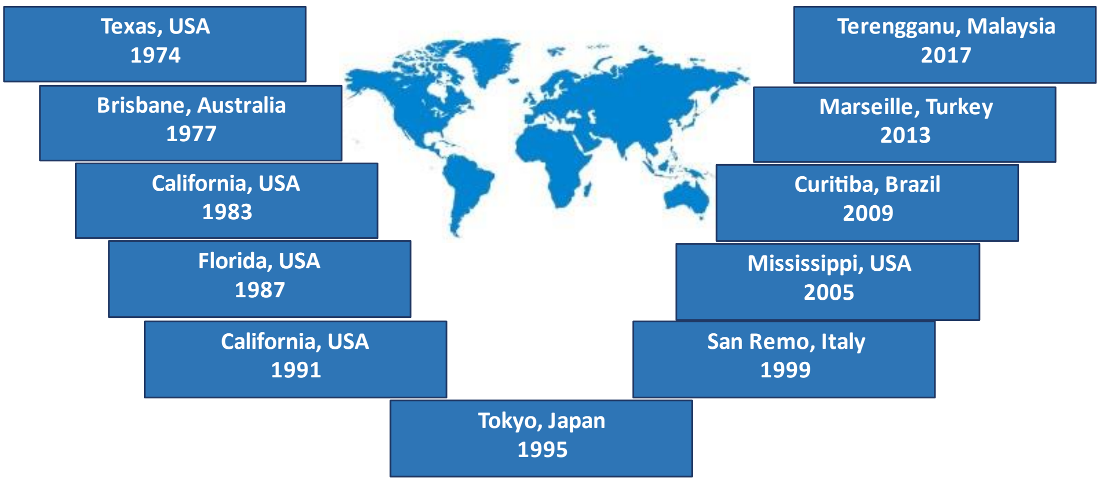

Fig.8. CARAH conferences around the world on Artificial reefs and Related Aquatic Habitats

Design, fabrication, and testing of artificial reef modules

Joe K Kizhakudan, Shoba Joe Kizhakudan, Remya L and Senapathi P.

Artificial reefs were earlier thought to be a disposal end to waste materials such as cars, boats, aeroplanes, tanks, tires, appliances, oil rigs, and demolition articles. It is often much cheaper to just dump these materials in the ocean than dispose of them in a landfill. Many of the reef structures built in the early 1900's were probably dumps to get rid of unsightly scrap materials. Then the concern among scientists increased when they realised that substances from these surplus materials might contribute to ocean pollution and destroy natural fish habitats. Materials used to make artificial reefs must be thoroughly cleaned to eliminate pollutants. They also have to be heavy enough not to be moved during storms and be made out of materials that will not corrode and collapse.

Building an artificial reef

The two major conditions that need to be satisfied before embarking on the establishment of artificial reefs along a coastal stretch are – (i) suitability of the site and (ii) suitability of the reef structure, both design, material, and mounting. Compromise in any of these conditions would result in a reversal of the favourable outcomes possible through the reef. Although artificial reefs and fish aggregating devices have been known to be used worldwide since time immemorial, the design and development of an eco-friendly reef remains a challenge

The stability and complexity of artificial reefs determine the amount of fouling (organisms attached to the substrate) and the numbers of resident species. The more complex the structure, the more diverse the resulting community will be. The spatial arrangement, number, and size of openings will determine the types and numbers of organisms present. Habitat choice is probably a determining factor of larval settlement in structuring the community but this changes over time as the reef evolves. One organism may be better adapted for a particular locale on the reef than the original pioneer species. So, until the environmental factors change, it will compete and displace the original organism and other potential inhabitants as well. This is typical of colonization of an artificial reef, due to competition and predation of the smaller individuals by fewer but larger individuals. It is also believed that smaller reefs are better at recruiting because they cover a greater horizontal space of the seafloor (Pickering 1994). In Bohnsack's 1994 study, larger reefs were found to be better for supporting fisheries while many smaller reefs promote greater diversity through recruitment. The more dispersed the reef material is, the greater the horizontal spread will be and thus, the greater the attraction capacity will be for settling organisms. The population structure in artificial reefs has been found to vary with the size of the reefs.

Therefore, the design of a reef is critical to the survival of the structure and the presence of desired species. Many different materials have been used to create artificial reefs such as tires, wood, concrete, PVC, fiberglass, plastic, metal, pulverized coal ash, and marine alloys. The use of these materials varies in different parts of the world. The following criteria are looked into for the fabrication: [1] ready availability of desirable materials, [2] matching materials to permitted reef sites, [3] avoidance of high transportation costs associated with heavy and bulky materials, [4] ease of deployment, [5] reef stability in high energy nearshore environments, [6] reduction of interference of reef structures with traditional commercial bottom fisheries, [7] longevity of reef materials, and [8] long-range cost and benefits, [9] Artificial reefs should be within easy and safe access of recreational visitors and/or fishermen.

Table 1. Purpose-specific location of artificial reefs

Purpose	Location
small boat fishermen	protected waters or within a few miles of a harbour or hamlet (within MFRA)
large boat fishermen (head or charter)	distant reefs

In Europe and Japan, the dominant material is concrete. Japan also uses steel and fiberglass. Tires are used in countries that have poor artificial reef management programs. In Australia, Jamaica, and the Philippines, tires are considered non-toxic durable materials. The United States and Europe view tires as a source of pollutant leaching, however, the United States nevertheless continues the predominant use of other materials of opportunity. There has been a serious shift worldwide towards using materials dedicated solely to the creation of artificial reefs. This allows for better designs and more effective reefs. They can be specifically designed for a single purpose such as to protect shorelines or any other of a multitude of objectives. Concrete has been found to be very favourable for artificial reef construction. It does not degrade in seawater, can be made to have neutral pH, is easily moulded and is not easily moved once in place but hard to transport to the deployment site. Concrete can be made to have a texture comparable to natural reefs and develops very similar communities as natural reefs (Pickering 1997). PVC and other plastics are also very mouldable, do not degrade, are easily transported, but are not as stable due to their lightness and are typically smooth textured. But will the structure withstand the fall to the bottom? Once in place will it withstand the stresses of currents, burial, and storms? If the reef is placed in an area of strong currents such factors as scouring must be considered along with the potential movement of the reef. Scouring under the edges of artificial reefs can result in the burial of the reef. It can also result in good burrows for cryptic species around the base of the reef. An important feature of steel is that it can be made into very complex structures. It is also very heavy and not easily moved by wave action but does corrode in seawater. Each of these materials has benefits and drawbacks.

The materials used for reef construction are to be selected with utmost caution. They must conform to the standards specified globally and nationally to ensure the quality of the seawater where the reefs are deployed. The use of hazardous materials must be avoided at all costs. In July 2022 in the United States, the Chesapeake Bay Foundation was ordered to remove all artificial reef materials from several sites in the Lynnhaven River in Virginia Beach after the reefs were found with prohibited items, such as asphalt and metal wire, sticking out of the water.

The environment of the deployment area determines the materials to be used. Artificial reefs at great depths or in protected areas with weak currents do not need to be incredibly stable. However, the greater the amount of wave action and current the more stable the reef must be to withstand having its structural integrity compromised. The seafloor’s bearing capacity, compressibility and soil strength also influence the design characteristics of the artificial reef. If the ocean bottom were made of a thick layer of fine sediment a heavy reef would sink and disappear into the bottom. In this situation, lightweight reef construction materials should be used.

The shape and size of reefs also influence the physical characteristics of the surrounding area, most notably the currents around and through the reef. When an artificial reef is placed in the path of a current, it displaces the current to varying degrees depending on the porosity of the structure. In the water behind such a reef there will be a shielded locale of little or no currents (shadow-wake region). This can attract fish by giving them an area where they do not need to fight a constant current. This area may produce pressure fluctuations associated with turbulence, which can also stimulate fish aggregation. A more spread-out reef has the potential for a greater number of different niches due to a larger area covered. Reef size significantly influenced the total numbers of species, individuals, and biomass. Smaller reefs had greater fish density while larger reefs had higher biomass density from larger, but fewer, individuals. Multiple small reefs supported more individuals and more species than one large reef of equal material. Artificial reefs that were created at different times, over the course of a year, become essentially the same after they have all been in the water for at least a year. This may be because the different seasons allow different colonists to occupy the reefs. Benthic species occur in greater numbers when the reef bottom area is larger while height does not affect their numbers. Mid-level species prefer reefs with a greater vertical profile. Several studies have identified that reef size significantly influences the biomass and the total number of species and individuals, with the efficiency of artificial reefs as attractors being far greater when formed into a structure than disaggregated into pieces" (Pickering, 1996). It also follows that more complex reefs are better attractors. In a different study it was found that several smaller, but just as complex, artificial reefs have more associated individuals and species than a single larger complex reef.

Table 2. Type of reef and associated species

Type of reef	Species/resource
Low profile reefs - major sport fishery	demersal (benthic) species such as sea basses, groupers, snappers, crabs, lobsters, flounders, codfishes, tautog, rockfishes, sheepshead, seatrouts, croaker, black drum, porgies, grunts, groupers.
High-profile reefs - increase productivity	pelagic species: mackerels, jacks, bluefish, spadefishes, amberjack, tunas, barracudas, and cobia
Floating reefs	pelagic species
Combination of low and high profiles	effective for both demersal and pelagic species.

Stability over time and achievement of the expected ecological results is important to consider both the engineering aspects and the scope of the artificial reef when planning the reef units and/or the reef sets. Reef units can range from very simple modules (e.g., rocks or manmade cubes placed singly on the seabed) to sophisticated, intricately designed structures made of several different materials (e.g., steel and concrete, steel and fiberglass). Simple reef units can be assembled in reef sets to increase the three-dimensional complexity of the reef, hence enhancing its potential in the recruitment of larvae of benthic organisms and fish species. For the same scope, different typologies of reef units and/or reef sets can be used to create an artificial reef. The shape, height and weight of the reef units and reef sets are crucial for their stability and durability. It often happens that structures completely sink in muddy bottoms because they do not have a base adequate to support their weight. Complex modules may collapse due to the forces of currents and waves. Hence, the ratio of weight to surface area is crucial for the stability of the artificial reef units. Different technical project approaches are required when using modules specifically designed for artificial reefs and constructed with new or pristine materials and new sites with particular attention to the design and spatial arrangement of the structures. As a precautionary approach, structures of opportunity (tyres, ships, buses, vessels, rig pipes etc.) should not be placed close to sensitive natural habitats.

The overall objective of the production of artificial reefs is to increase the productivity of the aquatic environment and promote sustainable utilisation of the resources. When opportunely designed, artificial reefs may increase the biomass, thus increasing the availability for human consumption, of a variety of aquatic organisms (algae, molluscs, sea urchins, fish) by enhancing their survival, growth and reproduction providing them with suitable habitats and additional food. This type of artificial reef can be also used to manage the life stages of targeted species favouring aggregation of juveniles in certain areas and gathering the adults at suitable fishing grounds.

The specific applications of the production artificial reefs include:

- Recovery of depleted stocks, by increasing the survival of juveniles by providing shelter and additional food;
- Enhancement of local fisheries, by aggregating and establishing permanent populations of fish at suitable fishing grounds;
- Shifting the fishing effort from an overexploited resource to other resources; e.g., if the soft-bottom associated species in an area are overexploited, artificial reefs can serve to shift a part of the fishing effort to pelagic or reef-dwelling species;
- Compensation for a reduction of fishing effort: when there is the need for reducing the fishing effort of trawling in an area, the production of artificial reefs can be used in negotiation to create new fishing grounds allowing fishermen to shift towards more selective fishing activities;
- Development of extensive aquaculture of algae and molluscs, providing suitable substrates for settlement.

The modules generally used for production artificial reefs should be spread out, of various shapes, and should have an appropriate amount of surface area and niches of various shapes and sizes available for the establishment of settling organisms. Differently from the protection reef units, production units have usually more volume to their weight, creating three-dimensional complexity and developing surfaces which can be colonised by sessile organisms. Rough surface texture enhances benthic settlement providing refuge and supporting greater diversity. Consequently, it also affects the fish assemblage attracting fish grazing.

Besides food availability, composition, diversity and abundance of the reef, fishes are strongly affected by the occurrence of adequate refuges and by the shape of the structures. Habitat quality affects habitat selection by fish and consequently, influences the demography and population dynamics of the reef fish assemblage. Hence, to host a permanent community, an artificial reef must provide adequate habitats for juveniles and adults. Based on the fractal crevices theory in structurally complex natural or artificial environments large crevices are much rarer than smaller ones. Consequently, the artificial reefs can host more small and medium-sized than large organisms which tend to migrate outside. Therefore, the placement of large-holed reef units (especially in marine protected areas) could avoid the depletion of broodstock by fishing and enhance the reproductive capacity of reef fish.

Other factors that should be considered in planning the artificial reef structures are:

- independent of the size and the life stage, generally fish prefer cavities where there is light and with many openings to enable them to escape from predators;
- size, number, and orientation of cavities should match with the behavioural features of the target species, such as whether they are territorial or gregarious;
- the overall design of artificial reef structures should assure adequate water circulation. Regarding the shape of the reef units/reef sets, it is well known that the affinity of several aquatic organisms towards the artificial substrates varies widely depending on the species and the life stage. Because of this, when constructing a reef for fisheries enhancement, it is important to deeply know the ecology of the different species to identify those that are more appropriate as targets for artificial reef deployment and that will have a higher probability of being manageable through manipulations involving artificial reefs.

CMFRI has been experimenting with several designs which include –

- Concrete rings
- Old tyres/fixed on a concrete bed
- Triangular or rectangular modules with PVC or stoneware pipes fitted inside
- HDPE pipe structures
- Rectangular box-like Circular (dense)
- Tetrapod
- Triangular modules (130 kg) 5 feet height units
- **MOU** with **Intermediate Technology Development Group, London and the Southampton University (1995) -** design of 5 feet triangular fish reef module took place (120 kg) and so was the module placement technique engaging the traditional crafts at Trivandrum.
- **Concrete Artificial Reef Modules-particulars**

Three types of artificial reef modules developed by CMFRI are Grouper Fish Module (GFM), Reef Fish Module (RFM) and Well Ring Module (WRM) and three-generational modifications have been adopted over a period of time, based on field trials and observations. Since the development of the standard modules for three classes of fishes (Reef fishes-Trevallies-breams-perches **Triangular/pyramid module**, Benthic crustacean fauna -**Well ring or flower module** and the cods-groupers-eel- **Tubular Pipe module [Patent 197/CHE/2012]** "Cement and concrete moulded artificial reef to aggregate marine fish") three generations of designs and sizes have evolved based on the observations in performances, stability, shelf life, compatibility with the fishing gears and substratum and the dynamics of the seabed and reef fish built-up efficiency.

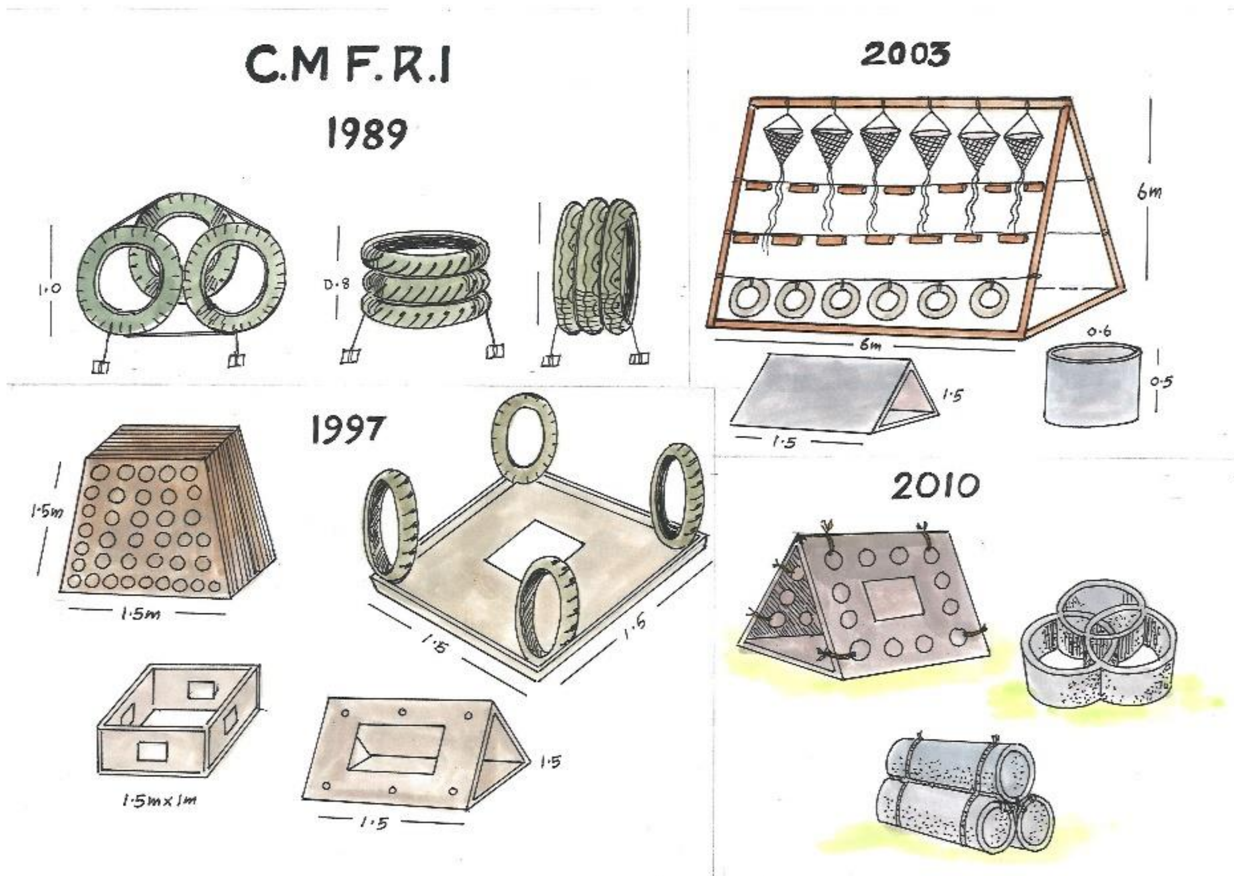

Fig.9. Different designs of AR Modules trailed by CMFRI

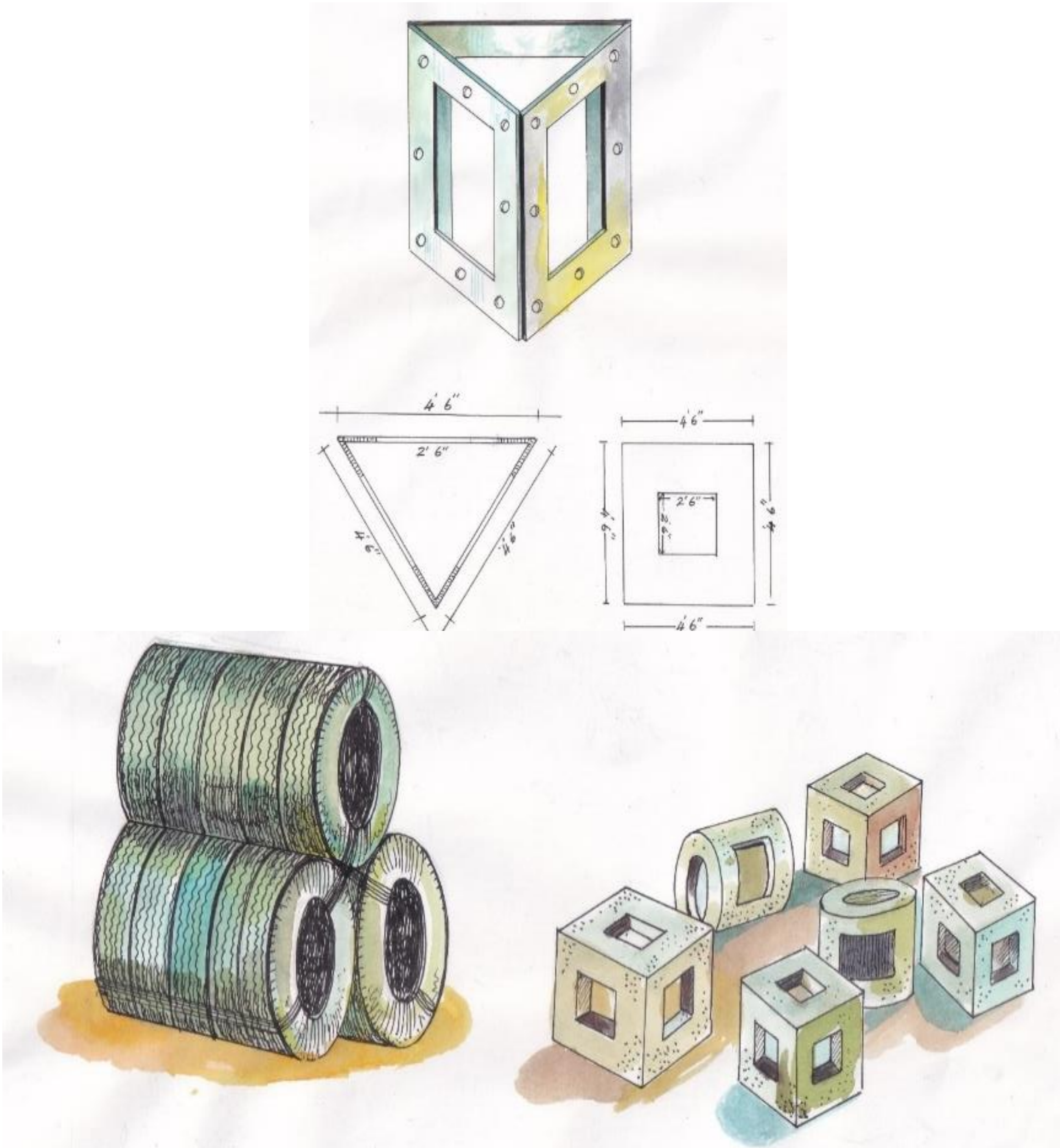

Fig.10. Earlier designs of AR Modules trailed by CMFRI

Generation A. 2009

Grouper Fish Module (GFM)

6 mm MS reinforced, with concrete (RCC) pipes (3 nos.) 280 mm ID 410 mm OD dia x 1000mm length, fixed and plastered and housed inside the triangular slab structure (1m x 1 m x 1 m), cured. The concrete and mortar of the best standards to be provided

Reef Fish Module (RFM)

6 mm MS reinforced, Triangular moulded concrete module (1.2 m x 1.2 m x 3 slabs of 2.5-inch thickness). Each slab has 0.23 x 0.23 m square opening in the centre & amp; 0.15 m dia circular holes surrounding the central square opening (12 nos. / slab)

Well Ring Module (WRM)

6 mm rod reinforced concrete Well Ring (overlapping) Module; 0.76 mm dia rings (3), 0.450 mm depth, 65 mm thick

Note: Concrete 1:1:2 ratio, 5mm baby jelly, stucco plastering and coarse sand and blue metal layering on the surface plastering (rough cast plastering).

2 weeks curing for all the above modules with fresh water

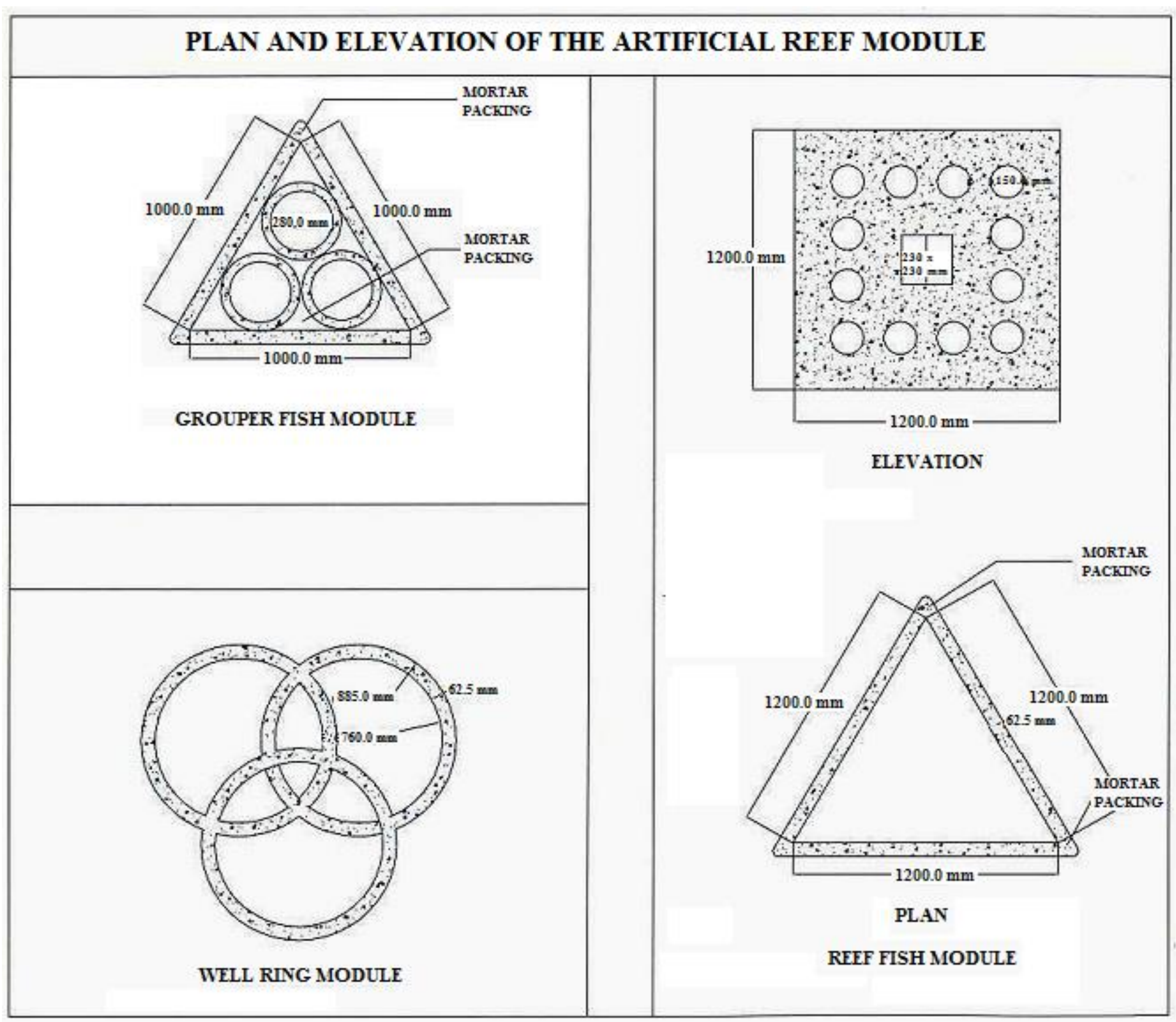

Fig.11. Dimensions of different reef modules

Generation B. 2012-2015

A. Grouper fish module (GFM)

1000 mm L X 300 mm ID (430 mm OD), 65 mm thickness, 6 mm MS rod
3 pipes held 20 mm by HDPE rope and loop for lifting
Rough cast plastering, 5 mm baby jelly

B. Well ring module (WRM)

760 mm ID, 890 mm OD, 450 mm depth, 6 mm MS rod
20 mm HDPE rope and loop for lifting
Rough cast plastering, 5 mm baby jelly

C. Reef fish module (RFM)

1200 x 1200 mm 3 slabs**,** 6 mm MS rod
mortar packed corners into a triangular hut, rough cast plastering, 5 mm baby jelly
20mm HDPE rope and loop for lifting
65 mm thickness, rough cast plastering
Each slab has a central window 230x230mm and 12 peripheral holes 0f 150 mm dia.

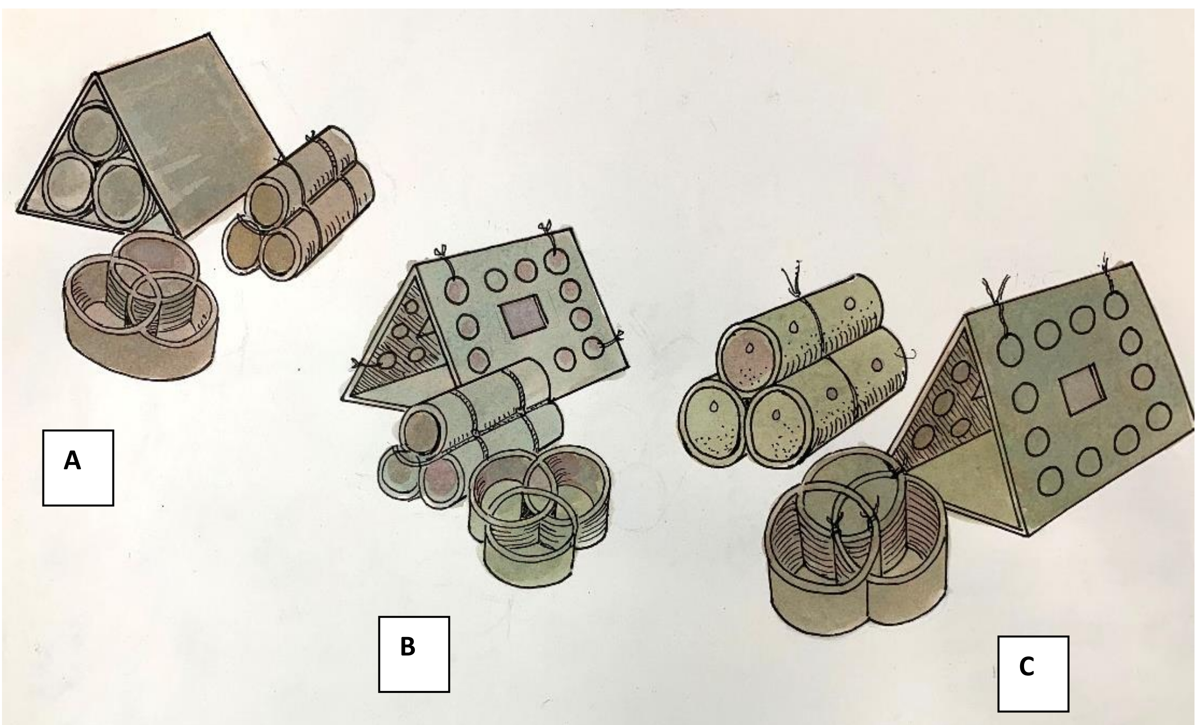

Fig.12. A – Module type I (150 nos.); B- Module Type II (150-175 nos.) & C- Module type III (200-275 nos.)

Two weeks of curing with fresh water is required for all the above modules.

Generation C. 2016

D. Grouper fish module (GFM)

1000 mm L X 300 mm ID (450 mm OD),75 mm thickness, 8 mm RDS rod
Fused pipes with holes coir loop for lifting
Stucco 12 mm plastering, 10 mm baby jelly

E. Well ring module (WRM)

760 mm ID, 890 mm OD, 450 mm depth, 8 mm RDS rod, 75 mm thickness
20 mm COIR rope and loop for lifting
Stucco 12 mm plastering, 10 mm baby jelly

F. Reef fish module (RFM)

1200x 1200 mm 3 slabs**,** 8 mm RDS rod, 75 mm thickness
mortar packed corners into a triangular hut, Stucco 12 mm plastering, 10 mm baby jelly
20 mm coir rope and loop for lifting
Each slab has a central window 230x230 mm and 12 peripheral holes of 150 mm dia.
Reinforced cement concrete of M30 (OPC)43 gradeIS8112 as per BIS-456-200 (440 Kg/M3) using 20 mm and 12 mm gauge HBG stone jelly. With water cement ratio 0.45 and super plasticizer 250 ml/50 kg cement. Stucco plastering 12 mm HBG chips of 10 mm CM 1:5 mix x 12 mm thick.
The recent versions are treated and cured for 3 weeks with freshwater and seawater for a week before the deployment.

Fabrication at the site, inspection and verification

During the evaluation and testing of the modules, it is imperative that -

- The dimensions and concrete mixture are to be checked
- The rod sizes, curing period and the stucco plastering thickness
- The cement grade and the plasticizer
- The strength and durability are to be tested between 7-28 days of fabrication.
- (Fineness Test., Consistency Test., Setting Time Test. Strength Test., Soundness Test., Heat of Hydration Test., Tensile Strength Test., Chemical Composition Test.)
- The modules are numbered and arranged for easy shipment and loading.
- The modules are to be weighed on a weighing scale and the GRT per trip per site has to be evaluated for port bills and clearances at harbours.

Fig.13. The latest AR modules being deployed by CMFRI

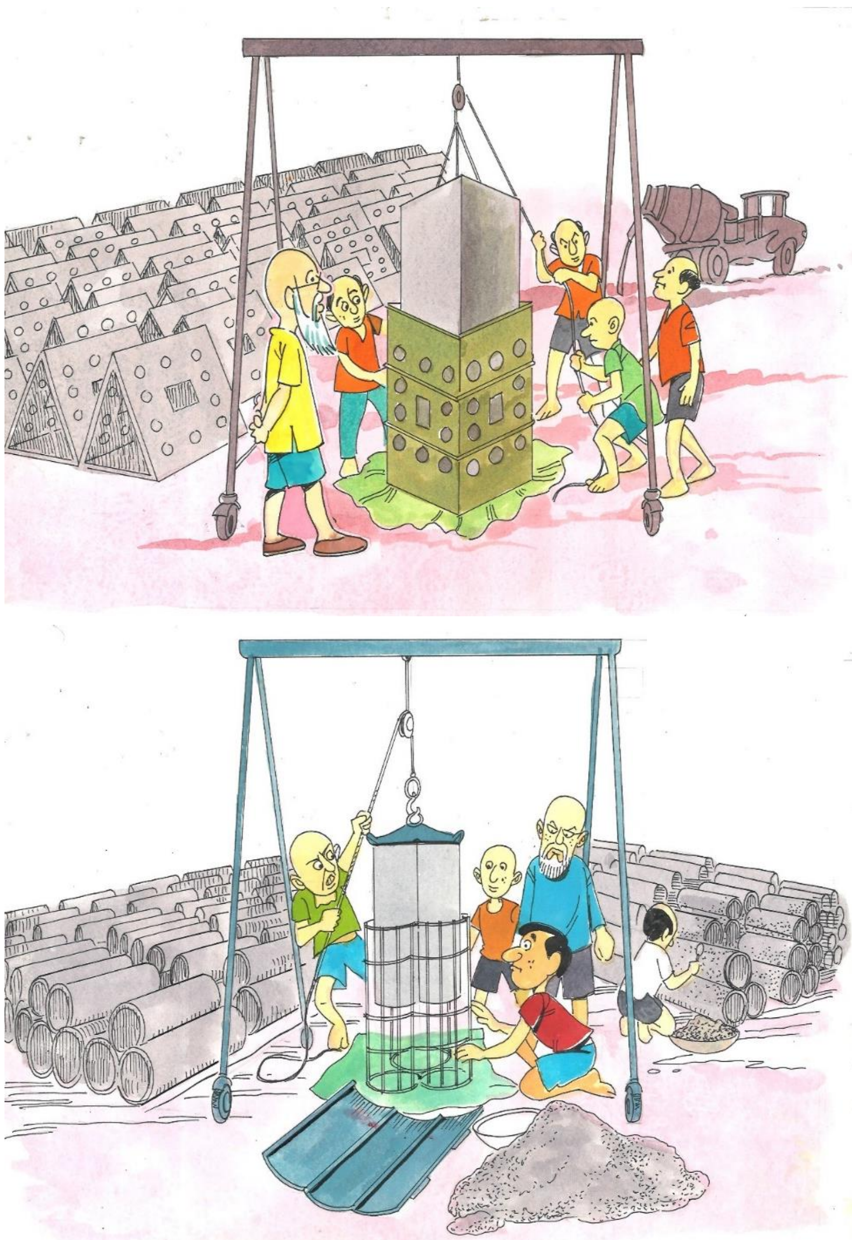

Fig.14. Fabrication of AR Modules

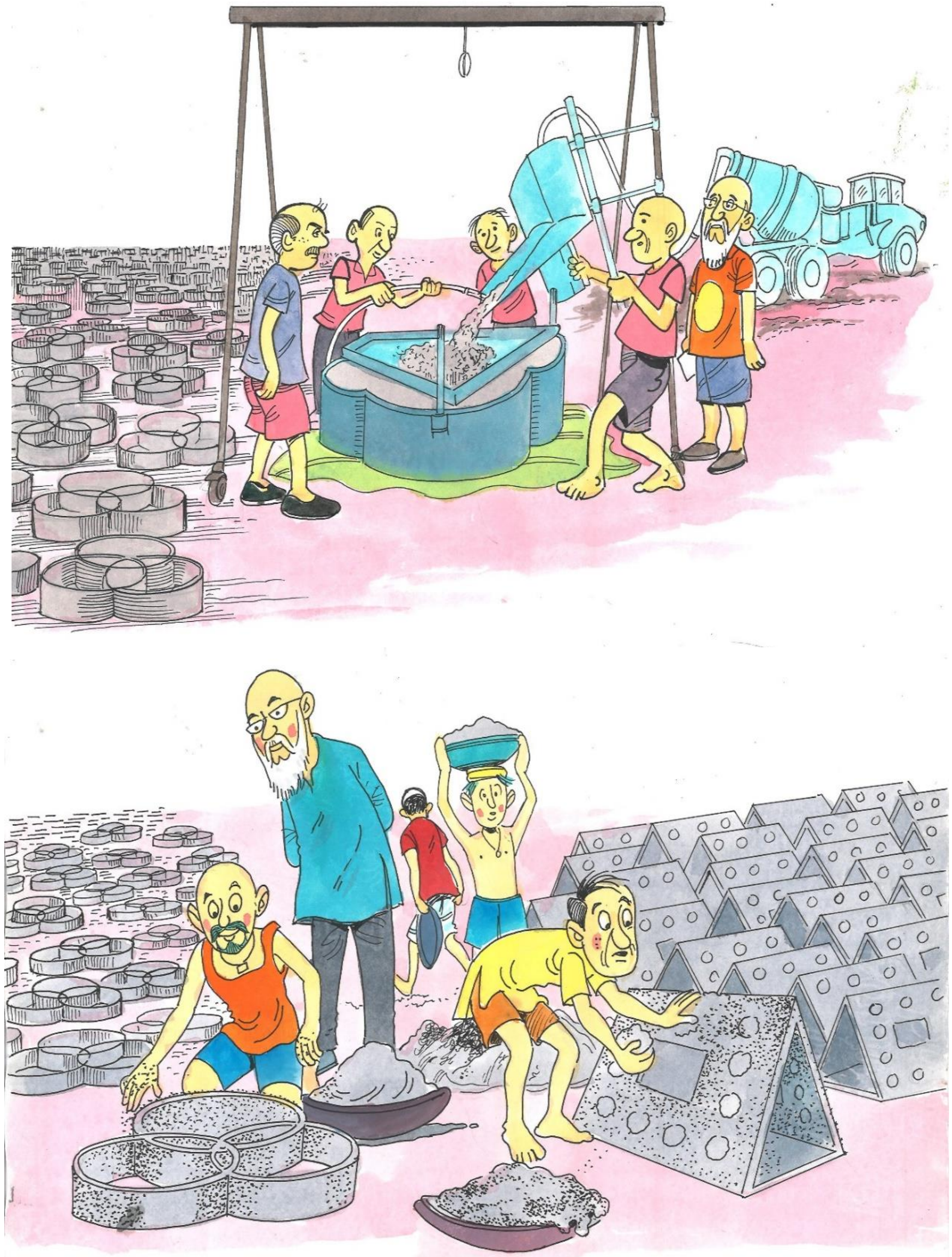

Fig.15. Fabrication of AR Modules

Table 3. The evolution of artificial reef modules developed by ICAR-CMFRI, with their dimensions and constitution

S. no.	Name of the model	Sizes LxBxH	Thickness	Stucco/ Rod	Additional remarks	Fishery resource	Weights	Functions
1	GEN. I REEF - PYRAMID FISH MODULE	1.2 m x 1.2 m x 3 slabs	63.5 mm	Concrete 1:1:2, 6 mm MS	Rough cast plastering 5 mm baby jelly	Snappers, perches,	250-350 kg	Shelter and attract forage fishes, house benthic forms, production units
2	G. I GROUPER FISH MODULE	Encased inside slabs on all sides, 280 mm ID 410 mm OD dia x 1000 mm length	63.5 mm	Concrete 1:1:2, 6 mm MS	Rough cast plastering 5 mm baby jelly	Groupers, eel, perches	400 kg	Home for big predators and keeps the mobility of fish in ease and develop corridors
3	G. I (WRM)WELL RING - FLOWER MODULES	0.76 mm dia rings (3), 0.450 mm depth, 65 mm thick	63.5 mm	Concrete 1:1:2, 6 mm MS	Rough cast plastering 5 mm baby jelly	Crustaceans, gobiids, wrasses, cardinals	350-450 kg	Stoppers in the sediment, secure platform and chambers, crustacean recruit houses, production units
4	GEN. II REEF - PYRAMID FISH MODULE	1.2 m x 1.2 m x 3 slabs	63.5 mm	Concrete 1:1:2, 6 mm MS	HDPE ROPE 18 mm	Snappers, perches, damsels, zanclids, Lions fishes, Wrasses, rabbits, surgeons, corals	500-550 kg	Shelter and attract forage fishes, house benthic forms, production units
5	G. II GROUPER FISH MODULE	300 mm ID 430 mm OD dia x 1000 mm length	63.5 mm	Concrete 1:1:2, 6 mm MS	HDPE ROPE 18 mm	Groupers, snappers, sea bass, damsels, eels, sweet lips, grunters,	650-750 kg	Home for big predators, and keeps the mobility of fish in ease and develop corridors
6	G. II (WRM) WELL RING-FLOWER MODULE	0.76 mm dia rings (3), 0.450 mm depth	63.5mm	Concrete 1:1:2, 6 mm MS	HDPE ROPE 18 mm	Cardinals, crustaceans, lobsters, sea lilies, corals,	550-650 kg	Stoppers in the sediment, secure platform and chambers, crustacean recruit

								houses, production units
7	GEN. III REEF - PYRAMID FISH MODULE	1200x 1200 mm 3 slabs	75 mm	MP 9OPC) 43 GRADE IS 112 BIS-456-200 (440 kg/m^3) 20 mm and 12 mm HGB stone jelly	20 mm COIR ROPE	Snappers, perches, damsels, zanclids, lion fishes, wrasses, rabbits, surgeons, trevallies, breams, corals, groupers, rabbits, squirrels	650-750 kg	Shelter and attract forage fishes, house benthic forms, heavy and hence creates more wake regions, increased substratum
8	G. III GROUPER FISH MODULE	1000 mm L X 300 mm ID (450 mm OD)	75 mm	MP 9OPC) 43 GRADE IS112 BIS-456-200(440KG /M3) 20mm and 12mm HGB stone jelly	20 mm COIR ROPE	Groupers, snappers, sea bass, damsels, eels, sweet lips, grunters	800-900kg	Home for big predators, and keeps the mobility of fish at ease and develop corridors
9	G. III (WRM) WELL RING -FLOWER MODULE	760 mm ID, 890 mm OD, 450 mm depth	75 mm	MP 9OPC) 43 GRADE IS 112 BIS-456-200 (440 kg/m^3) 20 mm and 12 mm HGB stone jelly	20 mm COIR ROPE	Cardinals, crustaceans, lobsters, sea lilies, corals, goat fishes, clowns, wrasses,	650-800 kg	Stoppers in the sediment, secure platform, and chambers, transplanting spaces, crustacean and cardinals, damsel and ornamental recruit houses, production units

Selection of villages, benchmark studies and formation of Reef Sub-committees

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The process of building an artificial reef in a particular site is a long one, involving several, often rigorous exercises and assessments. The steps involved in this process are listed below -

- → Assuring the source of funds
- → Listing the number of probable villages in the project zone
- → Primary stakeholder meetings for initial consensus
- → Benchmark survey and socio-economic evaluation of the community in the hamlet
- → Secondary stakeholder meeting, forming of the AR Sub Committee and arriving at a few probable sites with least fishing conflicts and standard protocols
- → Signing of MoU and collecting letter of acceptance from each selected village
- → Site study, diving, sediment and fauna studies and physical parameters
- → Confirmation of the ideal site and documenting
- → Probable numbers of different modules and density and assemblage affixed as per the site spec.
- → Fabrication, curing and transport to the site
- → Deployment at the site in the presence of the ARSC members and fisher heads and officials of the state Department of Fisheries
- → Collective and simultaneously release of leaf fronds and tree branches by the fishers depending on the fish resources gathering at the site, by attaching them to the modules
- → Handing over the layout, orientation, and GPS coordinates to the committee for further records and upkeep.
- → Setting up a display board with the name and coordinates at a public place in the village for easy access
- → Release of a circular with the GPS coordinates and depth of the artificial reef site to the local fisheries office and adjacent fishing villages

Fig.16. Preliminary enquiries with locals and officials for the listing of potential villages

Fig. 17. Primary stakeholder meeting

Given a coastal district and list of fishing villages and landing centers, the screening for potential villages has to be done with the information collected using a questionnaire for the following details -

- **A.** Name of the village/hamlet /details of the panchayath /FCS/society /Association
- **B. Screening information:**
  - **1.** Number of active fishermen/traditional fishers and hook and line operators;
  - **2.** Important fishing grounds, reefs, coordinates, and resources;
  - **3.** Important fishing gears and crafts;
  - **4.** Access to nearest markets and cities;
  - **5.** Adjacent natural reef areas or AR sites;
  - **6.** Adjacent villages active in traditional and hook and line fishing;
  - **7.** Rocky or limestone substratum areas as bottom;

8. Nearest access to industries and outfalls/discharges/extensions/jetties /remnants/rigs/platforms;
9. Distances from or to the salt pans/marshes/river mouths/ETP discharges /desalination plant outlets /thermal plant outlets;
10. Does the proposed area fall under the MPA/seagrass beds/seaweed beds/coral reef areas /sanctuary/no-take zones/prohibited zones etc.;
11. Average tidal amplitude/current speeds/and turbidity and the possibility of sediment transport if any;
12. Does the proposed area fall in the way of harbors and ports or admiralty/important navigation of ships, vessels, tugs and defence vessels;
13. The extent of fisher intent, interest, consensus, and minimal conflicts within and in neighbourhoods.

After listing down the probable villages a physical visit and verification of facts pertaining to the fishing practices, intensity, fishing ground and resource specifics, is very essential. This is done through a Primary Stakeholders Meet (PSM). If the concept is agreeable to a select group and fishers are keen to know further about the proposal, and all other factors and criteria converge to the possibility of reef installation, a second visit is to be arranged with a larger assembly, with prior notice to all the active fishers, leaders and youth along with the State Fisheries Department officials and representatives of SHGs, NGOs, and service wings/Cooperatives/Federations/Societies. At The Secondary Stakeholders Meeting (SSM), the detailed proposal is discussed with all scientific inputs, displays and video/ppt presentations. With the approval of the Panchayat and leaders, an **Artificial Reef Sub Committee (ARSC)** is formed by inviting nominations from the active fishers and youth recommended by the leaders (minimum of five and maximum of ten members) with the full approval of the audience and the officials. Their contact details and xerox copies of Aadhar cards are gathered and an agreement is exchanged between the village heads and the implementing Agency wherein these details are shared.

A few no-conflict/tentative proposed sites (directions and coordinates-with depth) suggested by the leaders and the ARSC members are noted down and a tentative date is fixed for physical site verification, and the members and boats assigned are also ascertained.

The next activity is the conduct of the primary socio-economic and benchmark evaluation studies and preparation of a status report on the livelihoods, profession, income levels and fishery resource sharing and potentials. A prescribed format of enquiry is used in the vernacular language engaging enumerators and the data is to be gathered within a set time frame. (Form annexure -1)

Fig.18. Secondary stakeholder meeting

Fig.19. Noting down the details of ARSC members

Fig.20. Socio-economic survey

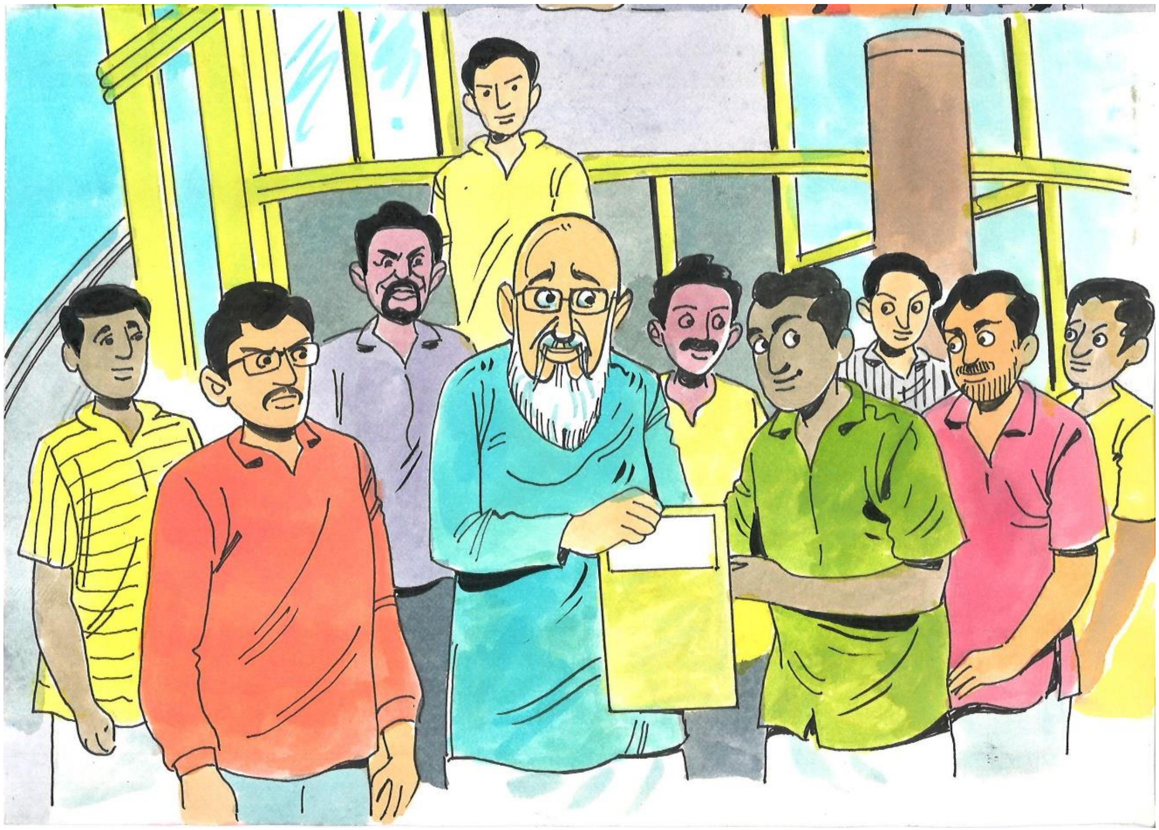

Fig.21. Signing of MOU & Agreement

Points to be discussed with the fishers:

1. Resource constraints and reality
2. The intensity and increased efforts into fishing
3. Declining diversity, economic outputs, shares and scope for expansion
4. Coastal resources in scant and so does livelihoods
5. Increasing water temperatures and other interventions
6. The increasing cost of living and deprivation of basic needs
7. Options: Improve the resilience of coastal communities by improving economic returns through sustainable fishing practices.
8. Revive fish habitats and resource multiplication.
9. Renew fish diversity /biomass and local production
10. Introduction and management of Artificial reefs as a means to revive, restore and conserve and reserve sufficient stock balances for breeding and recruitment.
11. Increasing shelters and substrates for the ecosystem engineers and invertebrates to colonize and create more productive habitats.

12. Reintroduction of hook and line fishing and reducing cost inputs /dependence on fossil fuels /and manpower and reducing efforts in scouting time and energy.
13. Moving towards green technologies and sustainable fishing practices catching only required species and sizes.
14. Creating an ownership attitude and inclination towards seeding and farming, thus brightens the prospects of sea ranching and restocking.
15. Being a partner in creating and stabilizing fish diversity and wealth, towards sustainability.
16. Being a partner in the conservation of vulnerable /threatened species.
17. Indirectly dissuading the large mechanized vessels operating floor scraping gears and dredges, bottom set trap nets and trammels. Being partners in making fishing more lucrative, interesting and economical.

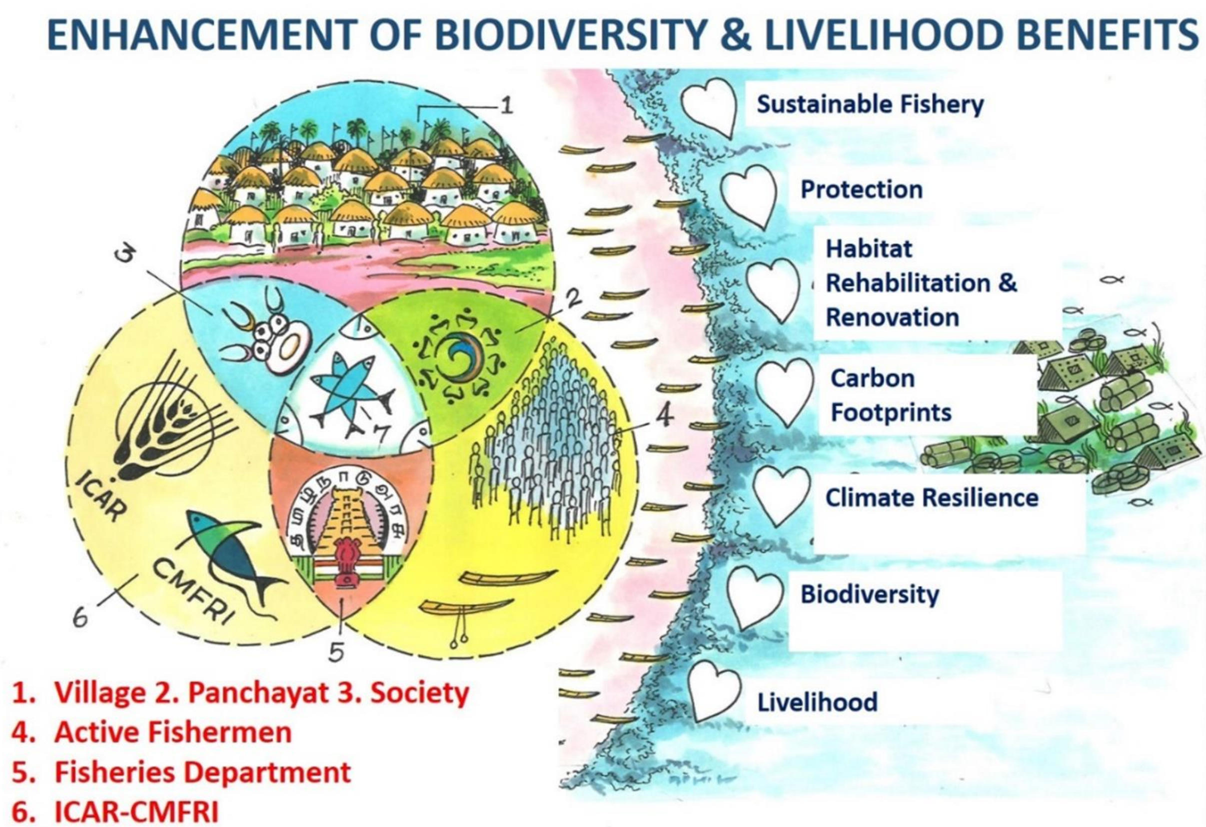

Fig.22. Artificial Reef Sub-Committee Organization & management objectives

Site selection criteria, sample collection and analysis

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The selection of suitable sites for the deployment of artificial reefs is a very important phase in the success of the reef functioning and efficiency. Following the primary and secondary stakeholders' meetings, on the proposed dates of field sampling, the team of experts with the SCUBA team, ARSC members and active fishers with GPS sail on the pre-identified country boats or vessels, carrying all the sampling gears and anchors. They sail towards locations suggested by the fishermen, at distances of 2-5 km from the shore with a water depth of 7-25 m. The tidal parameters, amplitude, wave heights, wind speeds and local weather details are noted before sailing. A Global Positioning System (GPS) and sonar can be used along with scuba gear to locate the reef sites. The coordinates of the sampling sites are duly recorded separately by the fisher ARSC team members and the sampling team and corroborated to fix the sampling site.

The sites for artificial reefs should be installed in coastal waters adjacent to fishing villages where non-destructive gears suitable for fishing in reefs, like hooks and lines are available and regularly used. It is necessary to ensure that the fisher stakeholders are involved in the sampling and site-fixing process. The sampling locations must be located at a suitable distance from outfalls, barmouths, river discharge points, mangroves, mud flats, mud banks, coral reefs, seagrass and seaweed beds, industrial installations, and industry/urban effluent discharge points. Sites proximal to thermal, saline, and chemical effluent discharge points are to be strictly avoided. No-take zones such as MPAs/Sanctuary/National parks/NHS are to be avoided unless specified for the conservation program. Locations with hard and sandy sediments are preferred while locations with soft sediments and turbid eddies are to be avoided. The site should fall within MFRA limits of the respective state allotted for the traditional sector and should not be in violation of the Coastal Admiralty or CZM rules, and should not be a priority area for fishing by other fishers or gears; it should be located within the geographical grid and limits of the village and not conflict with adjacent fishing zones of other villages. Any natural conflicts/reasons that may interfere with selecting the site for artificial deployment must be addressed prior to sampling and site fixing. A local fishery- and ground-based resource availability is ascertained through questionnaire surveys for benchmark analysis.
The notable parameters of utmost relevance to the performance of the AR are -

A. Depth and distance from the shoreline
B. Turbidity/visibility/productivity
C. Sea bed texture and nature/sediment characteristics

D. Current speeds and upwelling
E. Vicinity to barmouths/discharges /installations
F. Proximity to natural reefs and habitats/mud flats /mangroves
G. Proximity to AR and fish corridors

A. Depth: The water depth is measured using scuba diving computer and/or using the boat's depth finder; alternatively, a deadweight lead sinker tied to a marked rope can also be lowered for depth soundings. The preferred zone for the performance of production-based reefs is beyond the frequent surf zone and between **7-25** m depth range, while the perfect one would be in a **10-20** m zone, as this leaves enough space for the light penetration, causing less obstruction to drift gillnets, and is sufficiently away from the frequent surf beaten zone, depending on the sea bed slopes. The distance of the site could be anywhere within the MFRA approved limits of each coastal state, allowing for the traditional fishers while keeping in mind that the visibility and activity within sight range from the shore should make it more convenient for management and safety; hence ideally, the site should be at a distance of 2-5 km from the shoreline. The distance may vary depending on the depth profile of the sea in the village. For deployment in shallow sites, sufficient surface clearance is to be left for vessels and boats to navigate without obstruction.

Table 4. The fishing limits of traditional fishermen in coastal states of India (distance from LLT /depth)

State	Artisanal	Mechanized	AR deployment zone
Maharashtra	10-20 m depth	>20 m depth	within 20 m depth
Goa	<5 km	>5 km	<5 km
Orissa	<5 km	>5 km	>5 km
Karnataka	<6 km	OAL<15 m	>6 km
		OAL>15m	>20 km
Kerala	<10 km	GRT<25	>10 km
		GRT>25	>23 km
TN	<5 km	>5 km	>5 km
AP	<10 km	OAL <20 m	>10 km
		OAL >20 m	>23 km

B. Turbidity/visibility/productivity: The 8" Secchi disc readings should be sufficiently more than 1.5 meters and the observed turbidity should not be related to silt or clay suspension indicating heavy current speeds or bottom swells. However, reduced light penetration due to increased plankton production or reduced sunlight should be negotiable based on the local enquiry on the general trend in that zone.

C. **Sea bed texture and nature/sediment characteristics**: The composition of the ocean bottom is an important factor that could affect the length of time a reef will remain productive. If the material sinks into the sediments or is covered by them, the reef loses its effectiveness. Information about the bottom type and depth can be obtained with bottom sampling equipment like grabs, direct diver inspection, depth recorder, sounding lead, information from national ocean survey charts, state fisheries departments, game agencies, local colleges and universities with marine science programs, commercial fishermen, or oil company geologists. Natural reefs and rock patches should be completely avoided as they are natural ecosystems which support a unique ecosystem. Muddy bottoms experience shifting of sediments, hence sinking of structures and increased sediment deposit over the surfaces cause choking of invertebrate settlers. Plain hard sea bed floors are ideal for module deployments and longer life of AR sites.

D. **Current speeds and upwelling (Dutchman's log):** Another important instrument used can be a float buoy in the size of an orange along with a digital watch to measure current speed. It could be released to measure the distance it travels in a minute. This is done three times at each site to minimize error (0.8 x float velocity). This is an easy way to determine the average surface current at each site. Temperature is measured in two ways, either by an underwater thermometer attached to a sampler or by the dive boat's computerized sensor. All readings, surface to bottom, are taken at the same position and time. A current meter will be more accurate.

E. **Vicinity to barmouths/discharges /installations**: The AR sites should ideally be away from any barmouth or discharge point by at least 3 km on either side and should not be in a zone of influence of increased sedimentation rates or sinking. Any industrial or infrastructural installation also should be avoided due to other legal issues. Navigational and admiralty routes, and shipping and tug channels are to be strictly avoided.

F. **Proximity to natural reefs and habitats/mud flats /mangroves**: The experience so far in our waters shows that if the site is at a distance of 500 m from any natural reef or rock patch, the performance is very good and fish corridors are instantly built. However, if they are adjacent to mud flats and mangroves the logic of keeping a 3 km distance on either side is safer, to avoid soft sediment settlements and increased turbidity. Using underwater videotapes and photographs of the sea bed, the fouling coverage and diversity are estimated in the lab, using a monitor.

G. **Proximity to AR and fish corridors**: Keep a distance of 500 m and develop a subsequent unit, as resident and settling communities spread well and extend to a 300 m plus boundary. The extended satellite corridors help in increasing mobility, forage and shelter and escapement routes.

Table 5. Optimal parameters for selection of suitable sites for artificial reefs.

No.	Parameter	Range	Optimal	Remark
1	Depth (m)	7-25m	10-20m	Depending on the site and availability
2	Transparency (m)	1-5m	>1.5m	Effluent discharge points and loose sediments could be giving turbidity.
3	Current velocity	1-10cm/s	2-6cm/s	Bottom currents, particularly at estuary or river flow points, it will exceed
4	Wave heights	0.5-4m	0.5-2m	During monsoon could be the max
5	Soil texture sand: silt + clay	85-99: 15-1%	98: 2	Fine sand and organic sediments to be carefully identified and quantified
6	Proximity to barmouths, discharges outfalls	Away by >3 -5km	Away by >5	Avoid pollution, sedimentation and sinking, plastic debris accumulation
7	MPA/Coral reefs	500-1000 m away	At least 500 m away	Avoids conflicts and violations
8	Proximity to AR /natural reefs	300-500 m distance	500 m from the AR	Helps in creating fish corridors and reduces exits and transit losses
9	Dissolved orthophosphate (PO_4-p)	ideal range: 1-3 micro mols /l	2-3 micro mols /l	Indicates the nutrient wellness of the site for primary production
10.	Reactive silicate (SiO_4-Si)	4-8 micro mols /l	4-6 micro mols /l	Indicates the nutrient wellness of the site for primary production
11	Nitrate (NO_3-N)	1-5 micro	1-3 micro	Indicates the nutrient wellness

		mols /l	mols /l	of the site for primary production
12	Chlorophyll a	Chl a. 1-4mg/m^3	1-3mg/m^3	Indication primary production levels
13	DO	1.5-5 mg /l	2-4mg /l	Anoxia prevails during upwelling

Water and plankton sample collection

A portable GPS set and lead weight (200-500gm) depth sounder with a rope having measured markings are carried on board. The GPS coordinates and reading units of the fisher members are confirmed with the gadgets available with the team. The boat/vessel/canoe is anchored at the site and then the depth sounding is done to confirm the depth and the sediment nature. The SCUBA team then dives with the sampling equipment and containers (the sediment scoop, two wide-mouthed 1000 ml PPE water containers, camera, torch, and high-density polythene sealing type bags of 2 kg capacity). They take photos and videos of the sediment, habitat and fauna and also provide information on the topography and mound formation of the sea bed and slope. They collect bottom water and sediment samples.

Once the diving team comes back on board, the surface water and plankton sampling are done. Both the surface and bottom samples are to be collected to verify the site-specific parameters. Water samples collected for nutrient and chemical parameters are stored in PE containers and refrigerated till further analysis. Dissolved oxygen (DO) is sampled in BOD glass bottles (Winkler method) and fixed using the Winkler's solution on-site and analyzed in the lab. A portable field thermometer is used for temperature, a salinometer for salinity and a pH meter for pH. The sediments collected for benthos and meiobenthos are preserved in 10% formalin mixed with Rose Bengal stain.

Sample analysis

Zooplankton: A zooplankton net of 50 cm diameter x 3 m length with 40 µ mesh in the main area of the net and with 150 µ at the collars, and with a collection cup secured to a 500 g lead weight is lowered at the site. Three samples are collected from each site by a still net at natural flow in the current direction at the bottom, for an hour, followed by horizontal tow in the mid-water column and surface by driving the boat for 10 minutes each, noting the flowmeter readings**.** The bottom anchored collection gives a good account of the fish eggs, larvae, and fry at the sea bottom. Samples are filtered and preserved in 10% formalin with Rose Bengal stain in a 250 ml PP bottle. The net volume is calculated by the volume displacement method and sub-samples made through a Folsom splitter are used for quantitative and qualitative analysis under a microscope. Larger plankters would be counted and for the rest, a subsample taken on the Sedgwick Rafter cell would be observed under a microscope for identification and count. The total number would then be estimated. Species diversity indices, Margalef's Species richness (d) Pielou's Evenness (J'), Shannon Weiner Diversity (H') and Simpsons Dominance Index can be calculated using the PRIMER-E software. The total numbers are represented as numbers /10 m^3.

Phytoplankton: Bottom and surface samples are collected using a phytoplankton sampler which has 5 µ mesh size net and 30 cm diameter. Horizontal tow for 10 minutes with flow meter readings is done for the collection. The samples are preserved in 5% formalin with 0.1% Lugol's Iodine. The subsamples are observed under a microscope and the counts are taken later using a haemocytometer counting chamber. The total number would then be estimated. Species diversity indices, Margalef's Species richness (d) Pielou's Evenness (J'), Shannon Weiner Diversity (H') and Simpsons Dominance Index can be calculated using the PRIMER-E software.

Dissolved nutrients:

1. **Dissolved orthophosphate (PO_4-p)** is determined quantitatively by the spectrophotometric method (885 nm) using the Ascorbic acid method (Murphy and Riley, 1962). Merck Spectroquant method with instant reagent kits is more convenient and accurate (ideal range: 1-3 micro mols /l).
2. **Reactive silicate (SiO_4-Si)** is determined in seawater in the dissolved form mainly as orthosilicic acid $Si(OH)_4$ estimated by the Ascorbic acid method using a spectrophotometer at 810 nm as given by Mullin and Riley (1955) and modified by Strickland and Parson (1968). Merck Spectroquant method with instant reagent kits is more convenient and accurate (ideal range: 4-8 micro mols /l).
3. **Nitrate (NO_3-N)** is estimated following the method described by Morris and Riley (1963) and modified by Grasshoff and Wood *et al*. (1967) using a spectrophotometer. Merck Spectroquant method with instant reagent kits is more convenient and accurate (ideal range: 1-3 micro mols /l).
4. **Chlorophyll a**, **b, and c** are estimated from at least 1000 ml water samples filtered first through a 0.2 mm filter to remove all the particles, and then filtered through a 47 mm Whatman No 1 GF/C filter paper. The pigments are extracted from the paper by adding 90% v/v acetone 10 ml in a tube. The resultant pigments are calculated from UV spectrophotometer readings at 750, 664, 647 and 630 nm by applying the formula given by Gaarder and Gran (1927) (ideal range: Chl a. 1-3mg/m^3).
5. **Primary Productivity**: is estimated by light and dark bottle method. The changes in dissolved oxygen levels in the bottles after a suitable time are expressed in g C/unit vol/h (Winkler method).

6. **Total Suspended Solids (TSS)** are calculated by filtering a known volume (500-100 ml) of the sample using a vacuum pump with 47 mm GF/C paper and drying the residue; the dry weight gives an estimate of the TSS.
7. **Total Dissolved Solids (TDS)** are estimated by evaporating a known volume of the filtrate obtained during TDS extraction, in a crucible kept in an oven; the resulting residue gives an estimate of the total dissolved organic and inorganic matter in the sample.

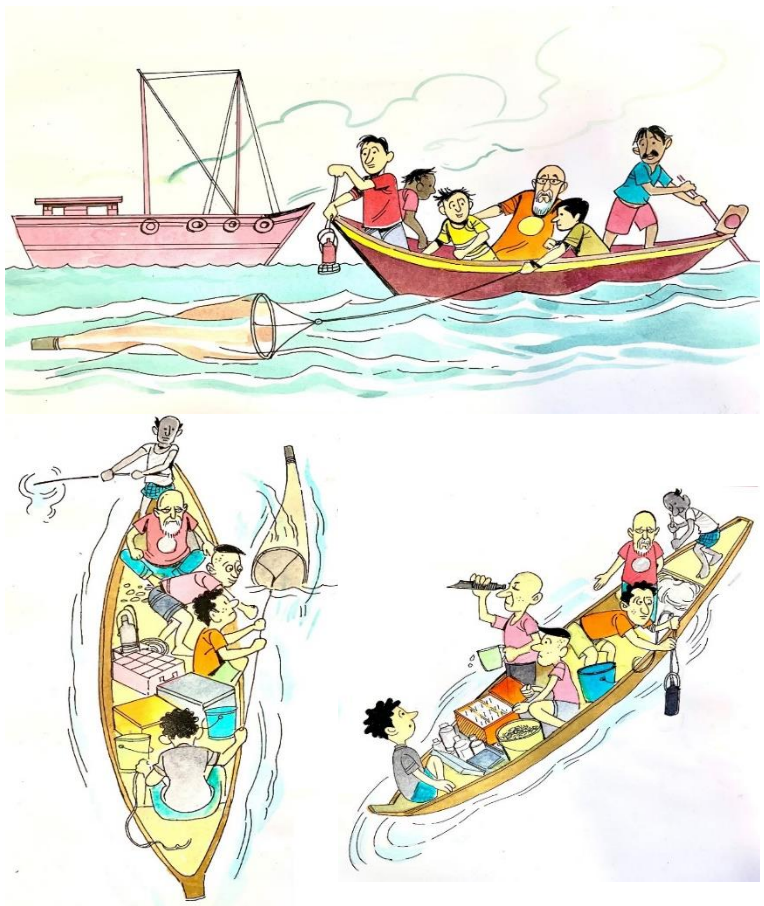
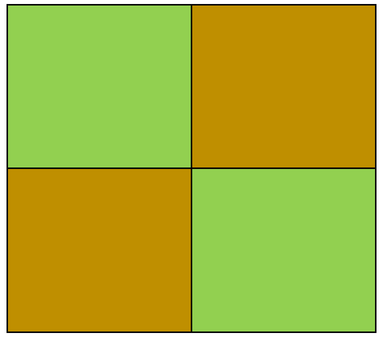


Fig.23. Illustration of water and sediment sampling for site selection

Sediment studies, benthos, and sampling procedures

The samples are to be collected at least from two random sites for the sediment textural classification and the benthos and meiobenthic status observations. The samples can be obtained using a Van-veen grab or any similar equipment or collected through scuba divers. A quadrant of 20 x 20 cm is usually taken for the divers' collection methodology and the top 2" layer of soil is collected into a high-density sealing type polyethene bags (2 Kg).



A 100 m x 100 m area is marked where the site is identified and fixed the sediment samples are to be taken and the samples for the textural analysis are to be mixed between two diagonally opposite station samples (brown)and then prepared for drying and sieving, while the samples for benthos and meiobenthos are treated separately with formalin and sieved and samples collected and then the average numerical abundance is computed (green).

The samples are taken back to the lab, dried and then passed through a series of five nested sieves. From this, the relative amounts of different particle sizes are determined by weight. The particle types and percentages are then determined and labelled according to the Wentworth classification. The collected bottom samples are dried and sieved through a series of five nested test sieves to separate the different grain sizes and each size class is weighed.

Table 6. Soil classification based on grain size.

Particle Size Class	Grain Size (mm)
Gravel	> 2.0
Very coarse sand	> 1.0 < 2.0
Coarse sand	> 0.5 < 1.0
Medium sand	> 0.25 < 0.5
Fine sand	> 0.125 < 0.25
Very fine sand	> 0.0625 < 0.125
Silt/clay	< 0.0625

The composition of the ocean bottom is an important factor that could affect the length of time a reef will remain productive. If the material sinks into the sediments or is covered by them, the reef loses its effectiveness. Information about the bottom type and depth can be obtained with bottom sampling equipment grabs or direct diver inspection, depth recorder, or sounding lead, information from National Ocean Survey charts, State fisheries dept, local colleges and universities with marine science programs, commercial fishermen, or oil company geologists.

Natural reef and rock patches should be completely avoided as they are natural systems which support a unique ecosystem.

Collecting representative samples in a marine area requires prior knowledge about the sea bed. Initially, some guidance can be obtained from bathymetric maps, knowledge of tidal currents, and information about the likely exposure to high-energy current forces such as waves from major storms. In areas with heavy use of bottom trawls for fishing. A great deal of information about bottom morphology and regional patterns of sediment texture can be obtained by using bottom imaging techniques such as side scan sonar also.

The wet samples collected are immediately preserved in a 10% aqueous solution of borax-buffered formalin mixed with Rose Bengal stain and brought to the lab and in a week's time sorted for the microbenthic fauna and later for the meiobenthos. They will remain in this solution for a minimum of 24 hours and a maximum of 7 days to allow proper fixation of the animal tissue while minimizing the loss of calcium carbonate structures (e.g., molluscan shells, echinoderm spicules). All sample-processing activities (including rescreening and sorting)

Sample Sorting: Sorting is the process of removing all faunal material from the sediment sample. All whole macroinfaunal invertebrates and fragments of organisms that were alive at the time of preservation are to be removed from the sample and sorted into the following taxonomic groups: Annelida, Arthropoda, Mollusca, Echinodermata, and miscellaneous phyla (counted separately).

Meiofaunal organisms such as nematodes and foraminifera will not be removed from the sample. Colonial organisms such as hydrozoans, sponges, and bryozoans will be removed completely from the sample. This includes all colony fragments and all parts of colonies attached to hard surfaces such as worm tubes, shells, or rocks (the substrate may be included in the vial with the organisms). Organisms will be stored in vials or jars containing 70% ethanol.

The sorting process is accomplished as follows: Identification and enumeration of sorted organisms will be performed to the lowest taxonomic level possible, usually to species-level. The identifications will be done by in-house taxonomists, using minimum 10X magnification dissecting light microscopes and compound light microscopes equipped with 10X, 20X, 40X, 63X, and 100X magnification objective lenses. Organisms should be sorted into the major phyla: Annelida, Arthropoda, Mollusca, Echinodermata, and miscellaneous phyla. All organisms will be sorted into vials containing 70% ethanol and tightly sealed with polyseal caps. The total number would then be estimated. Species diversity indices, Margalef's Species richness (d) Pielou's

Evenness (J'), Shannon Weiner Diversity (H') and Simpsons Dominance Index can be calculated using the PRIMER Vers(5).The total numbers are represented as numbers /M3

Analysis of sediment texture at artificial reef sites before and after deployment indicated varying patterns at each site with a tendency for an increase in coarser sediments at the sites, after deployment of artificial reefs indicating more sediment porosity, molluscan and crustacean fauna and hence more shell grits and carbon and calcium deposits. The macrobenthos in the sediment increases by 10-fold in numbers over the sediment from a non-reef area. Annual patterns in phytoplankton, zooplankton and benthos composition indicated higher species diversity and density in artificial reef sites, compared to adjacent non-reef sites. The diversity indices observations indicate higher values for richness in the reef sites amongst the phytoplankton, Zooplankton, meiobenthos and macrobenthos and fish fauna (Species Richness, Pielou's Species Evenness and Shannon-Weiner Diversity Index). The rich nutrient profile gives rise to developing diatoms and microalgal populations and in turn supports the recruiting larval forms of shrimps, oysters, mussels, clams, crabs, fish larvae and echinoderm larvae and the filter-feeding organisms. The composition at all reef sites remained fluctuating between similar groups indicating uniform performance in terms of the reef output in Tamil Nadu (Kizhakudan, 2019).

Fig. 24. Benthos

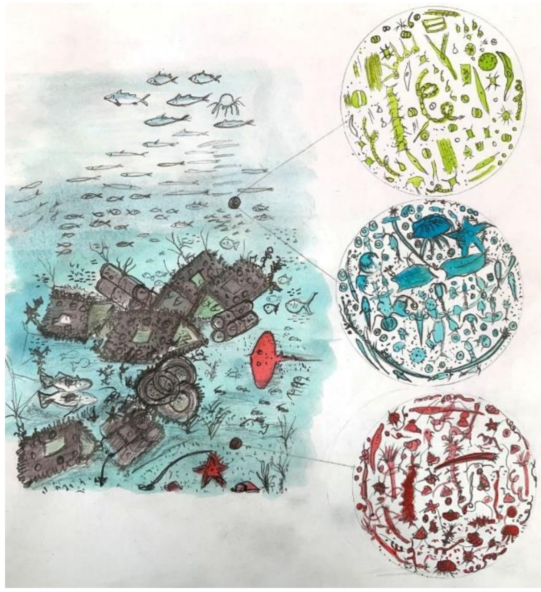


Fig: 25. An artist's impression on the productivity channels -sediment benthos, zooplankters and the periphyton and plankton from the artificial reef habitat.

Fig. 26. Processing of sediment sample and microscopic analysis of benthos in a sediment sample

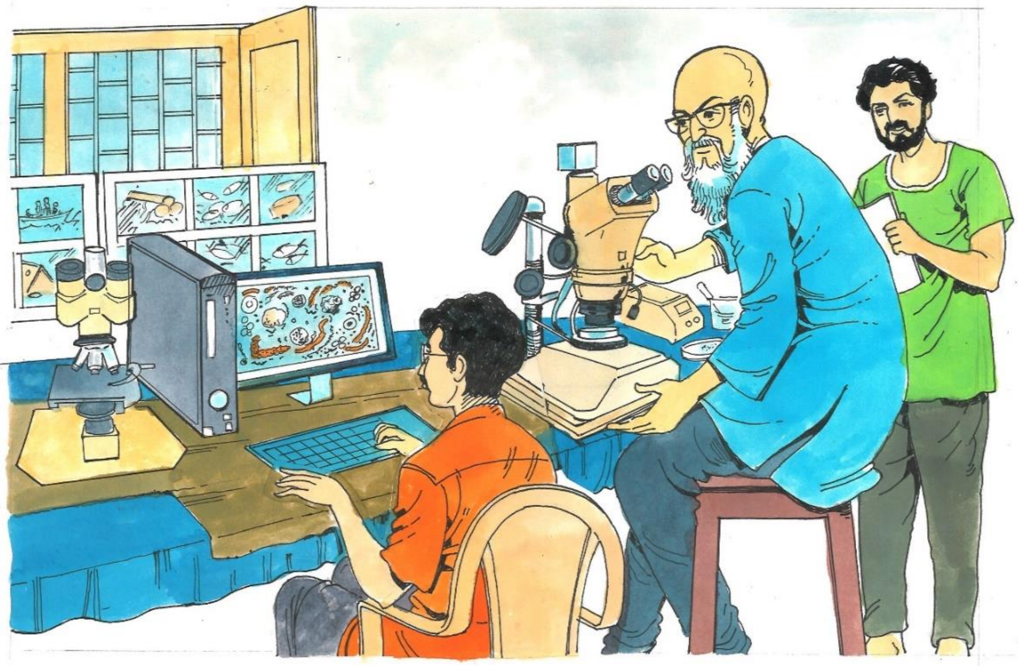


Fig. 27. Microscopic view of benthos in a sediment sample

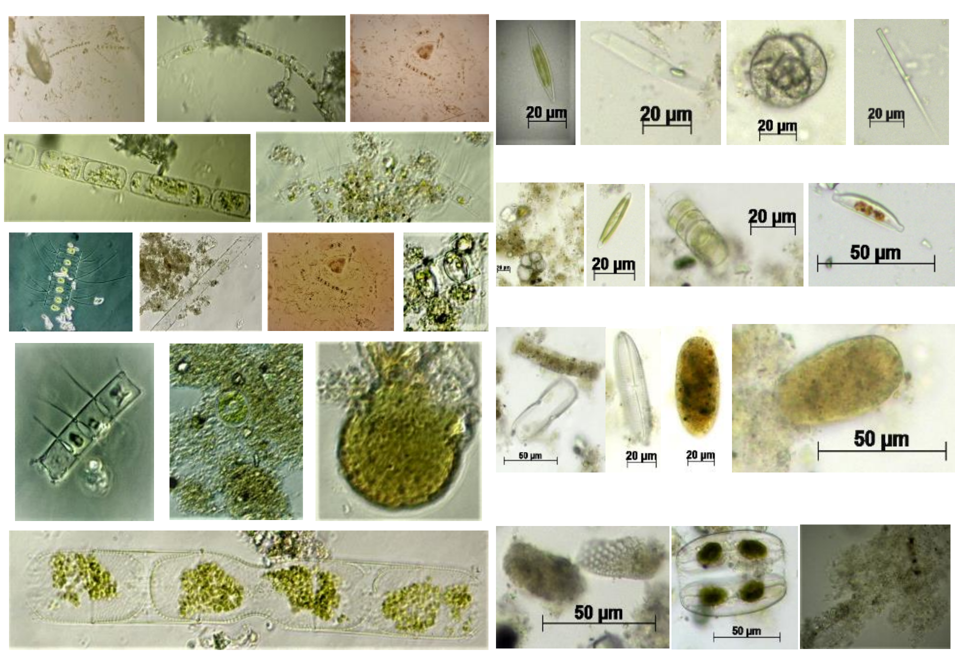


Fig. 28. Microscopic view of the periphytons and immediate phytoplankters around the reef modules after incubation

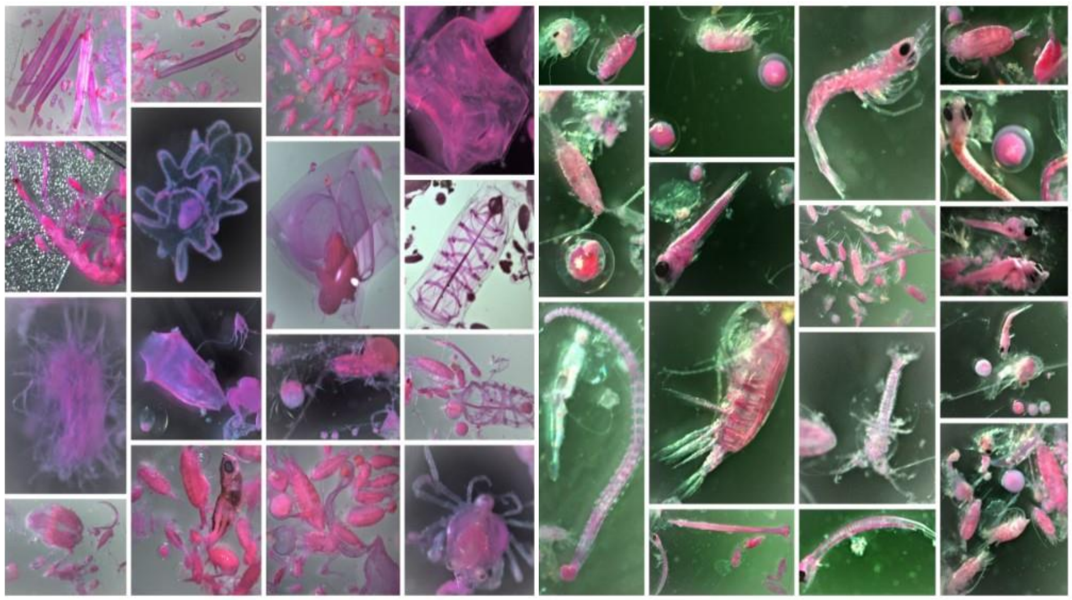


Fig. 29. Zooplankters surrounding the reef waters in the benthic realm.

Fig.30. Benthic engineers and recyclers of the reef sediment habitats.

Fig. 31. Microbenthic forms which add on to the coarser sediment and shelled forms

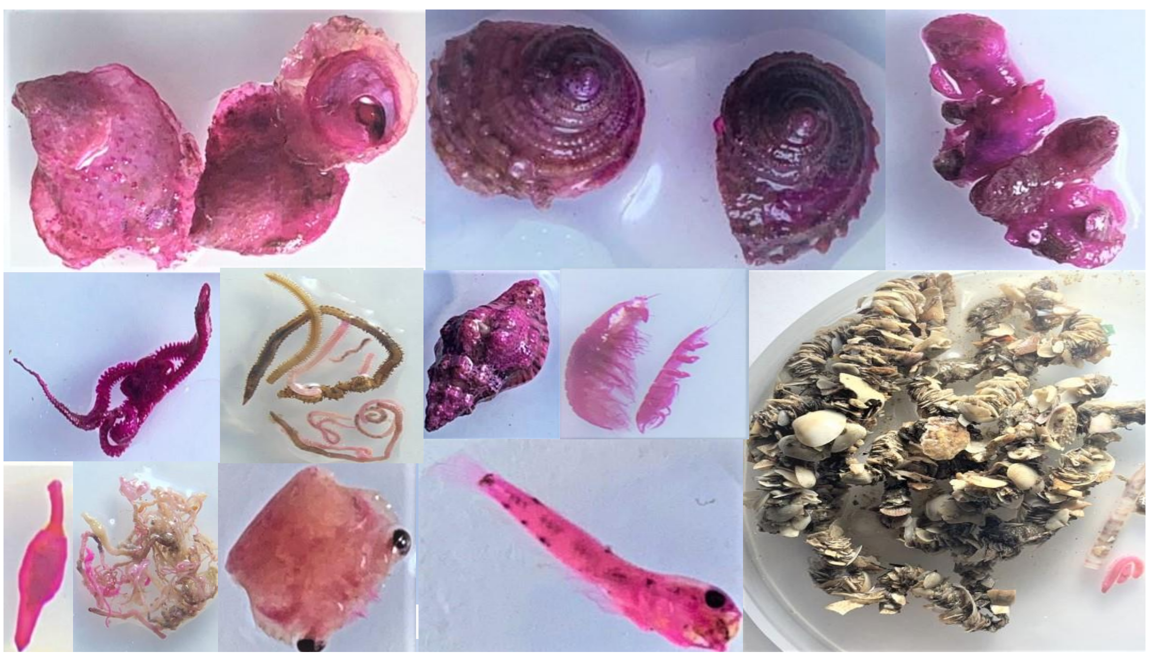


Fig. 32. Macrobenthic forms which are large-level converters

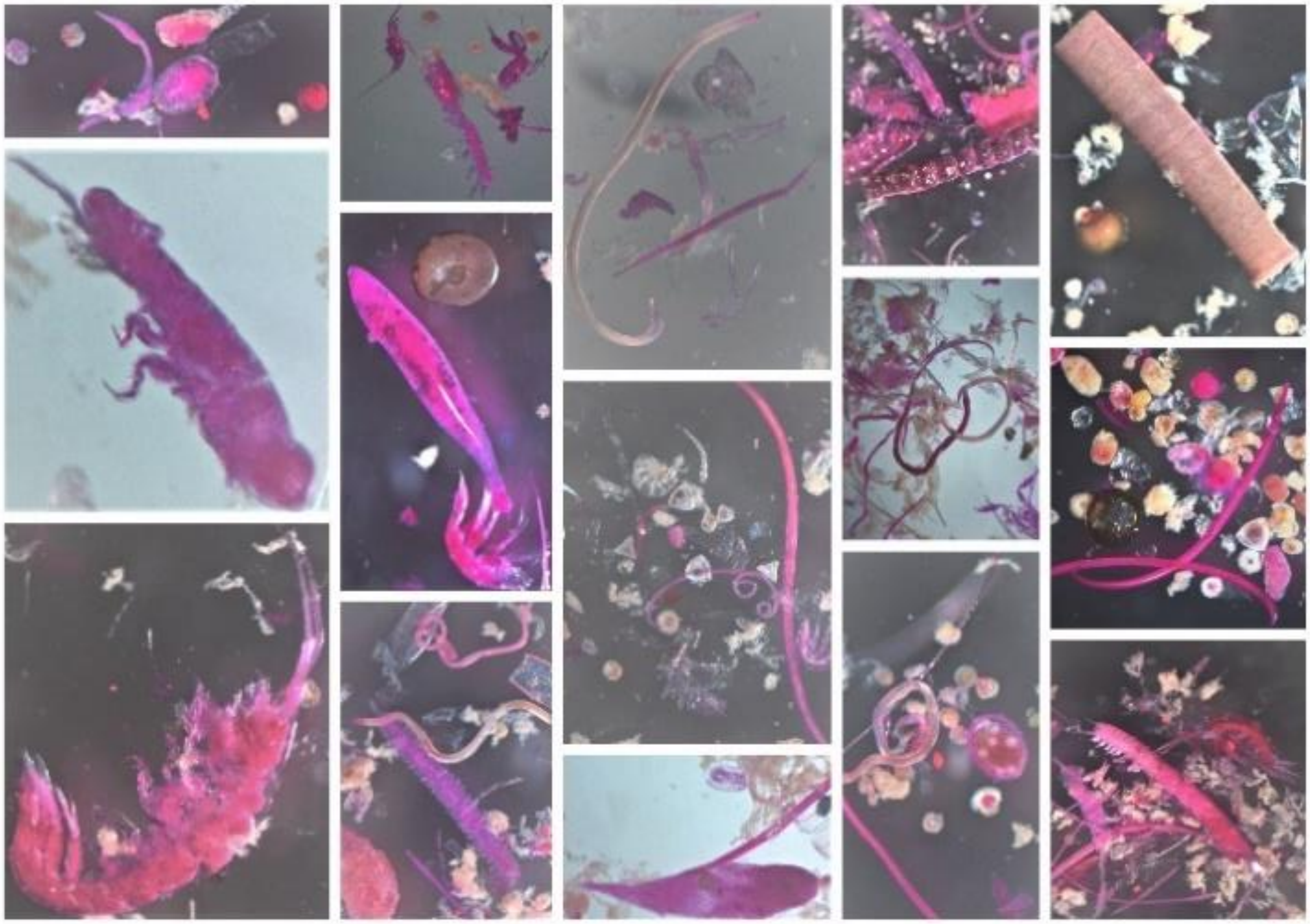


Fig. 33. Meiobenthos of the sediments around reefs - microlevel engineers of recycling

Deployment, orientation, capacity, and layout

Joe K Kizhakudan and Venkatesh P.

The critical activity resulting in the desired functioning of the ARs is the deployment of modules at the exact location, as derived after the studies, and setting them in a specified design and layout in the appropriate proportions of the species-specific and geography-specific numbers and modules.

As mentioned earlier, the proposed function of the AR is the target set. Accordingly, the grounds are to be chosen first, followed by the designs, modules, and the layout. The important factor again with regard to the fisheries and production-oriented reefs is the capacity of boats each reef area can facilitate for smooth/unhindered fishing at the same time of operation. Therefore, uniform design and the number of modules for all the villages will not reward well in terms of fishing, and management ease and levels of exploitation will vary. For eg., distributing 250 modules at each site with equal proportions of standard designs and modules will create identical area and spatial systems with variations in geography and local resources and the intensity of fishing and gears. It is always advisable to have a variable model approach to each situation where there is a need for recruitment promotion/forage fishing /predator fishing/proximal to nursery grounds/declining specific resources/number of active fishers and boats, etc.

Pre-deployment measures

The pre-requisites of a good reef deployment and service is to get them assembled in the proposed area in the required layout and ratio and geo-referenced in a quicker time. Larger barges and cargo vessels /Fatehmari /cargo ships could be used for the same with an inbuilt crane, facility for loading and unloading and skilled crew who can handle these activities with sufficient knowledge of the positioning and functions of the AR.

Fig. 3. Deployment of reef modules using cargo ships

Fig. 35. Flagging off and deploying the reef modules at the fixed coordinates

Fig. 36. Deploying the reef modules at the fixed coordinates in different locations

With a scaling up in the number of reef modules per site and an increase in the density and sizes of the modules (120 kg to 900 kg per unit) the gross tonnage increased from handling 80 tonnes to 250 tonnes. Therefore, the ideal choices were to engage professional cargo handling vessels, particularly the wooden Cuddalore/Thoothukudi/Mangalore type of vessel which can hold and safely transport up to 400 tonnes of solid materials. As these reef modules are more in surface area and volume each trip one such vessel is required to ship for deployment to one site. Barges of these capacities could also be employed as they have a shorter draft and navigation through smaller ports is convenient. However, the stability of barges at deployment sites when the sea is turbulent is a problem.

These vessels (115 feet OAL; 280 HP) need at least a draft clearance at harbours and ports of nearly 10 feet for unhindered sailing out with the full load. Therefore, the selection of ports and harbours for loading is very important. There should not be any disturbance in the loading and berthing of the vessel in the port, from other trading groups and vehicles.

Tentative sailing and berthing dates are to be informed to the port and harbour authorities well in advance and the anticipated load is also to be ascertained from a nearby taring station (weighbridge).

The units assembled at the fabrication site in order of the ratio and proportion decided must be loaded onto a truck according to the serial numbers for easy tally and then they are loaded onto boats. The unloading and loading are done using 10 tonne capacity cranes and the harbour berth/wharf space should be sufficiently wide enough for these operations.

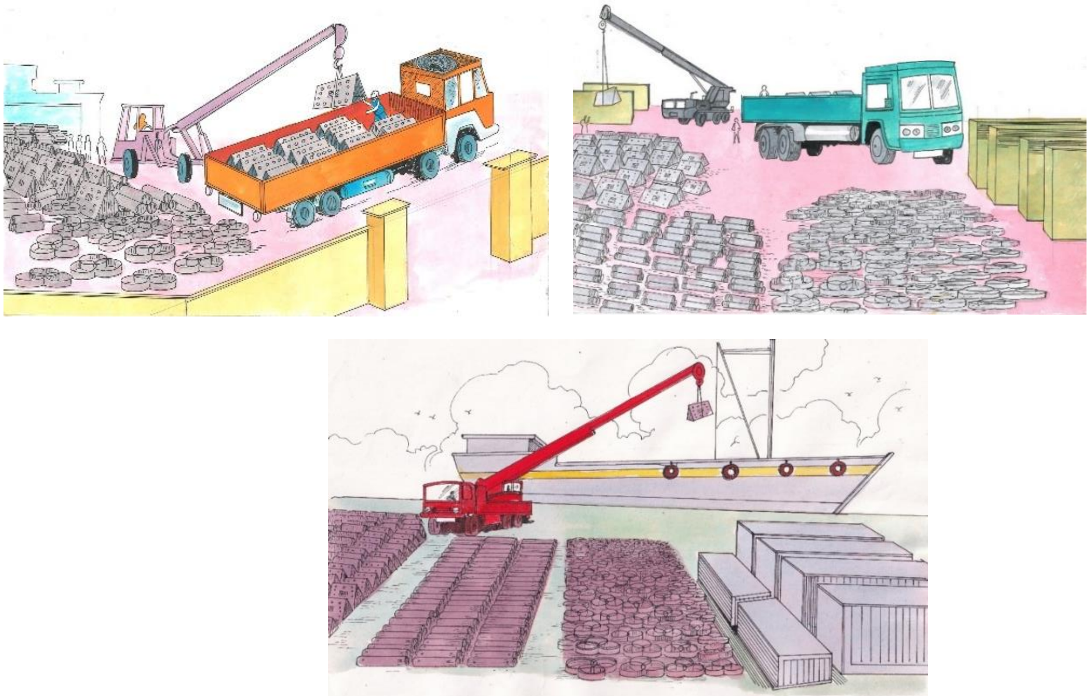


Fig.37. Loading of reef modules in the ship by cranes and JCB

The authorities who are to be informed well in advance for permissions to be sought include -

1. The state Fisheries Department officials /AD/DD
2. The state Marine Police Department
3. The state Harbour Office
4. The Port Authority with details of personnel sailing and load particulars
5. The Indian Navy or Coast guard station nearby with vessel particulars and purpose and material quantity.
6. The adjacent village's fisher society leaders.

Deployment

Deployment using boats

The normal practices followed during the centuries-old practices were loading stones/boulders secured with foliage's from known tree varieties and leaving at established spots of specific fish availabilities or aggregation sites or breeding sites following a seasonal calendar. The traditional canoes or catamarans load these structures (about 7-10 m tall when suspended) and logs would be floated as spotters in the sea. The catamarans would simply be tilted physically by rolling and leveraging weights onto one side. The coordinates were fixed and adjusted according to the visual triangulation methods by using visible shoreside landmarks like mountain

/chimneys/tree covers. But these locations were shared amongst a few operators particularly the ones who engaged in the process from the concerned village. These units were very few in number as the operation in itself was restrictive due to the physical inputs at loading and deploying.

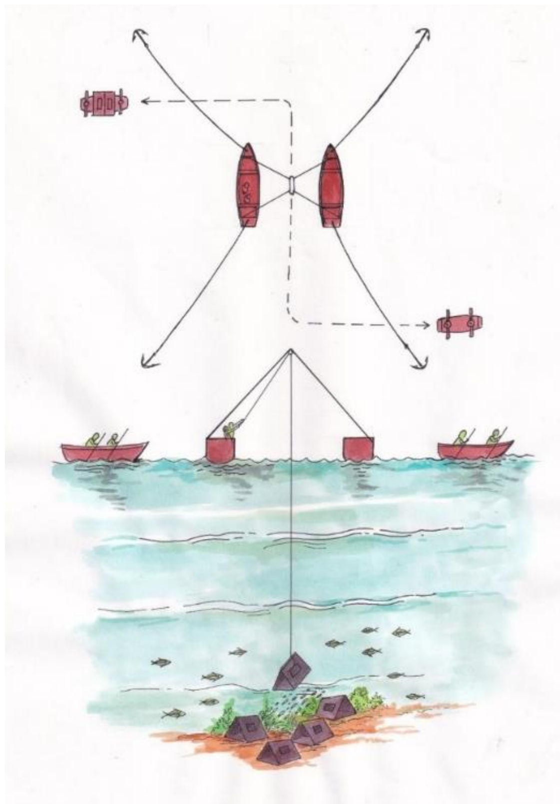


Fig.38. Deploying AR - method modified by ICAR-CMFRI in collaboration with ITGB

These methods were further modified by the fishers with the adoption of the advanced and heavier versions in larger numbers. With methods of having poles tied up between two boats and using the pulley rope leverage, the units were lowered in the sea (ICAR-CMFRI -ITGB); later this was modified into horizontally tying up two crafts with sound poles and loading modules over two crafts and transport to sites and deploying. This later shifted to single boat handling the units, when the boats used were more robust FRP make and had OBM engines to drive the loaded boats. These initiatives were good to involve the fishers themselves into the reef-building, however, it came up with issues such as the dispersion of units randomly and organizing a layout design was impractical when the operations were conducted for longer periods. The units while loading and deploying might develop hassles and damage boats and cause injuries at handling.

Deployment using barges and cargo vessels

The specified barges/vessels, if they can hold sufficient weights and have clearance draft at the respective harbours or ports, can be loaded with the full quota of the modules as far as possible, on one sailing, to reduce time and effort in gathering stakeholders and suspending other activities. ICAR-CMFRI has so far successfully deployed 250 modules/220 tonnes per site/trip**.**

The vessel anchoring facility is also very critical as it is often to be moved while deployment. A motor-driven winch-supported anchor would be ideal.

Steps to be followed further for the assembly and layout

1. Note the coordinates on the ship and the required anchorage length based on the existing current speed and direction.
2. Plan the anchor drop accordingly.
3. Check the coordinates again and confirm with the fisher team on board.
4. The cranes and deployment sides can be readied.
5. One by one the units can be lowered to the site.
6. At an average depth of 10 m, it is very unlikely that two units will fall on the same due to the currents, and flow rate existing at the site and the density of water.

Artificial reef orientation

a. Scattered into a square/rectangle/circle-a virtual boundary
b. Pyramid
c. Cluster formation - 4 patches of 50 each
d. Single large cluster - well spread but closely arranged
e. Corridor creation - making a village or hamlet-like lay out with exits and entrances using the different modules
f. Parallel to the coastline - a horizontal alignment
g. Vertical to the coastline - a perpendicular alignment to the coast line
h. A '**C**' shaped formation - the incurved space facing the horizon
i. An 'L' shaped formation - inner curve facing the horizon

All these orientations are to be decided based on the ground conditions and requirements in addition to the prevailing site weather. At times currents may not be favourable; then the desired results are to be obtained by using boats and tow energy to keep the deploying vessel in the required position at the drops.

Type (a) is more suited for fishing abundant forage fishes and pelagics. Type (b) is more preferred for raising only a select few species and larger predators. They are more suited for developing broodstock reefs of selected large predatory fishes (groupers/seabass/cobia). Types (c, d and e) are better for fisheries and management and creation of fish corridors and retention of the stocks over the reefs. Types (f, g, h and i) are more suited where the number of fisher operators are high and the sea conditions favour the orientation for the convenience of operations.

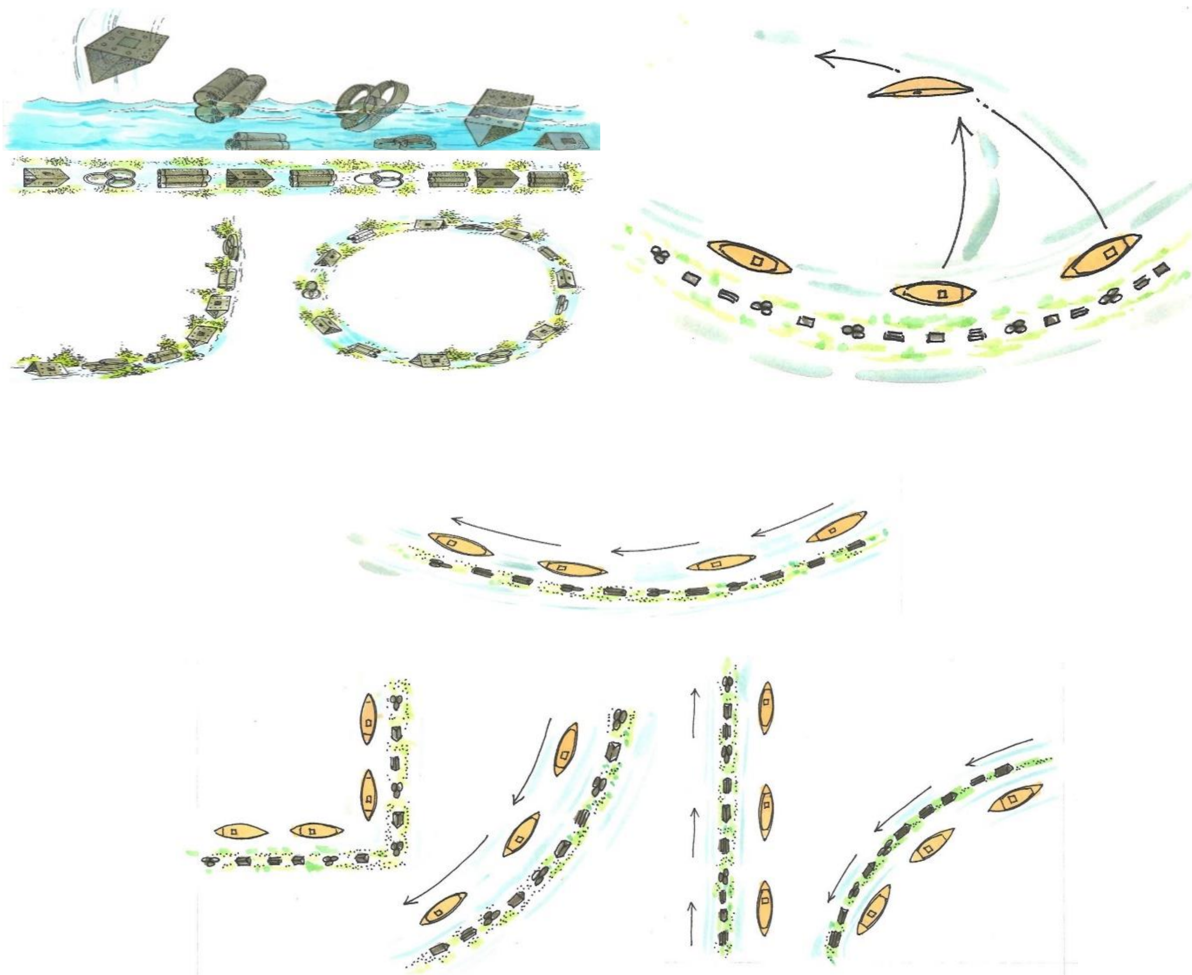


Fig. 39. Orientation of deployed reef modules-linear/along a curve, circles, patches, vertical line to the shore and L-shaped and C-shaped arrangement of modules on the seabed.

Artificial reef capacity

A well laid out production reef with multiple fish species as the target, the present densities and numbers of reef modules per site of 250 is adequate to support only 10-20 FRP boats of 18-20 ft at a time, and if gill nets and short seines are in operation this is restricted to a max of only 3-5 boats. A fisher hamlet with near about 100 crafts of such operation needs at least 3-4 reef patches for simultaneous operations and to reduce the exploitation stress on the fish stocks.

Essential: A portable GPS, compass, sonar on board vessel, and SCUBA team on board

*(The primary unit in which longitude and latitude are given is **degrees** (°). There are 360° of longitude (180° E ↔ 180° W) and 180° of latitude (90° N ↔ 90° S). Each degree can be broken into 60 **minutes** (′). Each minute can be divided into 60 **seconds** (″). For finer accuracy, fractions of seconds given by a decimal point are used. A base-sixty notation is called a **sexagesimal** notation. 1° = 60′ = 3600″. For example, a spot of ground can be designated by 43°2′27″ N, 77°14′30.60″ E. Sometimes instead of using minutes and seconds to measure the fraction of a degree, a decimal value is used. With such a convention the coordinates above are 43.040833° N, 77.241833° E. The first number was converted by taking the minutes divided by 60 and the seconds divided by 3600 and adding them together. That is: 43.040833° = 43° + 2′ × (1°/60′) + 27″ × (1°/3600″).*

Artificial reef layout

The better utility of an AR lies in the services it renders in fulfilment of the proposed functions and set targets. A series of field-level deployment trials and monitoring and fishery assessment studies have revealed that the layout of the AR plays a major role in achieving these targets. Pinnacle and pyramid formations benefit only larger predator fish assemblages and the diversity is less when compared to the broader peripheral distributed AR layout. The linear and cluster patch formations are also better than the pyramid ones. The advantage of a dispersed and spread-out reef is the scope for increased activity and fish mobility over a higher surface area such that the stock gets retained in the system itself. Several diver and fisher friend advisors have generated ideas and concepts on the layouts in our waters with (a) small pinnacle and randomly distributed modules, (b) a central pyramid cluster surrounded by small clusters of modules, and (c) preparing clusters on sand mounds in a random design such that fish gets escape and refuge routes to counter severe currents and predator attacks, and keep shifting or shuttling through the **proximal fish corridors** instead of exiting the reef area.

Fig.40. Central pyramid cluster and surrounded by small clusters of modules

Fig.41. Small pinnacles and randomly distributed modules

Fig.42. Clusters on sand mounds in a random design

The AR structures are therefore to be individually set with the proper understanding of the existing fauna and habitat characteristics. The AR situated in proximity to other reefs or rock patches are more productive and sustaining than the ones that stand alone in a plain area. The modules used in conservation areas could be arranged closely to limit the protected and no-take zones to specific locations with densely populated artificial reefs, which will ensure that conserved species and ranched seeds can be limited to and remain within the undisturbed MPAs. However, if the intention is for nursing and growth, the reefs could be more evenly spaced and random to generate more food resources.

A very healthy functioning unit could run sustainably for 10 years but for sustained fishing efforts and harvests every year it is advisable to add on 20% area or the number of modules every 3 to 4 years post-deployment, with regular upkeep of reef structures by diving teams. A well-planned and well-managed artificial reef can develop into a sustainable ecosystem supporting both, fisheries and conservation. This can, thus, effectively be recognized as an “Other Effective (area-based) Conservation Measure” (OECM) in marine fisheries.

Incubation period and indicators of the faunal assemblage

Joe K Kizhakudan, Shoba Joe Kizhakudan and Remya L.

The ARs act as source of food, shelter, refugia, stopover, attachment surface or substratum and proximity to the ecosystem community and food web. However, the actual cues which lead the multitude of species towards the AR structures are still under investigation. Many attribute it to the visual cues, the height of the structures, the assembly of the structures, acoustic signals, light and fluorescence, chemical cues and the community structures and assembly itself. The age of the reef can determine the type of communities in an AR site. The initial communities rapidly change during colonization and succession.

Three phases of colonization can be identified in an AR –

i. Pioneer settlement phase
ii. Barnacle/mussel dominant phase
iii. Regressive phase.

During these phases the substrates shift, soft sediments add on, and species diversity increases. The initial rise in colonization and a number of species later declines and stabilizes at an equilibrium, after which only cyclic changes take place in the composition.

Once the AR modules are deployed, in 30-45 days, **primary settlement** of epibionts like periphyton, larval stages of molluscans, barnacles and echinoderms and nematodes takes place. The settling sediments, particles and organic matter give a perfect substratum to support bacterial colonies along with protists, sponges and ascidians, and algal spores to build upon them. The primary settlers include –

A. Sediments, bacteria, and microbes.
B. Diatoms and periphytons - *Amphora* sp., *Bacillaria* sp., *Cocconeis* sp., *Navicula* sp., *Nitzschia sigma*, *Paralia* sp., *Rhoicosphenia* sp., *Synedra ulna, Thalassiosira* sp., blue green algae, cyanobacteria, heterotrophic microbes, and detritus.
C. Protozoans, foraminiferans and ciliates.
D. Invertebrate larvae - trochophore, tornaria, veliger, glochidium, planaria, auricularia, bipinnaria, zoea, megalopa etc.
E. Post larva, spats, seed, crablets, etc.

The planktonic stages of planktotrophic species swim and float for sufficient time till they identify a suitable substratum and settle down in the competent phase (which can be delayed) which gives them a long survival life in the larval phase. Truly demersal larvae metamorphose quickly and settle down and start consuming the detritus, fungi, and algae.

These assemblages happen quickly in our waters and hence the secondary consumers and small predatory fishes and plankton feeders assemble in rapid succession.

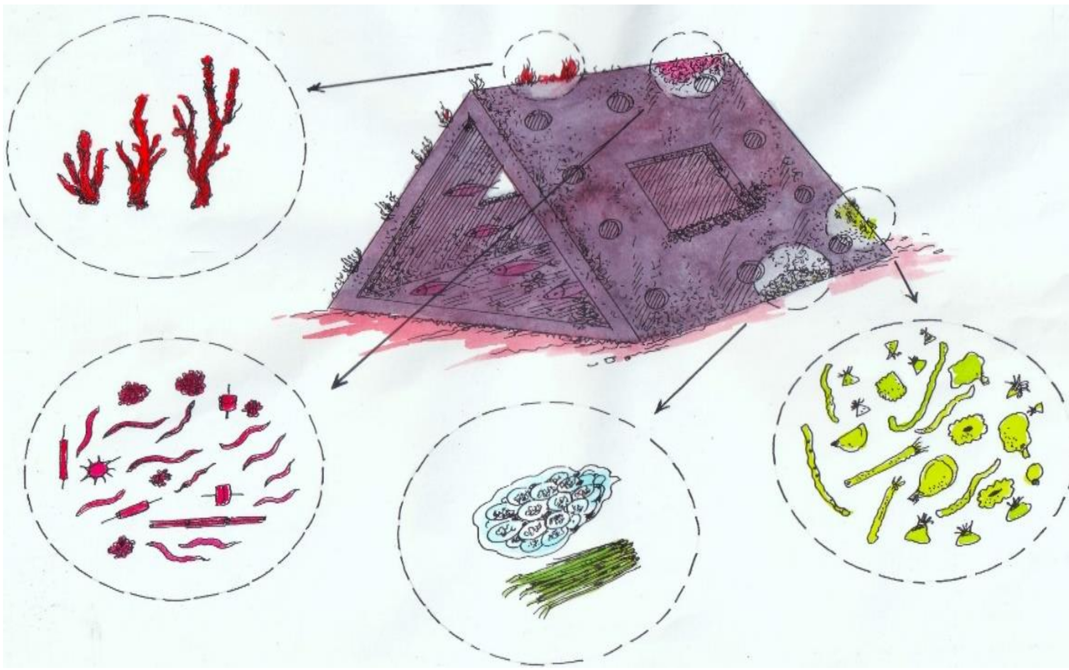


Fig. 43. Fauna assemblage indicators

The secondary succession (45-90 days post-deployment) follows with the growth of molluscans, polychaetes and nematodes converting the detritus, and the diatoms and bacteria creating the nutrient availability for more food and space for the primary settlers.

1. Nematodes and polychaetes dominate the recycling assemblers
2. Molluscans and barnacles and algal mats grow out
3. Sponges, ascidians, bryozoans, amphipods, ostracods, mysids, copepods, harpacticoids, hydroids and macro alga, coralline alga expand
4. Echinoderms, tardigrades, chaetognaths, caridean shrimps and crabs
5. Fish larvae and fry, zoea, nauplii, salps, doliolids and ctenophores create the ambience.
6. Gobiids, porcellanids, gammarids, galatheids, sea lilies, and brittle stars multiply and flourish on the surfaces.

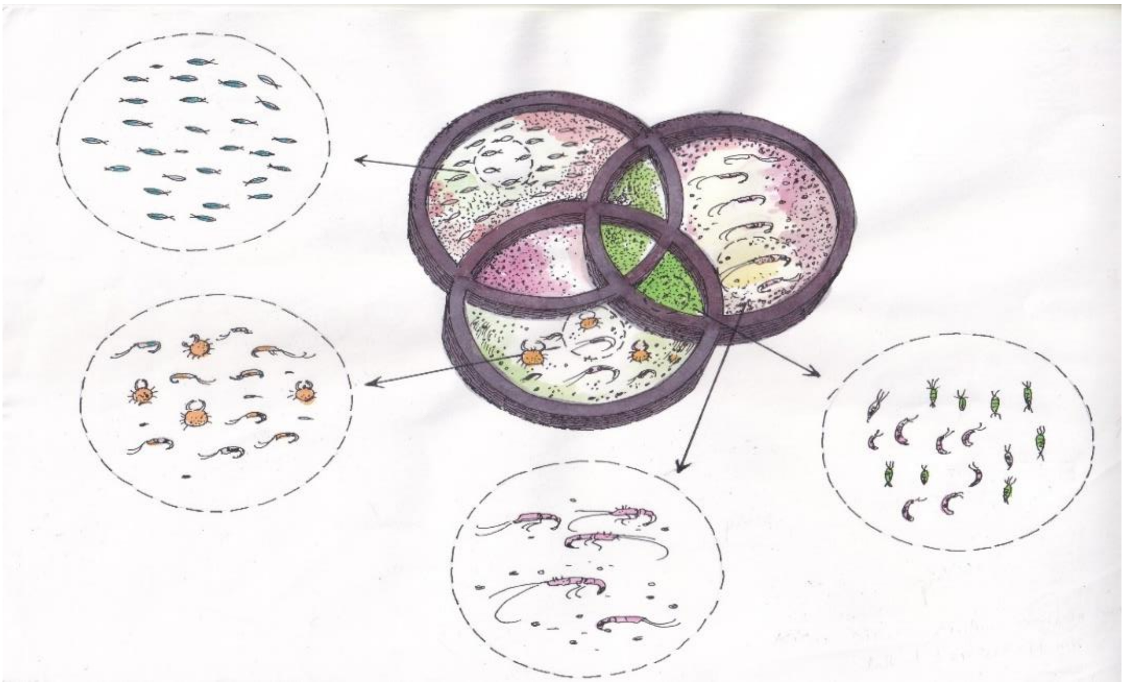


Fig.44. Fauna assemblage indicators

The tertiary settlers (3-6 months post-deployment) are mostly the permanent residents, refuge-seeking tenants and hiding populations, and include rays, *Amphioxus* sp, camel shrimps, spiny lobsters, larger crabs and crustaceans, serranids and lion fishes, scorpaenids, goat fishes, breams, zanclids, pomacanthids, sea horses and sea lilies, butterfly and squirrel fishes, sergeants and trigger fishes, wrasses and parrot fishes, puffer fishes, eels, starfishes, cardinals, damsels, perches, carangids and siganids.

Fig.45. Electric ray in an artificial reef site

The quarternary successors (4-8 months post-deployment) are the forage community (mackerel, scads, trevallies, barracudas, small tunnies, perches, breams, silver bellies, biddies) and benthic feeders. Many are residents, while others are temporary migrants frequenting the reefs for nursing, feeding and shelter during their grow-out phases. The small tunas and barracudas move out after a particular size, the seer fish move out after feeding, bigger perches move out as a thinning of the population over the reef, gobiids move out as they multiply, octopuses and spiny lobsters settle down while breams, surgeons, siganids and sergeants remain resident, around the reef but not necessarily in contact with the reef.

Fig. 46. Juveniles of the golden trevally, *Gnathodon* sp. and snappers and breams seen in artificial reef sites

Fig 47. Giant snappers and groupers resident to the reef fish and pipe modules and crustaceans and echinoderms in the well ring modules

Fig. 48. Recruitment of cardinals, snappers, damsels, pempherids, breams, squirrels, siganids and surgeons

The penultimate entrants are the giant groupers, perches, giant trevallies, grunters, sharks, cobia, seer fish and barracudas which are top predators; very few remain residents like the groupers, grunters and snappers while the others stop over only for feeding and hunting and move on.

Fig. 49. Larger snappers, trevallies and groupers in artificial reef site as bottom dwellers and settlers

The final groups are the visitors and long-distance migrants like whale sharks, hammer head sharks, dolphin fishes, bigger barracudas, tunas and cobias.

Fig.50. Whale shark spotted in an artificial reef site in Tamil Nadu

Fig.51. Faunal assemblage in an artificial reef site

The first and second years will show a very sharp rise in foraging pelagic fishes and barracudas; subsequently, the predator settlements in the reef bring about a balance in the reef populations, which remain more or less in equilibrium unless there is some serious impact or exploitation of certain communities. During the third to the seventh year of a well-developed and managed reef, the fishery output remains more or less steady and unaltered, unless there are damages or sinking of reef structures or increased exploitation in the reef site. Therefore, more expanded areas under AR will be beneficial.

The good health indicators of a reef in its developmental stages are -

1. Good fish catches in drift gillnets in the surrounding in the first six months of deployment.
2. The improving catch rates of scads and horse mackerel and mackerel in hook and lines fishing
3. The improving collection of perches and breams
4. The improving catch rates of the goatfishes, sciaenids and siganids in the set gill nets in the surroundings of the reefs
5. The tertiary and fourth succession are indicated by the catches of small groupers and perches in baited hooks and the capture of bigger trevallies
6. The capture of fresh live baits every season is an indication of the population underneath.
7. The shoaling of sharks and barracudas and cobias over reefs indicates good forage assemblages
8. The visits of whale sharks and small tunnies indicate the abundance of small forage fishes and plankton, and physical cues released from the reefs to distant water (sight/light/acoustic)
9. The surface shoaling of the bat fishes with their dorsal fins emerging out of the water shows a good healthy reef community underneath.

Applied sustainable fishing techniques over artificial reef sites

Shoba Joe Kizhakudan, Joe K Kizhakudan, Vignesh S, Mohan R, Damodaran M, Govind N and Baskar K

A management that pushes aquatic systems in the direction of their primal states, when the predators controlled the primary consumers, rebuilding ***and restoration of ecosystems should be the overreaching goal of new fisheries management*** **(**Ludevig *et al*., 1993).

As it is very well known that the artificial reefs aggregate several fish species, which settle and recruit therein, the resultant biomass becomes very lucrative for the local fishers to capture the maximum due to increased pressure and competition. This may tend to be unhealthy and lead to overexploitation in due course. A well-managed reef fishery involves self-restrained, regulated and selective gear fishing practices.

Fishing methods and practices in the AR:

1. Hooks and line:
   a. **Long lining**: mainly used for trevallies, lethrinids, snappers, groupers, cobia, seerfish, seabass, grunters, sweetlips, croakers, ghols and other sciaenids. Surface lines/mid-water lines and bottom lines are employed, all using bait.
   b. **Mid-water hand lines**: mostly used for small-sized fishes using small baits and live shrimps. The line has 25-30 hooks tied at intervals to a main line and is used to catch scads, mackerel, trevallies, small tunas, sweet lips, grunters, breams, and snappers.
   c. **Bottom hand jigging**: used for the capture of squids and cuttlefish. It consists of a line with a lead weight and hooks fixed amidst glittering paper stuck on the rod.
   d. **False bait hooks**: These are vertically lowered lines with a dead weight (iron rod) with at least 20 small hooks. The line is tied at intervals with glitter paper and gilt folds. This unit is just moved up and down to attract the small fishes like scads, other small carangids, lethrinids and small perches to get hooked onto the line. These gears bring in the fish in fresh, live condition. An interesting fishing technique that has opened new avenues for the reef-dependent fishers is the collection of small fishes and juveniles of scads and mackerel which are used as **live baits** to catch large pelagics in deeper waters, such as seerfish, tunas, barracudas, sailfishes, dolphinfish etc. This fishery, locally called **"Panjil"** fishery (in Tamil Nadu) has proved to be very beneficial for fishermen.

Fresh live baits are collected by altering a boat design making an extra fish hold tank inside the FRP unit which can support nearly 300 numbers of 100-150 gm sized fishes for nearly two hours as the boat runs into the deeper waters. These fishers get better catch rates for tuna/seerfish and dolphin fish/sail fish. This method has reduced their operation costs towards frozen baits (Rs 3000-4000 per trip) and also has permitted elderly fisher to go to the AR sites and catch live baits and hand them over to the young fishers who venture to deeper waters.

Advantages: Reduced use of destructive gears, reduced efforts for juvenile fishing, collective management process and proprietary resource adoption.

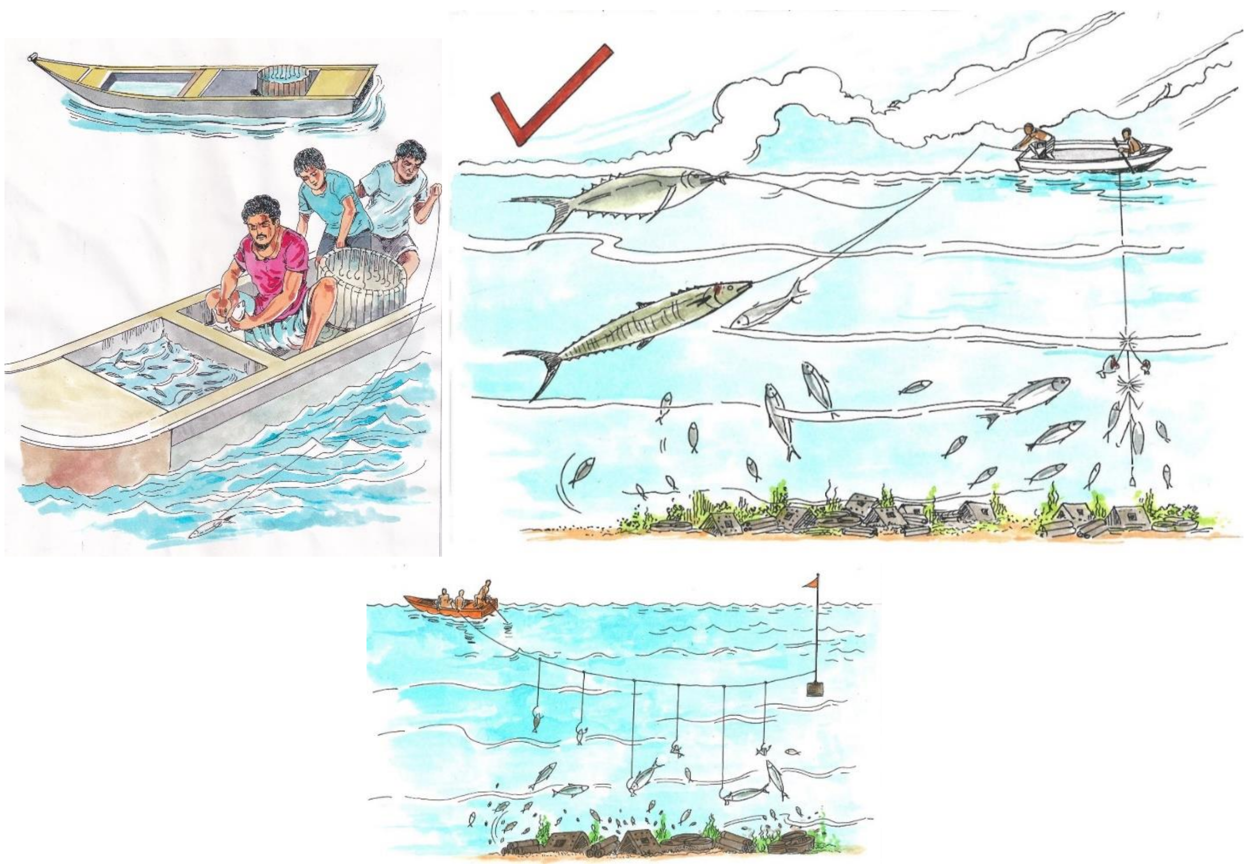


Fig.52. Hook & line and longline fishing using live baits in the artificial reef site

2. **Gill nets:**

Gill nets are set drifting along the outer boundaries of the area of the AR such that the natural currents will bring the fishes towards the nets. These are surface drift gill nets with a maximum hanging depth of 10 meters. They are used to capture mackerel and scads and small tuna and barracuda shoals over the reef.

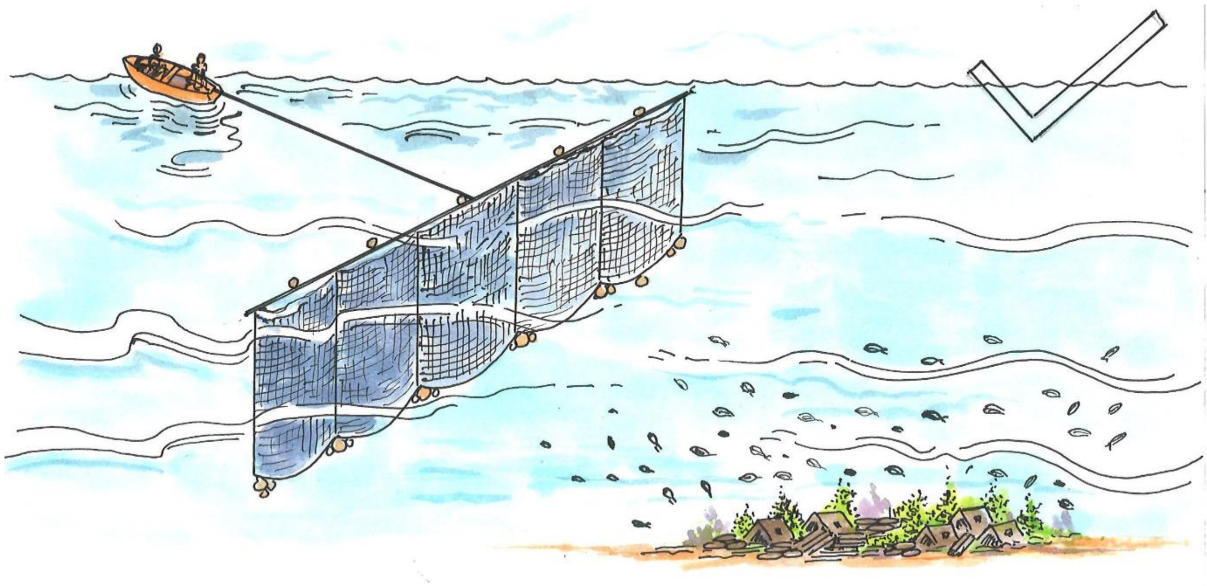


Fig.53. Drift gill net fishing in the artificial reef site

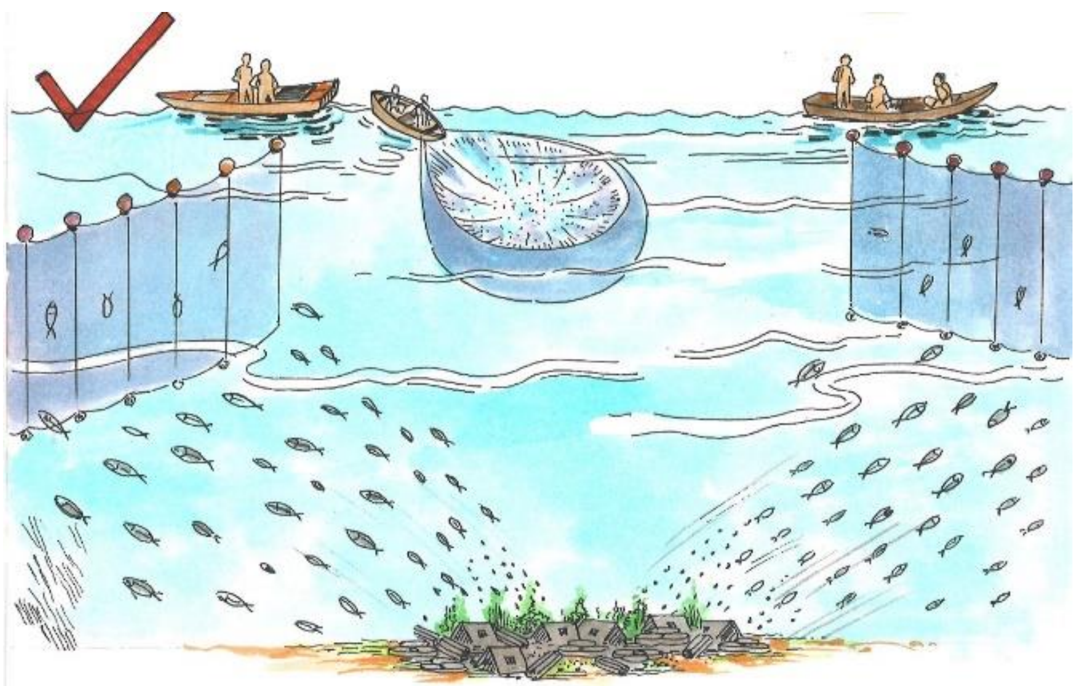


Fig.54. Encirclig net fishing for forage fishes in the artificial reef site

3. **Small bag nets**:

   Two small FRP boats operate encircling nets on the surfaces of the AR areas during the forage fish abundance - sardines, mackerel, scads, barracudas, small tunas and small carangids.

4. Gears such as traps, pots and spearguns by divers could also be options in the coming years.

Fishing in the AR sites is occasional and on rotation; often, when the other options are reduced, the fishers work over the reef areas.

How has the AR fishing turned more sustainable?

1. The capture of select species of utility and recommended sizes.
2. Maximum utility to the commodities captured over the reef.
3. Highly reduced scouting time and fixed destinations have improved access for the elderly to fish.
4. Reduced fuel consumption and reduced dependency on extra manpower.
5. The craft can be steered using sails and paddles and the units can be a very small canoe too – 3m unit, catamaran.
6. The fishing is optional and rotational and depends on the spatial availability; overcrowding is not possible as it is mostly first to come basis.
7. Release of the live ones of unwanted species back to the site.
8. Sensible fishing practices avoiding breeders and fresh recruits of big commercial varieties can see a fortune shift in the resource stocks.
9. Reduced use of plastic and nylon nets and reduced investments.
10. Reduced dependence on fuel subsidies and fuel, tending towards "green fisheries".
11. Improves the carbon footprint of coastal fisheries.
12. Improves biodiversity and the reserves of vulnerable and near-threatened species and sheltering stocks.
13. Opens opportunities towards sea ranching and stock rebuilding, transplanting.
14. Opens opportunities for marine ornamental stock reserves and trade.
15. Creates opportunities for alternate options for the fisher youth in sports, SCUBA, recreation and tourism.

Primary fishery assessments and status from catch statistics

Remya L, Shoba Joe Kizhakudan and Joe K Kizhakudan.

Primary assessments of fish catch from AR sites are done by ICAR-CMFRI, following a multi-stage stratified random sampling (MSSRS) technique introduced by the Institute to assess marine fish landings in the maritime states of India (Srinath et al., 2005). Hooks and lines and gillnets operated from traditional boats and motorized FRP boats are usually the chief gears monitored for fish catch assessments from AR sites. The villages or landing centres having AR are surveyed on a fortnightly basis as per MSSRS and the fishes landed by boats fishing in the AR site are identified and quantified. For comparison, the landings from non-AR sites (either in the same village or in the adjacent village without AR, if the former does not happen) are also surveyed simultaneously. The monthly catch from AR and non-AR sites are compared over a year or more. The catch from an AR site is also compared with the catch recorded in the previous year from the same site before the deployment of AR, obtained from the database of ICAR-CMFRI.

The catch per unit effort (CPUE, kg) where effort is the number of boats operated is taken as the index of performance.

$$\text{CPUE (kg)} = \frac{\text{Total catch by all the observed boats (kg)}}{\text{Number of boats observed}}$$

The catch and CPUE are compared for the total catch as well as catches of individual resources (either families or species, based on the occurrence and dominance in the catch). The percentage of variation across years in the AR site and between AR and non-AR site are estimated to understand changes in species composition, shifts in species dominance, catch trends and seasonal abundance of resources.

Fishery assessments provide an accurate measure of the species composition and abundance in the AR site; however, they tend to be biased towards resources that interact with the gears deployed and may not provide a complete picture of all the resources that may be housed in the AR. Nevertheless, fishery assessments provide the most reliable account of the maturation of the reef and its capacity to sustain an economically viable fishery, and thus the livelihoods of the fishers who fish regularly in the AR site.

Stock assessments

With catch and effort data assimilated from the AR site over a continuous period of 5 years and more, the status of the stocks that support the commercial fishery can be assessed using surplus production models, which give an idea of the maximum sustainable yield (MSY) and the effort level at which it can be obtained (F_{msy}). This can be assessed for the entire reef catch as a whole taken by a single gear (eg., hooks & lines), or by multiple gears (egs., hooks & lines and gill nets) after gear standardization. The status of individual resources can also be assessed (eg., snappers, groupers, barracudas, scads etc.).

Length-based species-wise stock assessments

With continuous data on the length frequency of different species in the AR fishery, length-based stock assessments can be done using microanalytical models which require biological parameters of growth and mortality as inputs. For small, short-lived species like sardines, mackerel, scads etc., data over two years will be sufficient. For medium-life span fishes like small perches, data for two-three years is required. For larger, long-lived species like seerfish, barracudas, tunas, groupers etc., the data requirement will be for five years or more.

Length-based stock assessments provide information on the behaviour of individual species and allow estimation of standing stock biomass (B) and spawning stock biomass (SSB), at the current level of effort (F) and F_{msy}. The indicators F/F_{msy}, B/B_{msy} and SSB/B are reliable descriptors of the health of the stock, particularly in the case of resident species.

While attempting length-based stock assessments, it is necessary to ascertain the nature of occurrence of the species, i.e., whether it is resident or migrant and whether it frequents the reef only in a particular phase of its life. Resident stocks will ideally be always present in the catches from the reef. However, there may be chances of only a particular life phase interacting with the fishery, in which case the length frequency will be biased towards those size classes (eg., groupers – juveniles and young adults are likely to be caught while larger adults tend to remain solitary at the bottom, usually within the crevices of the reefs and thus are rarely represented in the fishery).

Integrating the results of fishery assessments and stock assessments with the data gathered from direct underwater observations and ROVs will provide a near-perfect profile of the fishery resources supported by the artificial reefs.

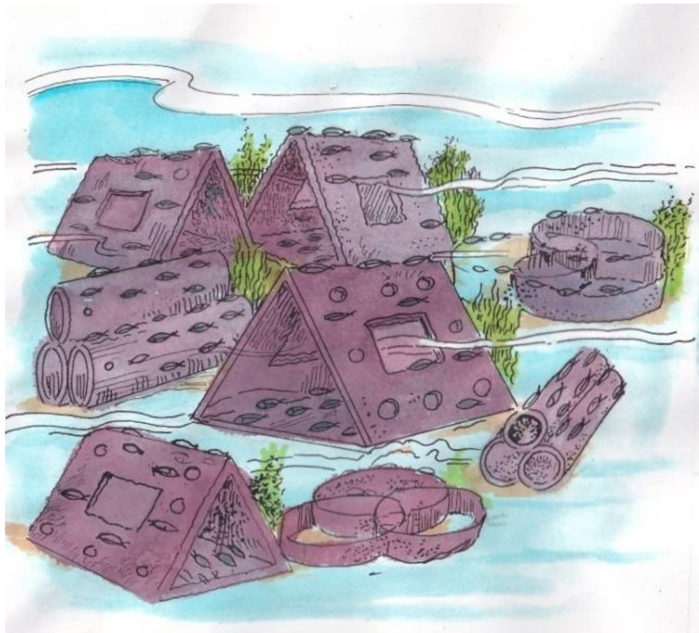


Fig.55. Benthic community in contact with the reef surface

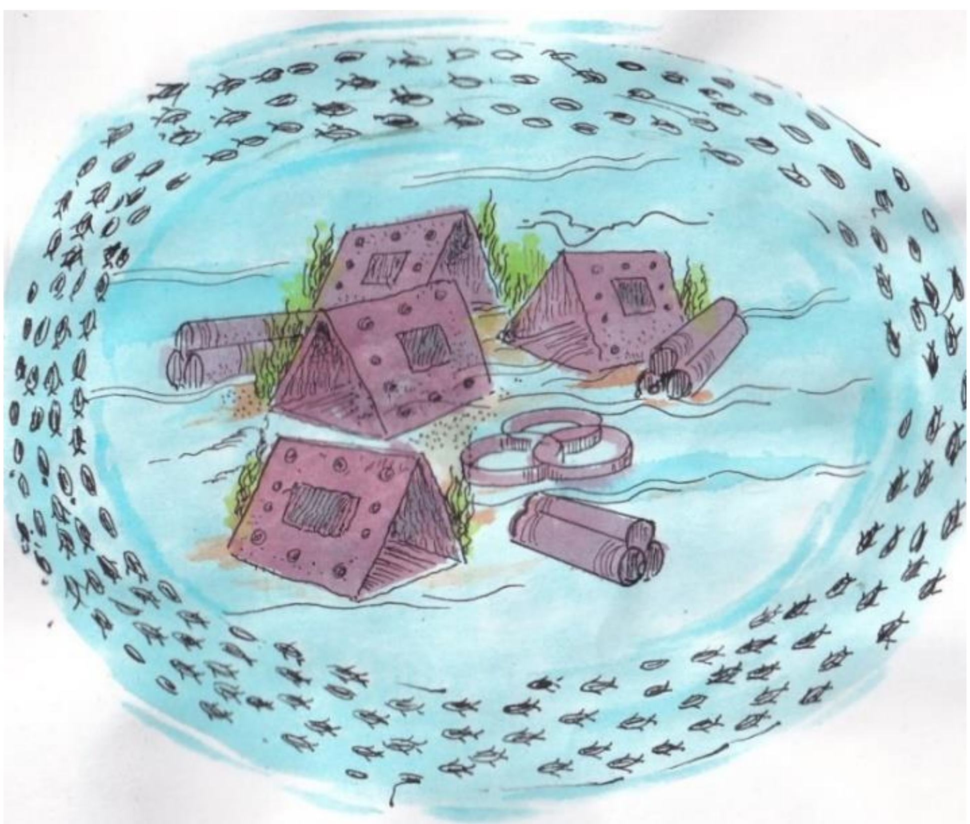


Fig.56. Demersal community surrounding the reefs

Fig.58. Forage fishes in the immediate water column above the reefs

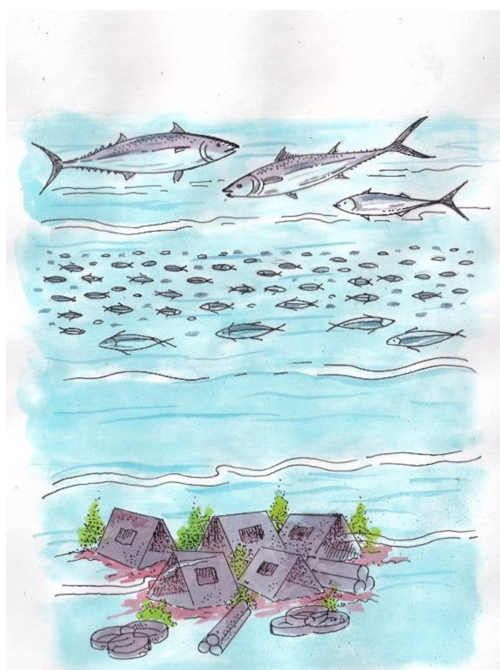


Fig.59. ***Large predators and pelagics on the topmost surface***

On-site fish assemblage analysis, experimental fishing methods and performance evaluation

Remya L, Joe K Kizhakudan, Shoba Joe Kizhakudan and Venkatesh P.

The artificial reef (AR) is assessed for its performance after deployment. The biomass, diversity, abundance etc. of fishes associated with AR after colonization is analysed through different methods. They are direct observation, remotely operated vehicles (ROVs) inspection, fishing gears and acoustic methods. No single method gives accurate inputs but combination of two or more methods ensures a better measure of the performance of AR. Various sampling methods and data analytic methods used to assess AR globally are described below.

1. **Direct observation - SCUBA diver survey -** The diving teams record observations on their slate and evaluate over a specified area (10x10 m) while swimming over the reef at good visibility. This method is good for recording general assessments but depends on the diver's knowledge. Data comparisons over time are not easy with this information. However, it is good at picking up strange and interesting occurrences and observations and is also of advantage in conservation, transplant and ranching trials and studies.

   A. **Visual census:** Underwater visual census (UVC) is the primary tool to assess fish assemblage in AR when there is very good visibility. Divers equipped with SCUBA perform counting and measurements and record photographs and videos of fishes in the reefs.

   i. **Strip transect**: The diver swims along a transect of pre-established length in a pre-established time interval. listing and recording all the species encountered.
   ii. **Point count**: The diver stands at a fixed point and enumerates the organisms observed within a prescribed area or volume in a pre-established time interval.
   iii. **Species-time random count**: The diver swims randomly over the survey area for a predefined period either simply recording the species encountered or listing them in the order in which they were initially seen.
   iv. **Combinations of methods**

   The data collected through the visual census is used to estimate the relative abundance of fishes at various reef areas or over the period from a single or a group of reefs and to calculate diversity indices of fishes.
   Advantage: Non-destructive *in situ* method

Disadvantage: As the visual survey is performed during the daytime, chances of biased sampling of diurnally active species are high, leaving out nocturnally active species from the enumeration.

Relative abundance (Odum, 1970)

$$RA = \frac{ni \times 100}{N}$$

Where, ni is the total number of individuals of a particular species and N is the total number of individuals of all species

Fish diversity index

Simpson's dominance index (Harper, 1999)

D = ∑ ni(ni-1)/N(N-1)

Where, ni is the total number of individuals of a particular species and N is the total number of individuals of all species

Simpson index of diversity

D'=(1-D)

Shannon-Weaver diversity index (H')

H'=−[Σpi(lnpi)]

Where, H' = Diversity Index; pi= ni /N; where "ni" is the number of individuals collected for a species, and 'N' is the total number of individuals of all species

Species richness (Margalef index, d)

d = (S-1/Ln N)

Where, S is the number of species and N is the number of individuals in the sample.

Species evenness (Pielou index, E)

E=H'/LognS

Where, S is the total number of species and H' is the Shannon-wiener diversity index

B. Quadrat survey: This involves placing a grid over the area being surveyed to either estimate percentage cover or ease the counting of a targeted organism. The size of the grid can vary depending on the goals of the survey, but often a 1m x 1m grid broken into 10 columns and rows is used for divers. The quadrats can either be randomly thrown out, haphazardly placed, or permanent. This is a good method for accurate estimations and counting of small organisms. A photographic inventory will aid more but requires some training, but larger areas cannot be assessed and the studied area should also be least disturbed. Good particularly for invertebrate recruitment and settlement studies.

C. Transect Lines: This is a technique in which a surveyor will lay out a measuring tape, and record all data or observations in relation to that line. The line can be laid out randomly or can be laid in the same place each time using permanent marking points. Surveyors may use multiple short lines, or a single long transect line, depending on their survey design. The transect line survey is the most used technique. The data can be compared and reduces subjectivity and gives better accuracy and a wide range of surveys can be planned. This is an excellent tool for assessment and recruitment studies over the AR sites but needs skilled, trained divers for the same.

D. The Manta Tow method: In this method where a diver with a snorkel or scuba is dragged over a reef for documentation and recording and visual estimates. This is a tool useful for comparative studies between AR and Non-AR sites on time and season scales. Larger areas can be represented and damages to the reef can also be estimated. But possible only in shallow installation areas where visibility is very good. Very rarely employed method.

2. **Remotely operated vehicles (ROVs) inspection -** Remotely operated vehicles (ROVs) are video-based survey tools for quantifying fish assemblages at a range of depths. Relative abundance and fish diversity indices are calculated here as the input data is the same for both direct observation and ROV**.**

3. **Bait fixed ROV -** consists of a steady weight supported stand with a platform holding camera and light settings facing a bait bag hanging in front of the stand for the reef fishes to accumulate. The continuous recording gives information on the seasonal compositions and size variations. This is a good method to understand recruitment and brood stock dynamics in ARs.

4. **Fishing gears/sampling gears employed to sample the fishes in AR -** They are traps, long-lines, hooks & lines etc. Here catch-based sources of data are used to assess the performance of the AR. Catch per unit effort (CPUE) in terms of the number of fish caught per effort and total weight (kg/net or kg/hook) per effort is estimated. In addition, abundance and diversity are also calculated using the equations mentioned above. At times, surface trawl and seine data can be collected if available, to give a comprehensive picture of the sizes, species, and abundance in numbers

$$Catch\ per\ unit\ effort\ (CPUE) = \frac{Total\ catch\ (kg)}{Total\ units\ employed}$$

Advantages: Provides catch/species composition, length-frequency distributions, biological data etc.

Disadvantages: Destruction of AR, gear selectivity - samples of particular length groups may be selected according to the gear type. The traps and trammels can estimate the reef-dwelling populations and particularly give estimates of ornamentals and their abundance and diversity.

5. **Acoustic methods -** Single-beam echosounder, multibeam echosounder, side scan sonar etc. are used to assess fish assemblage at the AR site. The relative fish abundance index, RFAI can be measured from survey transects at each nautical mile-long georeferenced elementary distance sampling unit (EDSU). The EDSU is 200 pings over a 5.5 m depth. The biomass density ρ_i (t/nmi^2, tonnes per square nautical mile) of the i^{th} species in the studied area is calculated by the formula (Simmonds and MacLennan, 2005):

$$\rho i = C_i \times \frac{RFAI}{4\Pi\ \bar{\sigma}} \times \bar{W}_i \times 10^{-6}$$

$$\bar{\sigma} = \sum_{i=1}^{n} Ci \times 10^{TSi/10}$$

$$TSi = 20 log li + b_{20,i}$$

where *ci* is the number percentage of the *i*th species estimated, RFAI is the nautical area scattering coefficient in m^2/nmi^2, $\bar{\sigma}$ is the mean backscattering cross-section in m^2, $\bar{W}i$ is the mean body weight of the *i*th species estimated in *g*, *n* is the total species estimated, *li* is the body length of the *i*th species estimated in *cm*, and $b_{20,i}$ is reduced TS (target strength) in dB (decibel).

TS-L relationships of the fish species can be calculated through different regressions of dominant species available in the literature to estimate the fish length, and the b_{20} values of other species can be adopted from their families.

The fish biomass (B,t) is calculated by the formula:

$$B = \sum_{i=1}^{n} \rho i \times A$$

Where, $\boldsymbol{\rho i}$ is the biomass density of the *i*th species estimated in t/nmi2, *A* is the studied area estimated in nmi^2, *n* is the total species estimated

Advantage: No damage to reef or associated flora and fauna.

Disadvantage: Crustaceans and molluscs cannot be recorded.

Often, a combination of acoustic techniques and fishing gear is also followed.

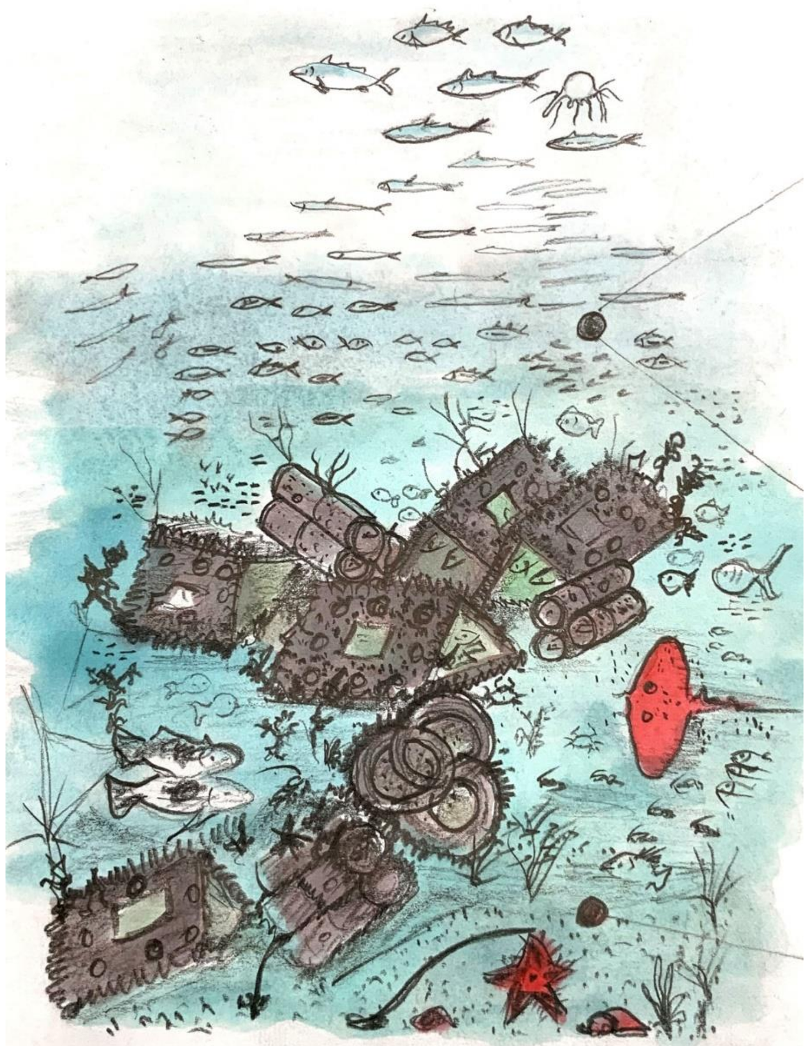


Fig.60. A multitier trophic level fish assemblage and ecosystem as visualized by a fisherman.

Fig.61. An artist's illustration of the AR site monitoring and assessment by divers.

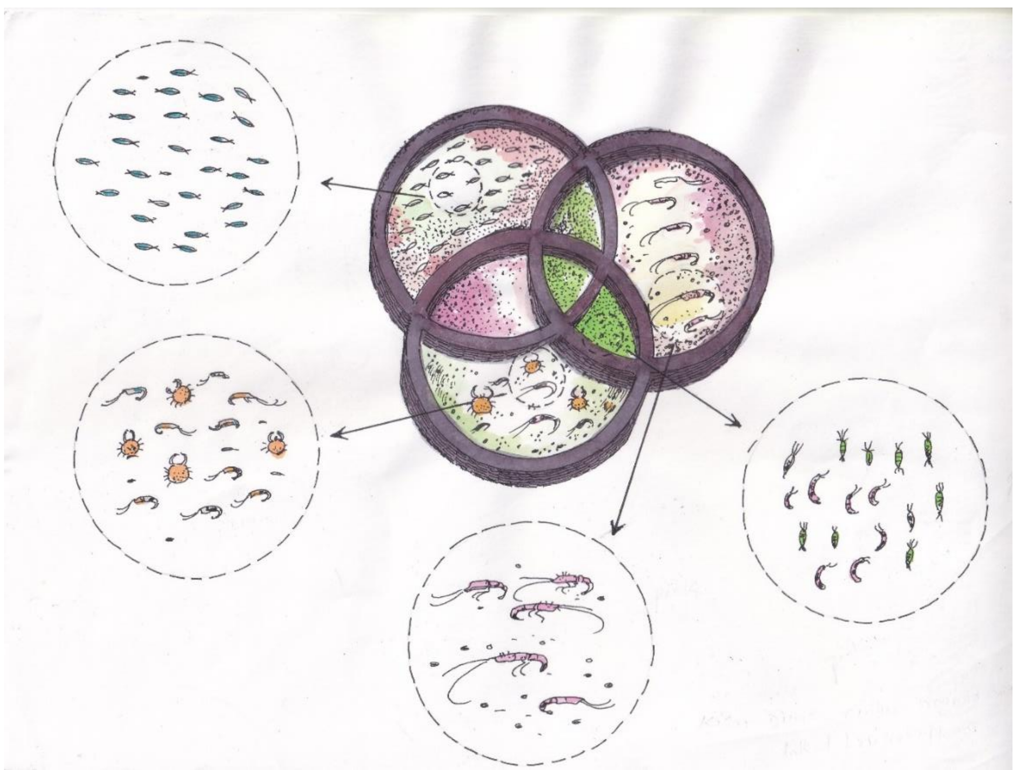


Fig.62. Benthic assemblages in the well ring modules -shrimp, crabs, lobsters, crinoids

Performance evaluation of reefs

Biological productivity indices - **Area of Influence**, **Primary Effective Boundary** and **Secondary Effective Boundary** for a fish caught from reef perimeter (PEB & SEB), **Biological Influence Range** (BIR) and biomass and density of fish fauna can be derived for artificial reef sites. The following indices - equations were developed for assessing the health of the deployed reefs (for the existing material and design by ICAR-CMFRI) in the coastal water of TN from case studies and analysis.

1. **Efficient Life of Artificial Reef (AREL, years)** *for the existing material and design by ICAR-CMFRI*

   AREL (years)= ((%a x0.1) +(%b x0.60) +(%c x1) +(%d x0.03) + (%e x0.005)) x CC x CS x df

   - *where a>3 mm, b=3-2 mm, c=2-1 mm, d<1 and e=clay in percentage composition of sediment texture*
   - *Coefficient of Current velocity = CC (factor values severe = 0.88 (current velocity >0.3 m/s, moderate = 0.95(0.15-0.25 m/s), mild=0.98 (0.1-0.14 m/s) and low =1(<0.5m/s) and*
   - *Coefficient of wave swell = CS (factor values severe = 0.87 (wave energy >6.8-8.5 kj/sqkm, moderate = 0.95 (4.5-6.5 kj/sqkm), mild = 0.98 (0.1-0.14 kj/sqkm) and low* ***= 1 (<0.5 kj/sqkm)***
   - *Df- depth factor (<4 m-0.75-,4-6 m-0.9,6-10 m-0.95,11-20 m-1.1,>21 m-1.2)*

2. **Sinking Rate of artificial reef modules (ARSR, mm/year)** *for the existing material and design by ICAR-CMFRI*

   ARSR (mm/year) = ((%a x1) +(%b x3) +(%c x3) +(%d x0.5) + (%e x 100)) x CC x CS x df

   - *where a>3 mm, b=3-2 mm, c=2-1 mm, d<1 and e=clay in percentage composition of sediment texture*
   - *Coefficient of Current velocity = CC (factor values severe = 1.1 (current velocity >0.3 m/s, moderate = 1.04 (0.15-0.25 m/s), mild=1.02 (0.1-0.14 m/s) and low =1(<0.5 m/s) and*
   - *Coefficient of wave swell = CS (factor values severe = 1.15 (wave energy >6.8-8.5 kj/sqkm, moderate = 1.06(4.5-6.5 kj/sqkm), mild = 1.03 (0.1-0.14 kj/sqkm) and low = 1(<0.5 kj/sqkm)*
   - *Df- depth factor (<4 m-1.5-,4-6m-1.3,6-10m-1.25,11-20m-1,>21m-0.75)*

3. **Performance efficiency of Artificial reef (ARPE)** *for the existing material and design by ICAR-CMFRI and a unit of 250 modules deployed*

   ARPE (%) = (AREL +ARSR x (0.7/100)) x FP x EP x RP x 10

   - *Fishing pressure (FP)-(0.5) heavy (>25 OBM + >trawlers, >others), -(1.1) moderate (15-25 OBM, few trawlers and least others), (1.5) low (10-15 OBM, nil, nil) and (1.8) poor (1-2 OBM, nil, nil)*

- *Estuarine Proximity (EP)-distance from bar mouth – 0.85(<3km), 1.3(3-10km),0.95(>10km) and 1(>20km)*
- *Reef patch or rock Proximity (RP)=distance from the nearest rock or reef patch -1.2 (300-500m),1.1(>500m) and 1(>1km)*

4. **Area of Influence**
   - *Surface and midwater –* ***200-300 m*** *from the epicentre of the reef, Benthic and bottom -* ***1-100 m***
   - *Maximum catches in gill nets from* ***40-60 m*** *extending from a periphery of the reef*
   - **Primary Effective Boundary for fish catch from the reef periphery (PEB)**
   - *Pelagic - 200-400 m, Bottom - 40-200 m*
   - **Secondary Effective boundary for fish availability from the reef periphery (SEB)**
   - *Pelagic- 400-600 m, Bottom - 200-300 m*
   - **Biological Influence range *(BIR)- 40-60 m***

Data logging, seasonal calendar, fishing schedules and conflict resolution

Joe K Kizhakudan, Shoba Joe Kizhakudan, Remya L, Vignesh S, Mohan R, Damodaran M, Govind N, Sreedevi S and Baskar K.

The AR sites in our experience get active in 12 weeks of incubation time and the fishers can test their sites using baited hooks. Based on the natural fishery grounds and the reefs areas in the vicinity it is ideal to draw a seasonal timeline series of the resource availability and grounds specific to the gears employed in each village. Many studies have been conducted to determine when communities on newly placed reefs have reached a point of equilibrium. This ecological stability seems to be reached after two to three years. Seasonality has been observed to be the second major factor to affect the quantitative species composition of assemblages. The effect of seasonality, however, seems to be mitigated in the course of a year. Inputs are to be generated from the fisher log books, analysed and compared with the benchmark data of ICAR-CMFRI from these sites and zones with respect to the specific gears and crafts.

Case study: Kovalam village in Chingleput district, Tamil Nadu

January: Trammel nets for cuttlefishes, bottom set gillnets for the reef fishes, hook lines fishing for the perches and groupers.

February: The capture of shore shoaling pelagics, anchovies, sardines and mackerel.

March: Hooks & lines over reefs and other areas, gill nets for mackerel, ground-set nets and lines for groupers and snappers, deep sea lines for seerfish, sail fishes, dolphin fishes etc.

April: Lean period. Gill nets for mackerel, carangids, bottom-set nets for reef fishes like belones and lobsters.

May: Lean period. Gill net fishing for pelagics, belones, tunas, seer fish lines, gill nets for mackerel

June: Reef fishing for snappers and groupers, bottom-set gill nets for goat fishes, rays, crabs, lines for seer fishes.

July: Better fishing season. Bottom-set gill nets for rabbit fishes, mackerel, carangids and barracuda, halibut, drift gill nets for pelagics, lines for seer fish.

August: Better fishing season. Reef fishery with drift gill nets and hooks and lines, bottom-set gill nets for goat fishes, rabbit fishes, gerrids, halibut.

September: Lines for seer fish, groupers, gill nets for mackerel, carangids, barracudas, bottom set gill nets for rabbit fishes, drepanids, breams, crabs.

October: Good fishing season. Bottom set nets for shrimps, shore gill nets for pelagics like sardines, carangids, silver bellies, mackerel, and lines for seer fish, groupers, and snappers.

November: Bottom-set gill nets and surface drift nets for pelagics like carangids, lobsters, crabs, shrimps, smaller pelagics.

December: Surface and nearshore fishery of mullets, bottom-set gill nets for shrimps, reef fishes, rays, sciaenid, rabbit fishes, surface gill nets for sardines and ribbonfishes.

Fishing practices prevalent over the reefs:

1. **Direct**
    - Fishing by hooks and lines
    - Drift gill nets
    - Trap nets and surface seines
2. **Indirect**
    - Small hooks –live bait collection
    - Shadow fishing –temporary fads

A typical model fishing calendar and schedule can be introduced once the fishing patterns and resource trends are available. They may vary from village to village and therefore need to be perfected to each village and zone based on the reef performance and assemblage characteristic. These calendars could minimize energy and effort costs and look into resource health in a better manner and as well could add value to the caught fishes since they are from sustainable practices. These tools would serve as the first step toward AR assisting in coastal fisheries management.

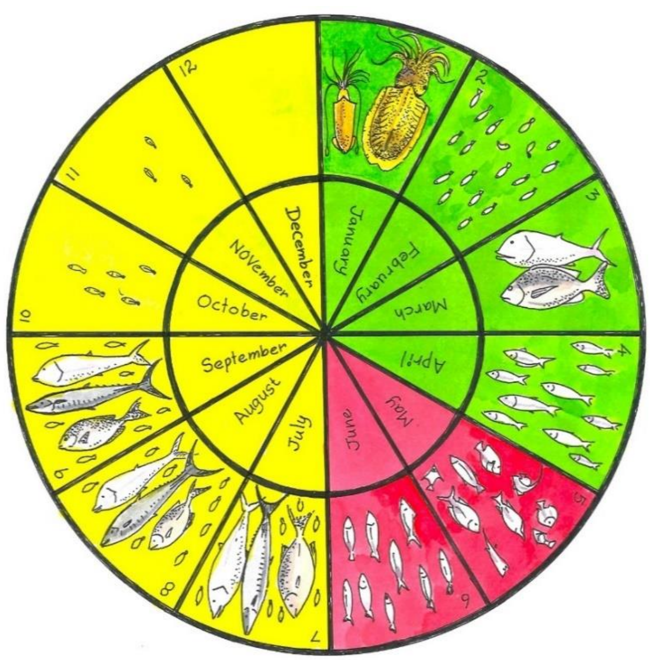


Fig.63. Model Seasonal calendar developed for AR site at Kovalam, Tamil Nadu

The calendars developed could be on different parameters

a. Fish availability and abundance
b. Migrants and visitors stay periods
c. Recruitments and nursing periods of important varieties
d. Aggregation and spawning intervals of important groups
e. Efficient fishing periods over reefs for select species and best periods for recommended sizes for capture
f. Periods of no fishing for select groups
g. Periods of good dives and visibility
h. Periods of annual visitors and large fishes, whale sharks
i. Periods of anoxia and upwelling
j. Periods for monitoring and ghost net clean-ups
k. Rotation of fishing amongst the AR patches and natural grounds and reefs.

Recreational fisheries

SCUBA Diving: When the water is clear and less violent and the sailing conditions are good, sport fishing and SCUBA could be a very interesting alternative for the youth to engage into eco-tourism.

Pole and lines: Live baits and jigs can attract fishes and thus be another option.

Troll lines: Having false baits and trolling over the reef sites in clear conditions can be a very good alternative for the capture of larger pelagics - seer fish, cobia, sharks, tunas, barracudas and coryphaenids for sport fishing.

Ornamental collections: A future scope for this is emerging and consistent brood stock and ranching to the ARs could possibly supplement the ornamental industry in a big way.

Breeder banks and juvenile repository: The breeding populations sheltering in the ARs could possibly give scope for the revival of a population: and this also gives us an opportunity to transplant/ relocate or ranch and wild release of select breeders onto the ARs sites and these programs could well be organized and supported through CSR fundings.

Transplantation and relocation space: The AR surfaces offer excellent spatial accommodation for the basic sedentary /immobile/ invertebrate colonial groups. Similarly, the shadow areas developed are ideally suited for the transplant of seagrasses, corals, pearl oysters and sponge colonies**.** They are also ideally suited for establishing marine ornamental brood banks in natural ecosystems. Typical examples are the success stories of transplant of kelp and ranching of sandfish and seabass in other countries. Cryptic species like the octopus and lobsters can revive their population abundance and thus the recruitment survival.

Live fish hold and trade: When the live fish trade becomes a trend and there is a good demand in the market, the AR offers immense scope for fresh capture and sustained availability for supply. If the sizes and the numbers are regulated by the ARSC members, this could see a premium jump in fish pricing and economic returns to the traditional fishers.

Data logging

After the formation of the ARSC in consultation with the leaders the expert team discusses the important functions and lead activities which they should perform during their administration. The roles and conditions are clearly mentioned, and include -

a. Record of the fish catches and boat details
b. Record on their average sizes and abundance
c. Record of off- season declarations and fishing moratoriums for a stipulated time.
d. Record of reef performance in terms of any damages, collapses, sunken, drifted or buried.
e. Record of diver's inputs on the fish stocks and habitat orientations and status of the diversity
f. Record of unwanted fishing practices, numbers, craft particulars, registration numbers and person and village names
g. Record any pictures or videos of such violations
h. Record of unusual observations such as whale sharks, dolphins, sawfish, hammer heads, dugongs, porpoises, and turtles
i. Record of ghost net presence and efforts on clean-ups
j. Minutes of successive meetings and concurrences with Panchayat leaders
k. Reports to the next-level leaders and other village leaders
l. Reports and complaints lodged with the AD Fisheries and ATR.
m. Review the benefits and note the decline of performance.
n. Agreements on the expansion and addition of the reef modules and the source of funding and budgeting
o. Reporting on the utility and management efforts to the ADF regularly.

Authentic records and documentary evidence will help in identifying violators of the system and penalizing them with reduced fishing days or subsidy cards, thus narrowing down the possibilities of errors on such field-level issues internally. An understanding of the efforts taken up by a community towards the preservation and revival of habitats and resources will attract attention and self-respect, and in turn, will be a motivating factor for others.

The ARSC log books will serve as an essential tool in understanding coastal fishery dynamics, resource characteristics, fluctuations and shifts during seasons, and long-term changes and impacts. This would serve as a perfect guide or reference point for future scaling up, sea ranching and transplanting trials for the enhancement of habitats and resources.

The installation of ARs and the involvement of the primary stakeholders in the frameworks of sustainable coastal fisheries management is the long-term goal of the program. With increasing coastal vulnerability and climate change impacts on coastal living and livelihoods, a **Sustainable Resilient Ecosytem** will be the best way forward.

In an open access system when competition with no limits is the rule, the resource takes a back seat and just participatory management alone is not a suitable solution to it. The extent of investments varies and the shares accordingly, but the sea cannot provide continuously. The AR in a stakeholder's purview and management involves his participation and operations, and resource utilization can see a revolutionary "U-turn" in the fishermen's attitude towards conservation and efficient management of valuable resources. ARs provide scope for an ownership/proprietorship framework and assist the progress in achieving the goals of sustainable harvesting and organizing management measures locally.

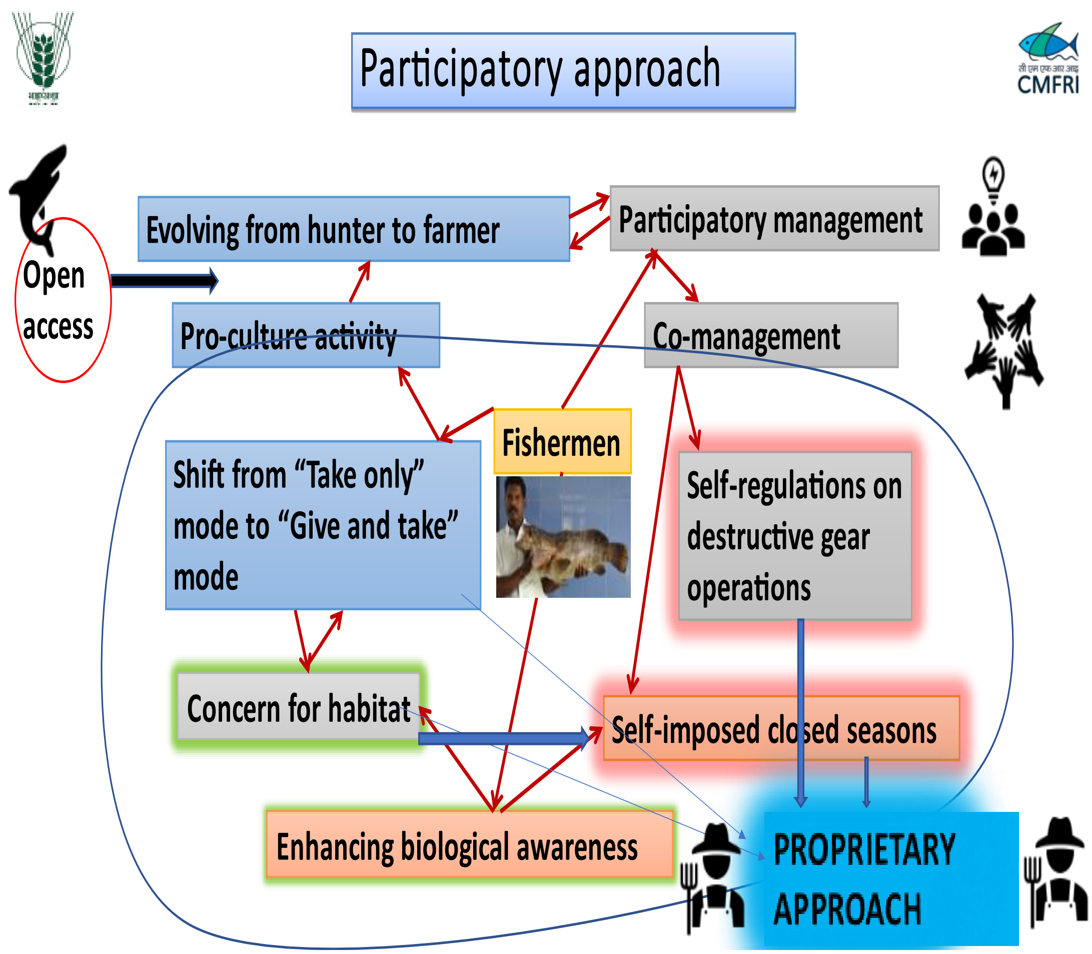


Fig.64. Evolution of participatory management concept towards the ownership/proprietorship approach by the intervention of Artificial reefs in the coastal systems.

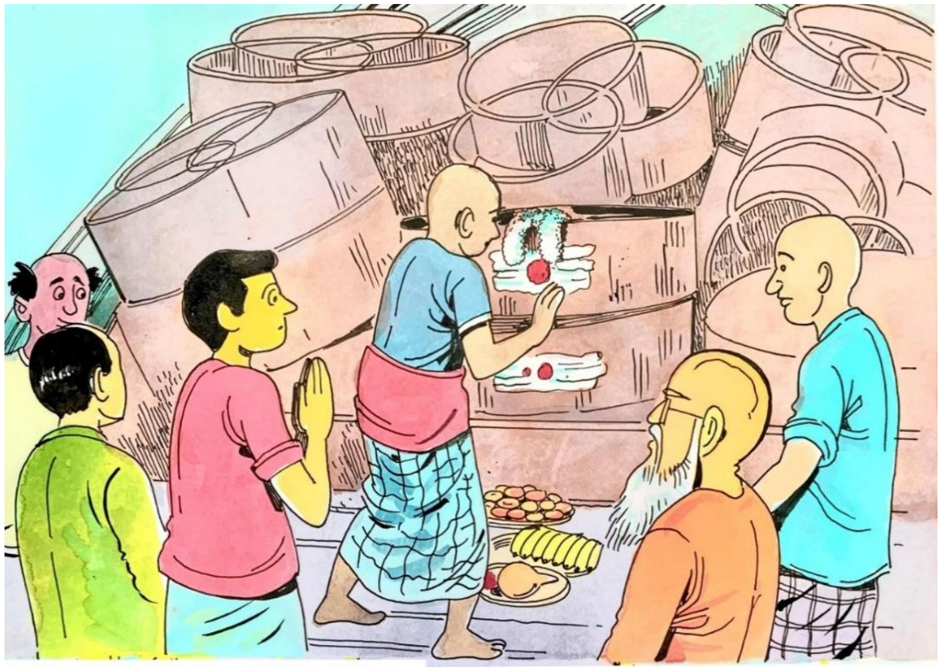


Fig.65. The fishermen at Nettukuppam offering prayers and worshipping the AR modules prior to the deployments indicating the intent, emotional and spiritual attachment to the resource wealth and its sustainability and the gifts from nature.

Fig.66. Interactions with villagers in different villages where artificial reefs have been deployed

Alert and stress indicators and fish behaviour/reporting

Joe K Kizhakudan.

Fishes are attracted to the reef mainly by visual sensors, light, acoustic signatures, chemical and chemosensory cues and shadows/shelter and feed availability. Different fish groups behave differently as they grow. For eg., barracudas remain in large shoals when juveniles but as they grow into larger adults they swim in groups of lesser numbers; similar instances are seen in spiny lobsters, gobiids, scorpion fishes, lion fishes and snappers. Smaller carangids, rabbit fishes and cardinal fishes continue to remain in the same populations in similar densities in all phases of their life. Therefore, an assessment should be made of selective species which are indicators of large assemblies, indicators of singular forms, and indicators of migrants and visitors separately, based on which judging the reef performance would be ideal.

However, artificial reefs are susceptible to negative impacts, both natural or induced, which may in turn negatively affect the reef communities. The ARSC members and the active fisher community should always remain in communication regarding the fishery and performance of the reefs and indicate the changes and information in their log books. Poor catch rates, reduced CPUE and lack of indicator species or signs of fish life should induce curiosity in the fisher's mind. In the event of such signs, they must demand an immediate inspection of the reef engaging a diver to verify whether the structures were physically removed or dismantled or rolled up in large nets.

If the AR modules are covered in ghost nets and the nets harbour large numbers of dead fishes, then they emanate a very bad smell into the adjoining waters and the fauna that have settled there moves out. Although this is a temporary phenomenon the impact can remain for at least a month. The nets then age with the reefs and become an integral part of the system because they assemble a lot of fauna and microorganisms, and many tiny creatures and fishes find these extra spaces as useful refugia. But these nets are extremely dangerous to marine mammals and reptiles and therefore, the AR sites are to be periodically monitored and cleaned.

Stressed fishes often search for adjacent reefs or shelters and move temporarily out until they find a suitable hide-out with sufficient feeds. The smaller groups and resident dwellers re-adapt to the changed structures; however, the corals and broken-shelled invertebrates lose out. The foraging fishes stay away for a long time when the ghost nets are with dead material. But larger predators remain.

The constitution of the ARSC empowers the members to raise, discuss and report the incidents and violations regularly through peaceful means to their fisher leaders, who can then report the matter to the adjacent village leaders; further, the matter can be represented to the State Department officials with evidence such as on-field photos or vessel registration numbers etc.

Alert signs:

1. Poor fish catch and rates
2. Fishes not biting the baits
3. Live fishes not available as earlier
4. The lead weights of the hook & lines and jigs getting entangled in nets
5. Indications of operations by other fishers employing bottom set gill nets and trammels
6. Indications of sepia nets and set gill nets
7. Indications or reports of trawlers operating over the sites
8. Indications of larger seine operators fishing over the sites
9. Dead fish floating
10. Anoxic conditions at the bottom, for instance, upwelling periods during August-September in Tamil Nadu bringing up the bottom fauna in a semi-sedated state. Even fishes which are truly benthic like the halibut and flat fishes and trigger fishes will surface indicating and zero oxygen state due to excessive bottom upwelling in the reef zone.

Essential dos and don'ts in artificial reefs

Joe K Kizhakudan, Shoba Joe Kizhakudan and Remya L.

The successful implementation of the AR in coastal waters, fisheries management and utilization depend on the following factors -

1. Proper site selection and stakeholders' agreements.
2. Well-built modules with good strength and durability.
3. Stakeholders' participation and responsibility sharing and ownership attitude.
4. Frequent maintenance shutdowns and visits and discussions between the leaders and the ARSC members.
5. Frequent additions and extensions to the reef area and expansion as the need arise, after sufficient review.

The essential activities to be followed strictly are (Dos)

a. Reporting and maintenance of daily fishing log entries on catches and revenue.
b. Following the weather and fishery forecasts from the responsible agencies.
c. Maintaining and regularly updating a chart of fishing periodicity and calendar relevant to the grounds and AR sites.
d. Sharing the coordinates of AR with all the fishers of the hamlet and the adjacent fishing villages.
e. The naming of the AR sites - this makes it convenient for memorizing, comparisons, and data recording.
f. Informing other fisher members and the ARSC members of the developments over the AR sites and issues.
g. Bringing to the notice of the ARSC, any uneventful or accidental stranding of nets or damages to the reef structures.
h. Expansion of the AR reef area and supplementation every third year since installation, partnering with any agency or from within.
i. Recording rare collections or observations/sitings and spawnings and aggregations of recruits and their seasons.
j. Observing a vacation for reef fishing or intervals of non-fishing over these areas.
k. Promoting the use of hooks and lines and surface jigs, and the live bait collection.
l. Promoting SCUBA enthusiasts among the fisher communities and making them guardians of the reef and promoting scope for eco-tourism.
m. Promoting more affiliations and ownership attitude towards the resources and habitats.

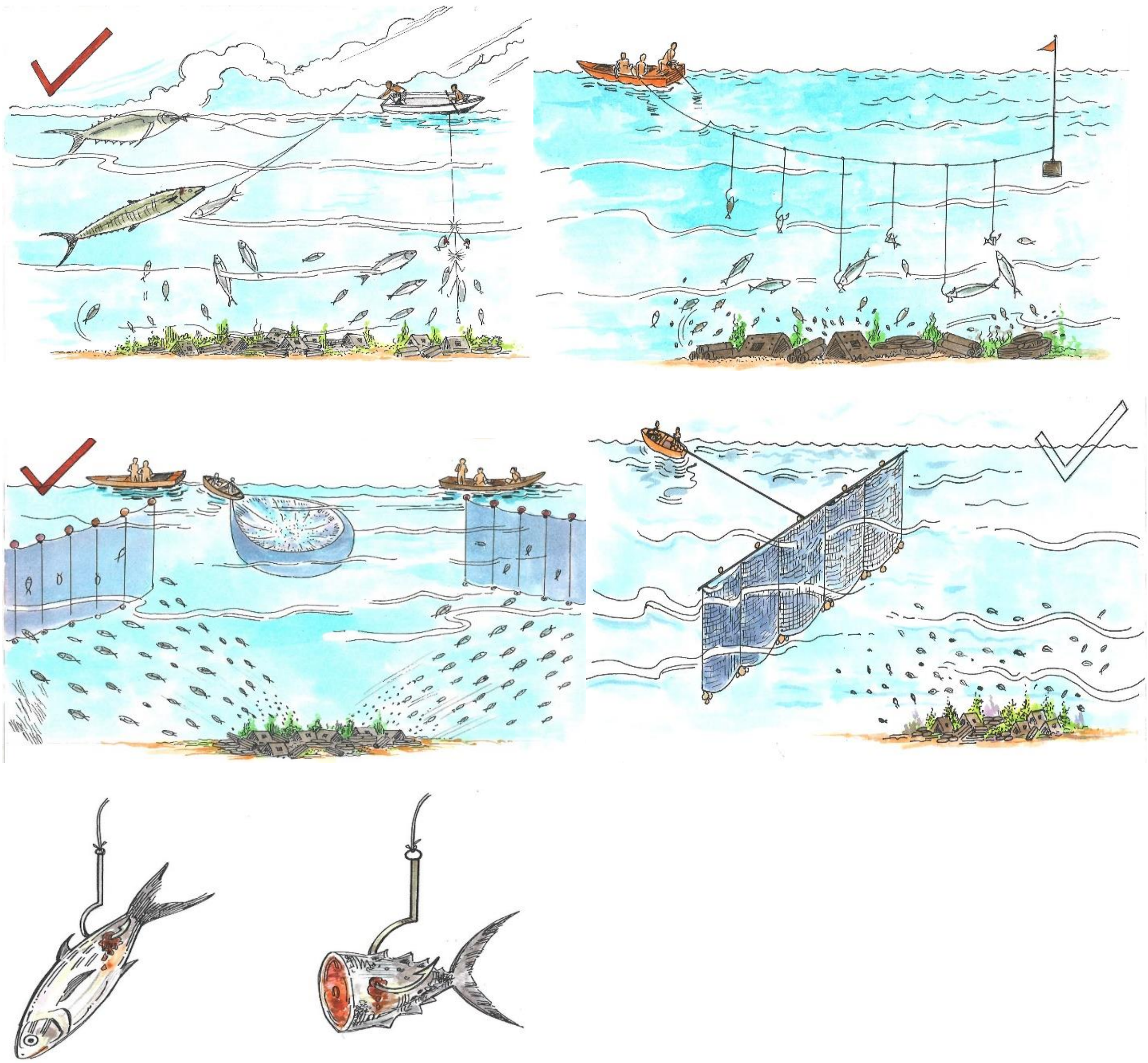


Fig.67. The best gears to be operated over artificial reefs are hooks & lines, baited lines and troll lines, drift gill nets (surface gill nets) and small bag nets. depending on the direction of currents and depth of operations. The reliance on the dead fish and meat is reduced by the availability of fresh live bait from the reef systems.

Fig.68. Worshipping the reef structures and naming/marking the sites have been noticed regularly, indicating the importance of the restoration of fish habitats in their livelihoods.

Fig.69. Regular upkeep of an AR site.

n. Developing project-based programs at fisher levels - inviting CSR-supported funds in promoting breeder/spawn/seed ranching programs, ghost net clean-ups, eco-tourism, and restoration programs.
o. Developing more coastal clean-up awareness programmes and sustainability camps.
p. Penalising the defaulters and devising a system to bring them to books.
q. Recording any untoward incident and deliberate, intentional or accidental, operation of illegal or unapproved gear over the AR area in the log book and the registers maintained

by the ARSC committee, which can then be presented to the fisher leaders and further, with their consent, can be referred to the Department officials for action.

r. Rewarding the best operating fisher and village on a biannual basis for the perfect upkeep and management of reef fisheries in an area.

The activities are which strictly to be avoided (Don'ts)

1. Do not allow any discarded vehicles and matter to be dumped as AR.
2. Do not use any bottom-set gears - gill nets, trammels nets, trawl nets, dredges, bottom seines and explosives in the AR.
3. Do not allow bottom trawlers to operate in the stipulated artisanal fishing limits in the vicinity of AR areas.
4. Discontinue the use of the above nets in this area and gradually decrease the harmful gear numbers in the fishing areas.

Fig.70. The practice of discarding or dumping unwanted and scrap items on the sea bed is against conventions and it should be avoided.

5. Do not discard any old or torn nets over reef areas.
6. Do not use lights and attract the reef fishes to gather the stock for fishing as this can lead to overexploitation.
7. Do not operate nets for the target species when they are juveniles and recruits.

Fig.71. Bottom dragging gears and efforts should be completely avoided over an AR site.

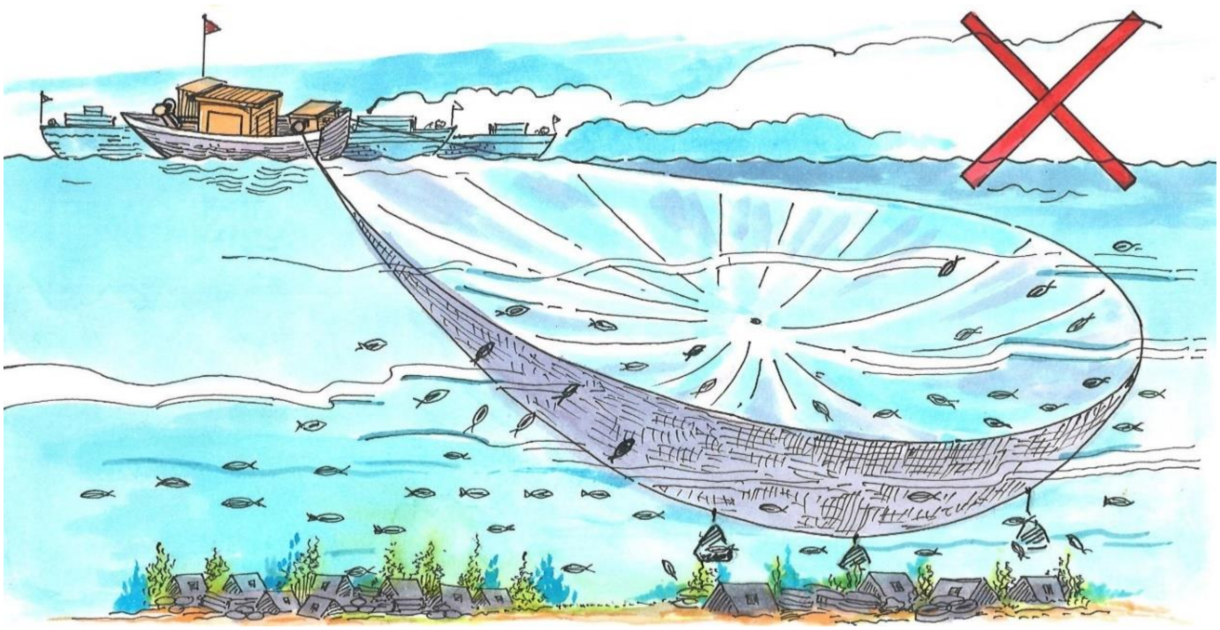


Fig.72. Large bag nets and seines with more bottom draft and drag should be avoided over AR sites.

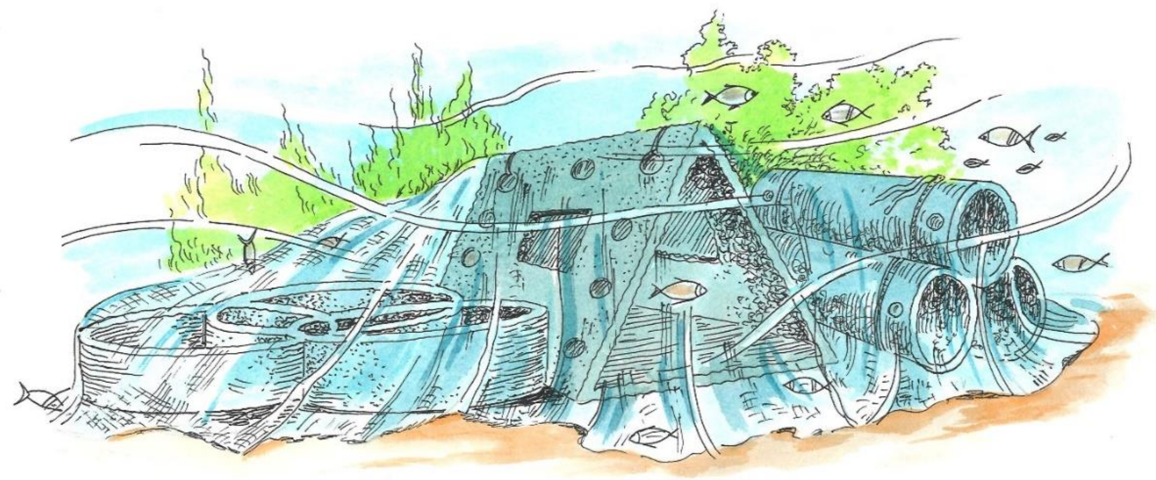


Fig.73. The bottom set gillnets, trammel nets and trap nets and drift gill nets are very detrimental to the AR reef life and shall create ghost fishing and spoil the environment.

8. Do not deliberately capture broodstock.
9. Do not let the ghost nets permanently disfigure and damage the reef faunal assembly.
10. Do not drag the reef area with anchors and heavy objects.
11. Do not let offenders continue the violation; that will lead to failure of faith in the management and governance.
12. Do not suppress the opinions and suggestions kept by reef fishers even when they are a minority.
13. Do not set up reefs in very shallow waters and nearshore areas.
14. Do not set up reefs in conflict zones or vulnerable zones.
15. Do not set up reefs in seagrass beds or coral reef areas, MPAs, sanctuaries (except when reefs are meant for conservation) and near industrial installations.

Economics, visible turnover, and impacts

Joe K Kizhakudan, Shoba Joe Kizhakudan, Geetha R, Remya L and Narayanakumar R.

An assembly of 150-250 units of the various modules at one village site constitute one Artificial Reef and this provides a faunistic support area of 0.10 Ha and 0.17 ha in the latest versions per site on the sea bed. The area of Influence of fish was observed to extend up to 200-300 m from the epicentre of the reef for surface and midwater fauna and up to 100 m for bottom fauna. Primary Efficient Boundary and Secondary Efficient Boundary were found to be 200-400 m and 400-600 m for surface waters, and 40-200 m & 200-400 m for bottom waters. Fish fauna was found to be **10 to 15-fold higher in bottom waters** and **20 to 25-fold higher in surface waters as compared to the adjacent non-reef area**. Maximum catch in gill nets were observed from 40-60 m extending from the periphery of the reefs. Nearly **10-15-fold** increase is observed in the number of fish species occurring per unit area of the reef when compared to the non-reef area in the same zone. The resources (**rare and over-exploited resources)** like large sciaenids (*Protonibea diacanthus*), blue spotted rays, sharks, parrot fishes, black perch, serranids and many grouper species are remerging at the reef sites. Several sites have established as spiny lobster seed settlements and cuttlefish breeding (egg attachment) grounds. Similarly, galatheid lobsters, pistol shrimps, camel shrimps, marbled shrimps, pearl oysters, edible oysters, mussels, amphioxus, polychaetes, echinoderms, sedentary coelenterates-corals, soft and hard etc. breed and multiply on the substrates.

The zooplankton and phytoplankton productivity in the reef adjoining waters and suspension is 2-3 folds from a non-reef area in terms of volume and density and the species diversity is also very high when compared to open adjacent waters. The benthic sediment biota is nearly 5-10 folds higher per sqm in numbers and 2-3 folds high in species diversity. The AR sites thus serve as corridors for fish settlement, movement, feeding and nursing and breeding, and also act as shelter and refreshment habitats like hotels and canteens for migratory groups and rehabilitation centres for the vulnerable ones, thus improving resilience to environmental stress and extreme impacts.

The developed sites after an initial incubation period of nearly 1 year stabilise the population balance over the reef in the third and fourth year and subsequently, they sustain a stable life and community structure with seasonal movements, additions and desertions and forage and predation for another 10 years. If the sediment texture is coarse and the bottom dynamics is not disturbed for a great instance, the units sustain longer. The **Benefit Cost ratio** values observed at a series of stations studied indicate the values ranging from **1.4** to **1.8**, indicating positive turnover and efficient returns. The studies in 2020 undertaken indicate the presence of a standing stock biomass over each reef site at around Rs 25 lakhs and commercial fisheries from an efficient reef site to be Rs 100 lakhs per annum. The present model can sustain 15-25 FRP outboard engine boats, operating in shifts and a maximum of 10-15 at the same time during currents and drifts. The present dimension and density can support 50 fishers directly engaged in small-scale fishing practices and another 50 who are indirectly involved.

The hook and line fishers have been able to improve the quality of fish catch, reduce their input costs by a reduction in fuel costs and scouting time and increased catch rates and thus the revenue to the tune of Rs 1200 to 4000 per trip. This has thus facilitated single fisher operations and reduced dependency and more independent savings. The trend of diversifying into smaller mesh-sized gill nets and using encircling nets and larger intensified efforts started to reverse when these reefs started to perform with traditional fishing methods and reduced input costs and manpower.

The artificial reef concept has thus reinstated the participatory role in marine fisheries management and the way forward to sustainability amongst the traditional sector. This has also helped in evolving strategies towards solutions towards conflicts arising out of sharing and use of unapproved gears or operating out of turns or seasons, thus bringing a feeling of self-discipline amongst the operators and getting serious behind such conservatory and long-term sustainable development goals.

The Artificial Reefs concept is developed fully to support the traditional artisanal fishermen, specifically the ones operating small-scale low investment crafts/gears and less energy dependent. The Artificial Reefs developed for coastal productivity are placed within the fishery jurisdiction of the traditional non-mechanised sector as per the state MFRA. This is to derive two distinct benefits for the resource and fisher stakeholders. (a) Promote productivity in the near coast and improve fish habitats. (b) Give better access to the traditional fishers, improve their economy and livelihood and reduce pressure on engines/fuel and manpower. And two indirect benefits: (a) Avoid bottom exploiting/habitat damaging gears and reduce conflicts and reduce soft sediment plain areas vulnerable to intensive mechanised exploitation. (b) Increase sustainable fishing practices by promoting of long lines, hooks & lines and drift gill nets.

With sustained efforts in this direction with relentless fisher participation and management efforts, the coastal productivity scenario can make a huge turn around in the coming years with sufficient efforts towards the fulfilment of the ecosystem restoration and conservation goals of the SDG.

The cost of one reef consisting of 250 reef modules creating approximately 1700 sq. m surface area ,400 cubic meters of volume can cost 35-40 lakhs depending on the site, distance from the nearest harbour, labour costs and transport charges. One good and well-deployed such site can ably support 25-30 fisher boats year-round and on an average income of Rs 25 lakhs and could go upto 100 lakhs if the sites are well managed into the fourth year onwards.

Table 6. Socio-Economic-Biological and Environmental benefits from Artificial reefs

1. Increase in Biomass	• **10-25 tones per reef site** • **10 fold increase in bottom fish biomass** • **25 times increase in pelagic & midwater fishes** • **300 time increase in Annual Biomass Flux over the reef area.**
2. Increase in Fish Catch	• 5-25 Kg/Sq.Mt • 2-3 times increase in Fish Catch • **25 lakhs worth fish catch per annum** • **Sea Ranching of Species** which have economic value and ecologically suitable
3. Increase in income	• Up to 70% increase in income is reported from hook & line fishing • Additional Livelihood opportunities like **Tourism like Scuba Diving, Snorkeling**
4. Savings in Fuel & Labor Costs	• 30% savings in Fuel Costs
5. Environmental Benefits	• Coral Restoration • **Attachment of natural coral recruits on ARs** • Enhancement of Biodiversity • Stabilization and Reconstruction of Islands • **reduction of wave energy and thereby coastal erosion**
6. Social Benefits	• **Participatory Approach and Co-Management** of the Reefs will promote ownership • Empower the Small & Artisanal Fishers by improving their income & livelihoods • Prevents Bottom Trawling in the Reef Sites

The overall impacts are in terms of reduced fuel consumption and costs and reduced gas emissions and therefor better carbon foot print advantages, reduced scouting time hence, time saved for social life. The togetherness in the management brings in more integration and social binding and equitable sharing creates a harmonious existence at village level.

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Annexure 1

ICAR-CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
MADRAS REGIONAL STATION

Artificial Reefs: Pre-installation benchmark survey

District:______________________________ Village________________________________

Form No. ____________________________ Date__________________________________

A. Personal details

Name	
Full postal address	
Phone number	
Age	
Education (tick whichever is applicable)	Not educated Primary classes S.S.L.C. level H.S.C level Graduate Post-graduate Others (Specify)
Fishing background	Family profession YES / NO Active fisher YES / NO Experience (in years)

B. Fishery characteristics

Peak season of fishing	
Types of fishing	
Time of fishing operations	
Distance of fishing grounds (km) from	

shore	
Depth of fishing operations	
Average number of fishing days in a month	
Number of trips/hauls per day	
Duration of trips/hauls (h)	
Actual fishing hours per day	
Major fishing holidays/season breaks	
Logbook maintenance	
GPS used?	
Any other technologies used?	
Neighbouring village co-operation/conflict	

C. Resource characteristics

Major species targeted	
Other species common in fishery	
Seasonal species (mention which season)	
Juvenile abundance (name the species and season)	
Disappeared or disappearing species	

New species occurrence or dominance	
Change in size of common species	

D. Economic indicators

Number of boats in village	
Number of active fishermen in village	
Boat owner/shareholder/labourer	
Boat length (ft)	
Engine (hp)	
Types of gears used	
Gears which give maximum catch	

E. Operational costs

Crew size (No of labourers)	
Labour and owner share (%)	
Total labour cost per day (Rs)	
Fuel expenditure (Rs)	
Maintenance charges (Rs)	
Ice cost (Rs)	
Bait cost (Rs)	

Tractor cost (Rs)	
Bata charges (Rs)	
Food charges (Rs)	
Total expenditure per trip (Rs)	
Catch per day (kg)	
Total value of the catch per trip/Gross income per trip (Rs)	
Net income per trip (Rs)	

F. Fixed costs

Year of purchase of boat	
Purchase price of boat (Rs.)	
Life span (years)	
Gears used	
Purchase price/fabrication charge of gear (Rs)	
Life span (years)	
Cost of engine (Rs)	
Life span (years)	
Subsidy (if any)	
Total investment on boat and net per year (Rs)	
Annual income (Rs)	
Regularity of fishing	

G. Marketing characteristics

Major market(s)	

Market structure	
Average price per kg (Rs) (species-wise)	
Demand-supply mismatch	
Marketing cost (Rs)	
Price spread (%)	
Middlemen's involvement	
Consumer's willingness to pay	

H. Financial aspects

Source(s) of income	
Major source for loans	
Burden of interest	
Saving for future	
Saving with	Bank Post Office Co-operatives Other (specify)

Indebtedness	
Membership in co-operative societies?	

I. Social aspects

Societal status	
Family size	
Gender disparity (Fisher women status)	
Women's involvement in marketing/earning	
Children's Education	
Health status	
Livelihood status	
Major occupation (self & family members)	
Allied activities for improving income	

J. Climate change

Recent environmental changes	
Awareness on climate change	

Impact of climate change felt in the fishery	
Knowledge of any adaptation or mitigation activities	

K. Artificial reefs

Awareness on artificial reefs	
Have artificial reefs been installed earlier in this or any neighbouring village	
Impact of artificial reefs observed	
ITKs on artificial reefs	

Do you want artificial reefs to be installed?	
Do you think more artificial reefs can be maintained/increased by the village, without government support?	

L. Institutional interventions

Government agencies active in the village	
NGOs active in the village	
SHGs active in the village	

Name of enumerator ____

Address ____

____

____

Mobile ____

Signature

Annexure 2:

Contacts of firms and individuals who have been associated for the AR program in TN and Kerala, thus far

Deployment vessels with experience and expertise (100-120 ft OAL) 400-ton GRT:

1. K.A. Shipping, No.5, Arunachalam Nagar, Velli Semmandalam, Cuddalore. Ph:9443150706.
2. R.Kumaran, No.3, Krishna Nagar, Extension Dawalat Nagar, Semmandalam, Cuddalore. Ph:9443220309.
3. R.Mukundan, 9/1, Friends Nagar, Semmandalam, Cuddalore. Ph:9443225255.
4. R.Velavan, 9/1, Friends Nagar, Semmandalam, Cuddalore. Ph:9443266177.

Experienced Civil Contractors:

1. EJJ Constructions, No.1, Raghavendra Street, Yeshodambal Nagar, Thenpalani Nagar (Extn.), Kolathur P.O., Chennai – 600 099. Ph:9444822390; 9566076211.
2. VPM Projects, K. Vediyappan, Managing Partner, No.6/173-2, Uthukinathuvalavu, Earikarai, Kalparapatty Post, Salem South Taluk, Vembadithalam, Salem – 637 504.Ph:9965877130; 9443770832.
   Email: vpmprojects2021@gmail.com

Experienced SCUBA Divers:

1. Aravind S.B., Temple Adventures, 9, Archbishop Gandhi Street, 1st Road, Opposite Indira Gandhi, Colas Nagar, Puducherry – 605001. Ph:9940219449. Email: sbaravind10@gmail.com
2. Venkatesh P., Ocean Delight Scuba, No.1/191, Carmel Nagar, Kovalam -603112. Tamil Nadu. Ph:9841486218. Email: venkatsurf5v@gmail.com
3. Aquba Outback, Arjun Motha, No.105, 2nd Street, Tooripuram, Thoothukudi, Tamil Nadu -628003. Ph:9894111277.
4. Jehaan, Quest Adventure Sports Academy, Dive & Surf Centre, No.1/1164, Beach road, Pirapanvalasai Village, Ramanathapuram, Tamil Nadu – 623516. Ph:9820367412; Email: info@quest-asia.com

Annexure 3:

Contacts of Department of Fisheries/ R&D Agencies in Coastal States and UTs of India

The Secretary, Department of Agriculture, Cooperation and Fisheries, 7, Sardar Bhawan, 6th Floor, New Sachivalaya Complex, Government of Gujarat, Gandhi Nagar-382 010 Fax No.079-23252480 Email: seccpd@gujarat.gov.in	The Principal Secretary, Fisheries Department Aquaculture, Aquatic Resources and Fishing Harbours, Government of West Bengal, Writer's Building, Kolkata-700 001 Fax No.033-22141346/22143929 Email: secfisheries@wb.gov.in
The Secretary (Fisheries), Union Territory of Daman & Diu, and Dadra & Nagar Haveli Secretariat, Moti Daman - 396 220 (Fax No.0260-2230383) (Email: collector-dnh@nic.in)	The Secretary-cum-Commissioner, Government of Odisha, Fisheries & AR. Department, Bhubaneshwar-751 001 Fax No.0674-2390681 Email: itsec@ori.nic.in
The Secretary, Government of Maharashtra, Department of Agriculture, Animal Husbandry Dairy Development & Fisheries, Mantralaya Annexe, Mumbai - 400 030. Fax No.022-22026139 Email: sec.adf@maharashtra.gov.in	The Principal Secretary, Government of Andhra Pradesh, Animal Husbandry, Dairy Development & Fisheries Department, H-Block, Secretariat, Hyderabad – 500 002 Fax No.040-3450279 Email: prlsecy_ahf@ap.gov.in
The Secretary (Fisheries), Government of Goa, Secretariat, Porvorim, Panaji- 403 521 (Goa) Fax No.0832-2419687 Email: neeraj.semwal@nic.in	The Secretary, Government of Tamilnadu, Animal Husbandry & Fisheries Department, Secretariat, Chennai - 600 009. (Fax No.044-25672937) (Email: ahsec@tn.gov.in)
The Secretary, Government of Karnataka, Animal Husbandry & Fisheries Department, Secretariat, 4th Floor Vikasa Soudha, Dr. B.R. Ambedkar Veedhi Bangalore – 560 001 Fax No.080-22253734 Email: prs_ahf@karnataka.gov.in ; prsahf@gmail.com	The Secretary (Fisheries), Government of Puducherry, Chief Secretariat, Goubert Avenue, Pondicherry- 605 001 Fax No.0413-2334036 Email: dhte.pon@nic.in
The Principal Secretary, Government of Kerala,	The Secretary (Fisheries), Andaman & Nicobar Administration,

Department of Fisheries, Secretariat, Thiruvanathapuram-695001 (Fax:0471-2333115) Email: prlsecy@lsg.kerala.gov.in	Port Blair- 744 101 Fax No.03192-232479 Email: gangavalli2003@yahoo.com
The Secretary (Fisheries), Administration of the Union Territory of Lakshadweep, Department of Fisheries, Agatti Island- 682 555 Fax No.04896-263896/262184 Email: mishra.op@gov.in ; secy-home.gov.in ; fisheriesdirectorate@gmail.com	The Director of Fisheries, Government of West Bengal, 31, GN Block, Sector-5, Salt Lake City, Kolkatta - 700 091. (Phone No.033 – 23576416, 033-23577783) (Email: dfwb_kol@hotmail.com)
The Commissioner of Fisheries, Government of Gujarat, Dr. Jivaraj Mehta Bhavan, Block No. I 0, 3rd Floor, Gandhi Nagar - 382 010 (Fax No. 079-23253730) (Email: commi-fisheries@gujarat.gov.in)	The Director of Fisheries, Government of Orissa, Dry Dock, Jobra, Cuttak-753 007 (Fax No.0671-2414739) (Email: director.odifish@gmail.com)
The Director of Fisheries, Fisheries Department, Union Territory of Daman & Diu, Silvasa (Fax No. 0260-2230689) (Email: fish-daman-dd@nic.in)	The Commissioner of Fisheries, Department of Fisheries, Government of Andhra Pradesh, Matsya Bhavan, Shanthinagar, Hyderabad - 500 028. (Fax No.040 - 23376256) (Email: comfishap@gmail.com)
The Commissioner of Fisheries, Government of Maharashtra, Taraporewala Aquarium, Netaji Subhash Road, Charni Road, Mumbai - 400 002. (Fax No.022 - 22822312) (Email: commfishmaha@gmail.com)	The Commissioner of Fisheries, Department of Fisheries, Government of Tamil Nadu, Administrative Office Buildings, Teynampet, Chennai - 600 006 (Fax No.044 - 243335585/24320791) (Email: coffisheries@gmail.com;/tnfisheries@nic.in)
The Director of Fisheries-cum Joint Secretary (Fish), Department of Goa, Dayanand Bandodkar Marg, Panaji - 403 001. (Fax No.0832 – 2224660/ 2227780) (Email: dir-fish.goa@nic.in)	The Director of Fisheries, Department of Fisheries, Government of Pondicherry, Botanical Garden Premises, Puducherry - 605 001. (Fax No.0413 - 2220614) (Email: secyrev.pon@nic.in)
The Director of Fisheries, Department of Fisheries, Government of Karnataka,	The Director of Fisheries, Andaman & Nicobar Island, Port Blair - 744 101.

No.3, Podium Block, Vishvesharaiah Centre, Dr. B.R. Ambedkar Veedhi, Bangalore - 560 001 (Fax No.080-22864619) (Email: dfkarnataka@rediffmail.com; ramacharya.63@ka.gov.in)	(Fax No.03192 - 231474) (Email: dirfish.and@nic.in)
The Director of Fisheries, Government of Kerala, Directorate of Fisheries Vikas Bhavan, Thiruvanathapuram - 695 035. (Fax No.0471 - 2303160) (Email: fisheriesdirector@gmail.com/ ddfmarinehq@gmail.com)	The Director of Fisheries, Administration of Union Territory of Lakshadweep, Department of Fisheries, Kavaratti Island, Kavaratti - 682 555 (Email: lk-dof@nic.in)
The Director, Central Marine Fisheries Research Institute (CMFRI), Post Box No. 1603, Ernakulam North P.O., Kochi - 682 018 E Mail: director.cmfri@icar.gov.in	The Director, National Institute of Ocean Technology (NIOT), Velacherry - Tambaram Main Road, Narayanapuram, Pallikaranai, Chennai - 600 100. Tamilnadu E Mail: ramadass@niot.res.in / ramadass.niot@gov.in
The Director, Central Institute of Coastal Engineering for Fishery (CICEF), Bangalore – 560 013 E Mail: director@cicef.gov.in	The Director, Central Institute of Fisheries Nautical Engineering Training (CIFNET), Kochi - 682 016. E Mail: cifnet@nic.in / directorcifnet.1963@gmail.com
The Director General, Fisheries Survey of India, 2nd Floor, Sasson Dock, Colaba, Mumbai - 400 005 E-Mail: dg@fsi.gov.in / dg-fsi-mah@nic.in	PS to Joint Secretary (Marine Fisheries), Department of Fisheries, M/o. FAH&D, New Delhi - 110 001
Dr. Joe K. Kizhakudan Principal Scientist, PI &Coordinator of ToT Program Madras Regional Station of ICAR-CMFRI No.75, Santhome High Road, MRC Nagar, Raja Annamalaipuram CIBA Campus, Chennai 600028. Ph: 9445153671; 9790908299, Email: jkkizhakudan@gmail.com ; joe.kizhakudan@icar.gov.in ; cmfrichennai@gmail.com	

Contacts of Regional centres/Stations of Central Marine Fisheries Research Institute

Head Quarters at Kochi

The Director
Central Marine Fisheries Research Institute
Post Box No. 1603, Ernakulam North P.O.,
Kochi-682 018. Phone: +91 484 2394357 /12, 2391407, 2394867, 2397569, 2394268 /96, 2394750
Fax : +91 484 2394909; E-mail : director.cmfri@icar.gov.in

Regional Centres of CMFRI

Head-in-Charge Mandapam Regional Centre of CMFRI Marine Fisheries P.O. Mandapam Camp-623 520 Tamil Nadu. Email: scientistincharge.incharge@gmail.com /mandapam.cmfri@icar.gov.in Tel : +91 4573 241456; Fax : +91 4573 241502	Head-in-Charge Visakhapatnam Regional Centre of CMFRI Andhra University P.O. Behind Aqua Sports Complex Visakhapatnam-530 003 Andhra Pradesh. Email: cmfrivsp@gmail.com / visakhapatnam.cmfri@icar.gov.in Tel : +91 891 2543793, 263779; Fax : +91 891 2543154
Head-in-Charge Mangalore Regional Centre of CMFRI, Post Box No. 244, Bolar Mangalore-575 001 Dakshina Kanara, Karnataka. Email: cmfrimng@gmail.com / mangalore.cmfri@icar.gov.in Tel : +91 824 2424152; Fax : +91 824 2424061	Head-in-Charge Vizhinjam Regional Centre of CMFRI, P.B. No. 9 Vizhinjam P.O., Thiruvananthapuram-695521, Kerala. Email : vrcofcmfrivzm@gmail.com / vizhinjam.cmfri@icar.gov.in Tel : +91 471 2480224; Fax : +91 471 2480324

Regional Stations of CMFRI

Scientist-in-Charge Veraval Regional Station of CMFRI Bhidiya Plot, Near B.M.G. Fisheries Veraval-362 269, Gujarat. Email : cmfrivrl@yahoo.co.in / veraval.cmfri@icar.gov.in Tel : +91 2876 231865; Fax : +91 2876 231865	Scientist-in-Charge Tuticorin Regional Station of CMFRI South Beach Road (Near Rochi Park) Tuticorin-628 001 Tamil Nadu.Email : trc.cmfri@gmail.com / tuticorin.cmfri@icar.gov.in Tel : +91 4612320274; Fax : +91 461 2322274
Scientist-in-Charge Mumbai Regional Station of CMFRI C/o Central Institute of Fisheries Education (Old Campus)	Scientist-in-Charge Madras Regional Station of CMFRI CIBA Campus 75, Santhome High Road

Fisheries University Road Seven Bungalows, Versova Mumbai - 400 061. Maharashtra. Email : cmfrimumbai@gmail.com / mumbai.cmfri@icar.gov.in Tel : +91 22 22845260; Fax : +91 22-22822653	Raja Annamalai Puram Chennai - 600 028, Tamilnadu. Email : cmfrichennai@gmail.com / madras.cmfri@icar.gov.in Tel :+91 44 24617264, 24617310; Fax : +91 44 24617290
Scientist-in-Charge Karwar Regional Station of CMFRI Post Box No. 5 Karwar, North Kanara – 581 301, Karnataka. Email : ddokwr@gmail.com / karwar.cmfri@icar.gov.in Tel : +91 8382 225165; Fax : +91 8382 221371	Scientist-in-Charge Calicut Regional Station of CMFRI P.B. No. 917 West Hill P.O. Kozhikode-673 005, Kerala. Email : cmfricalicut@gmail.com / calicut.cmfri@icar.gov.in Tel : +91 495 2382033; Fax: +91 4952382011

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