Fishery Technology 60 (2023) : 240 - 246

Artificial Reef Deployment in North Bali, Indonesia: An Innovative Strategy to Rebuild Reef Ecosystem in Climate Change Affected Area

Anju P.[1*], Sariga P. K.[2], Mini Sekharan N.[2], Swagat Ghosh[1], Nidhin Balachandran[3] and Gayatri Reksodihardjo-Lilley[4]

[1*] *Sasya Shyamala Krishi Vigyan Kendra, Ramakrishna Mission Vivekananda Educational and Research Institute (RKMVERI), Arapanch, P.O. Sonarpur Dist. South 24, Kolkata - 700 150*

[2] *School of Industrial Fisheries, Cochin University of Science and Technology, Lakeside Campus, Foreshore Road, Kochi, Kerala - 682 016*

[3] *Centre for Marine Living Resources and Ecology (CMLRE), Kochi, Kerala - 682 508*

[4] *LINI (Yayasan Alam Indonesia Lestari), Denpasar, Bali 802 26, Indonesia*

Abstract

Cyanide fishing, ghost fishing, explosive fishing and other destructive practices are already impacting the reefs and the scenario may get worsened by climate change. As a result of climate change, coral bleaching and coastal erosion is taking place, because of the drastic change in the oceanographic conditions, such as currents, salinity, surface water temperature and waves. Increase in temperature and salinity are particularly harmful to corals, marine fish, and benthic organisms associated with reefs. In order to address the impacts of climate change, it is necessary to develop adaptive measures. As a means of restoring reef ecosystems deteriorated by exploitation, natural calamities and climate change, artificial reef deployment is being investigated as an adaptive strategy. As part of this study, artificial reefs were deployed in the Pacific Ocean in North Bali, Indonesia in assistance with the reef restoration activities by the non-governmental organization LINI (Yayasan Alam Indonesia Lestari) Aquaculture and Training Centre (LATC). Three types of artificial reefs were constructed (Roti buaya, Shrimp pots and Fish domes). Fish and corals were less abundant in places where these structures were deployed. All deployed structures were found to be thriving with coral and fish species after deployment. The deployment strategy of artificial reefs was effective in creating microhabitats.

Keywords: Roti buaya, shrimp pot, fish dome, adaptive strategies, reef conservation, coral reef

Received 11 February, 2023; Revised 12 September 2023; Accepted 03 October 2023

Email: girijadevika@gmail.com

Introduction

One of the biggest problems faced by all living organisms is climate change. By 2100, the temperature is projected to rise by up to 6.4 ºC, posing serious environmental problems for our ecosystems (IPCC, 2007). The effects of climate change on fishing communities will rely on the susceptibility of the ecosystems and target species, as well as the capacity of the fishermen to adapt to the shift (Grafton, 2010). The ecological regions that host fish populations are especially susceptible to the effects of climate change (Brown et al., 2010). Climatic changes have an impact on every aspect of the planet, including the environment, living things, community and population patterns (McCarthy, 2001; Walther et al., 2002; Fukasawa et al., 2004). Climate change threatens the viability of marine fisheries and is predicted to exacerbate already-existing biophysical, social, and economic constraints (Cochrane et al., 2009). Dredging, reclamation, pollution, diseases, pests (boring sponges and bivalves), cyclones, erosion, siltation, diseases, pests, indiscriminate exploitation of corals and the associated flora and fauna, algal blooms, and global warming are additional natural processes that have threatened the reef ecosystem (Korakandy, 2008). The sustainability problems that the reefs currently encounter due to cyanide fishing, ghost fishing, explosive fishing, and other damaging practices are made worse by climate change. The effects of climate change include coral bleaching, variations in sea and air surface temperatures, coastal erosion, and modifications to oceanographic conditions such as currents, salinity, and waves. Marine ecosystem health depends critically on the health of the reefs. This makes the creation of adaptable measures for climate change consequences necessary. Restoration techniques aid in restoring the reef ecosystem that has been damaged by environmental problems and climate change. Deploying artificial reefs is one of the methodical adaptive technique that can be employed.

An archipelago, Indonesia has 3.1 million km^2 of coastline with 17,500 islands in it and 51,000 km^2 of coral reef. The two primary pillars of their economy are fishing and tourism. More than 2,200 different kinds of coral reef fish and 400 different types of corals can be found on the island. Because Indonesians have fewer options to contribute to the GDP and are therefore aware of system changes, any change to the fisheries stock would have an impact on the country's economy and way of life. Artificial reef submerged breakwaters (Goliath Ball, Super Ball, Ultra Ball, Reef Ball, Pallet Ball, Bay Ball and Mini-Bay Ball) were employed for beach restoration and stabilisation by wave attenuation and wave refraction in Florida, Thailand, and the Caribbean for post-hurricane reef restoration. These techniques include coral rescue and propagation, eco-tourism, environmental enhancement, and biodiversity replenishment. (Harris, 2009).

However, the efficiency of artificial reefs remains a contentious issue. Artificial reefs are one of the main tools used by marine conservationists to restore coral reefs around the globe. They are made from a variety of natural or synthetic materials, and come in an infinite number of shapes and styles. It is a submerged structure placed on the seabed to mimic some functions of a natural reef, such as protecting, regenerating, concentrating and enhancing populations of fishes, invertebrates and corals.

Les is a traditional fishing community on Bali's north eastern coast. In the pre-deployment survey, it was noted that the region was sparsely populated with fish, and corals were hardly present. By providing alternate gathering locations such as roti buaya, fish domes and prawn pots, the project hoped to restore a damaged reef ecology and lessen the fishing load on natural reefs. The ability to create and use artificial substrates, erect coral tables, and manufacture coral plugs gives fishermen other sources of revenue.

This study was undertaken to evaluate the performance of artificial reef structures placed in the Pacific Ocean, Les Village, Buleleng District, North Bali, Indonesia.

Materials and Methods

The study was conducted in the North Bali region of Indonesia, encompassing specific reef sites in the coastal areas of Pacific Ocean (8.1373° S, 115.3750° E) near Desa Les, Les village, Buleleng District, North Bali, Indonesia (Fig. 1). LINI (Yayasan Alam Indonesia Lestari), an NGO working towards the conservation and sustainable trade of ornamental fishes and corals was involved in the study. The deployment area was 7 m from shore line and 5-12 m in depth from surface. The specific location for study was selected through random sampling.

North Bali, Indonesia, is located within the Pacific Ocean, situated in a tropical region, resulting in warm water temperatures throughout the year. Sea surface temperatures in this area typically range from 26 °C to 30 °C (79 °F to 86 °F). The warm waters are conducive to the growth of diverse marine life, including coral reefs. North Bali is renowned for its coral reef ecosystems, which thrive in the warm, clear waters. These reefs are home to a diverse array of coral species and marine life, making them a popular destination for snorkeling and scuba diving. North Bali, is situated on the Pacific Ring of Fire, characterized by active volcanoes. Volcanic eruptions can occasionally impact water quality and marine ecosystems, especially in areas close to volcanic activity. The salinity of seawater in the Pacific Ocean, including the waters off North Bali, Indonesia, typically ranges from approximately 33 to 37 parts per thousand (ppt).

Climate change has significant and detrimental impacts on the coral reef ecosystems in North Bali, Indonesia, within the Pacific Ocean. These impacts are a growing concern and have long-term consequences for the health and resilience of these valuable ecosystems. Impacts such as coral bleaching, ocean acidification, extreme weather events, sea level rise, altered ocean currents, increased water temperature variability, disease outbreaks etc. have

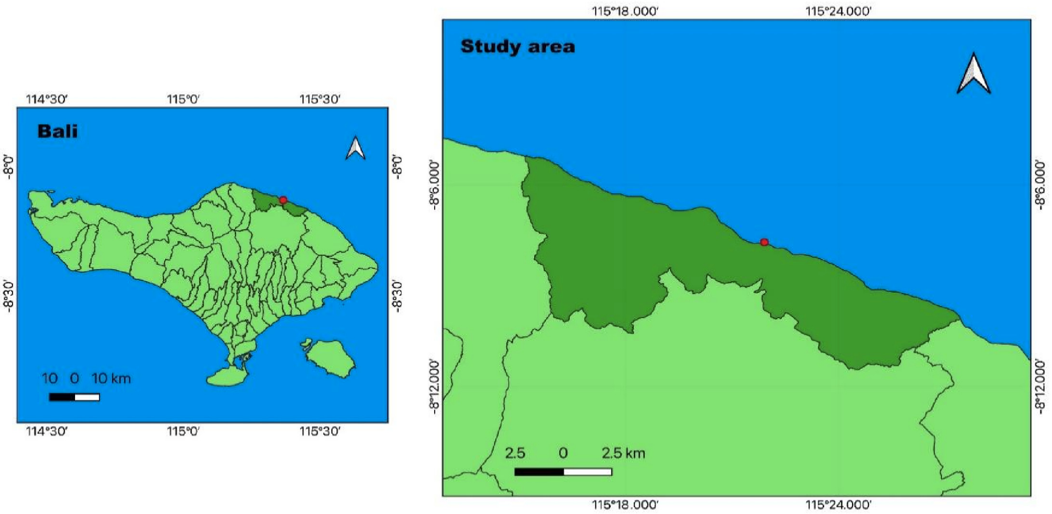

Fig. 1. Study area in Desa Les, Les village, Buleleng District, North Bali, Indonesia

cumulative impacts and can reduce the overall resilience of coral reefs. Weakened reefs may struggle to recover from disturbances, and their ability to provide habitat and support biodiversity diminishes. The following criteria were considered for site evaluation before the artificial reef deployment (Pre construction phase); presence of natural reefs nearby, areas with patchy reefs and low species diversity, sandy and destroyed coral system to position the artificial reef, presence of broken coral reef, deteriorating environmental quality and areas with coral bleaching. Based on the above mentioned criteria a degraded habitat was selected through reef survey. The species wise abundance of reef fishes in the area selected was recorded.

This study was undertaken to evaluate the performance of artificial reef structures placed in the Pacific Ocean, Les Village, Buleleng District, North Bali, Indonesia in increasing the fish abundance in the climate change affected area.

The most common observational method for studying shallow (< 20 m) reef fish is an underwater visual survey (UVS) by snorkeling. Snorkeling with underwater video recording and line transect methods were used for assessing diversity and reef assemblages of fishes. Data on the habitat, physical features of fishes and invertebrates and its quantification were recorded by snorkeling with under water pen and clipboard. Transect lines (English et al., 1997) having 10 m were set up horizontally to the coast and 3 m on either side of transect line. Artificial reefs were constructed using cement, sand, calcium, iron rods (8 mm diameter), wire mesh, wooden pipe pieces (3/4 inch) and nails (5 cm). Roti buaya (0.5 m) functions as supporting structures for the growth of corals, Fish dome (1 m) (Fig. 2) act as structure for protecting reef fishes and supporting the growth of corals and Shrimp pot (0.3-0.4 m) provides a hide out for shrimps.

Sea mobilization was carried out by attaching the artificial reef to a buoy and carried over an on-board boat. Scuba divers deployed the structures in predetermined places (5 – 12 meter) and then arrange it in different shapes in proper positions. Once the artificial reefs were set up, scuba divers plugged coral fragments into these reef structures. Shrimp pots were deployed at a depth of >20 m. A total of 2000 artificial reefs were deployed by LINI in

Fig. 2. Artificial reef (fish dome) preparation

different selected regions till date. LINI deployed 116 Roti buaya and 12 fish domes during the period (2017 – 2018).

Fragments of coral Acropora (*Acropora granulosa* from Fishdome, *Acropora loripes* and *Acropora muricate* from roti buaya) between 5 and 10 cm size were harvested using steel pliers. They were transported to the aquaculture center in containers filled with sea water (Transport time <10 min). Fragments of Acropora were attached using glue to the cement bases. They were placed in cement tanks with approximately 5000 L seawater for growth. Aeration was provided. The regenerated fragments (1 month) were brought to the experimental site and attached to the artificial reef structure. These artificial reef structures were constructed and deployed (1 fish dome, 2 roti buaya and 3 shrimp pot) in places where fish and corals were found to be destroyed. Visual survey was conducted to assess the fish species assemblage.

Data analysis was done using SPSS software; the sum of each species identified was counted and descriptive statistics were performed. The significant difference between the number of individuals obtained from each family before deployment and after deployment was calculated using Paired t test. The p value was calculated to determine the significance of results.

Results and Discussion

Climate change has a wide range of effects on ocean ecosystem. Coral bleaching is one of the most obvious and worrisome consequences, but disease, temperature change, sea level rise, stronger storms, changes in ocean currents, and ocean acidification are all expected to have an impact on coral reefs (McClanahan et al., 2001). In order to lessen stress and promote speedy healing for the corals, artificial reefs were constructed for the study. Around the world, artificial reefs are set up to attract fish and make it simpler to collect them for human consumption. In addition, it is employed for fisheries management, fish stock augmentation, and habitat restoration (Fabi et al., 2015). The study region frequently experiences tsunami, earthquakes and sea level rise. After the installation of artificial reefs into the environment, it was seen that the study area had attracted a substantial number of fishes and had been effective in creating a stable parallel habitat.

When coral reefs are physically degraded, fish diversity and biomass often decrease significantly (Alcala & Gomez, 1987). This statement is consistent with the present research findings, which showed that fish distribution was sparse during the pre-deployment survey. Reef fishes are dependent on coral and are adversely affected by coral loss right away (Wilson et al., 2006). Communities in Indonesia took part in coral cultivation actively. Corals grown at facilities along the coast are plugged into man-made reefs, giving fish that depend on natural reefs a comfortable place to hide, breed, nest and sleep. The study discovered that encouraging coral regeneration is vital since herbivorous fish make up the majority of the species that have returned to the artificial reef habitat. Both ex situ and in situ methods can supply enough coral for commerce, decreasing the need to gather coral colonies from the wild (Borneman & Lowrie, 2001). According to the findings of our present investigation, there has been a noticeable increase in the number of fishes visiting artificial reef structures since the coral pieces first began to grow. According to Heeger & Sotto (2007), transplanting corals directly from the reef to the area that has degraded is the cheapest technique of coral reproduction (Ammar, 2009). Based on the proportion of live coral, which includes Acropora and non-Acropora life forms, it is possible to assess the health of coral reefs in the surrounding seas. After artificial reefs had been in place for a year, a large Acropora population had developed there. Fast-growing branching corals like Acropora and Pocillopora spp. are appropriate for planting on artificial reefs due to its hardy fast growing nature. Reef restoration strategies include coral transplantation, to repair damaged reefs and increase the habitat of the reef (Auberson, 1982; Harriott & Fisk, 1988; Guzman, 1991; Bowden-Kerby, 2001). According to Harriott & Fisk (1988), adding existing colonies with a higher probability of surviving and a quicker growth rate is the primary objective of coral transplanting in order to avoid the early sluggish development stage. According to Edwards & Clark (1998), Lindahl (1998), and Lindahl (2003), transplanting boosts biodiversity in a region that is damaged, providing habitat for fish and other organisms that are associated to reefs. Additionally, it helps rare species to survive. Coral recruitment to the area can be enhanced by utilising branching transplants that reproduce asexually (Highsmith, 1982; Harriott & Fisk, 1988).

The population of the fish aggregating around the structures were counted (Table 1). *Zanclus cornutus*, one of the four fish species studied, was discovered to be aggregating in significant numbers around the artificial structures (56.25 %), whereas *Chlorurus Bleekeri* made up 18.73 % of the total number of fish present. It was discovered that the populations of *Chaetodon decussatus* and *Fistularia commersonii* (12.5 % each) were in equal propotions (Fig. 3). *Chlorurus Bleekeri* showed the biggest increase in number (50 %) when assessing the percentage increase in fish occurrence following deployment, followed by *Fistularia commersonii* (33.3 %) and *Chaetodon decussatus* (33 %) and *Zanclus cornutus* (20 %).

The samples were collected from 3 m radius of the transect line. The abundance of these 4 species was subjected to study before and after deployment of artificial reefs. The survey was repeated and average was taken. Paired t test shows that there was a significant difference between the species assemblage before and after deployment of artificial reefs as $p < 0.05$ [Sig. (2-tailed) p value=.035; DF=3] which implies that deployment of artificial reef was effective in aggregation of fish. In a highly damaged reef region, the placement of artificial reef structures and the subsequent transplanting of corals onto them have often demonstrated a good trajectory of coral and fish recovery within a brief period of 2 years. In the present study, the time frame was cut in half to only one year. To lessen stress and support its regeneration, artificial reefs such roti buaya and fish dome were erected in that habitat. Fish biomass, diversity, and abundance are strongly correlated with the health of the coral environment (Bell & Galzin, 1984; Sano et al., 1984; Bozec et al., 2005). In the long run, it is anticipated that the eventual development of large corals could support larger populations of fish, and contribute to demonstrating the potential use of combined artificial reef structures. This expectation is based on the continued growth of transplanted corals and natural recruitment of corals on the artificial reef structures. Transplanting coral fragments is recommended by Mwaura et al. (2022) as a conservation strategy for severely deteriorated reefs. In that study, several reef species, including those crucial to the fisheries, such as the Lutjanids and Acanthurids, as well as ecological indicators, such as Chaeotodontids, quickly colonised the artificial reefs within one year. The family Chetodontidae is a sign of a healthy coral reef (Sahetapy et al., 2019; Mwaura et al., 2022). In the present study, Chaeotodontids were also detected in greater numbers when artificial reefs started to develop in a habitat, indicating an improvement in the ecosystem's environmental conditions. *Chlorurus*

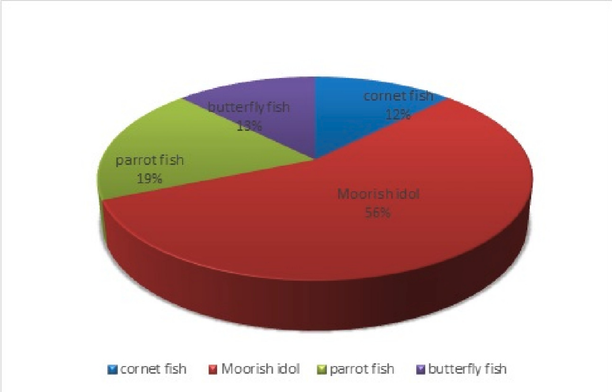

Fig. 3. Percentage composition of fish species observed near deployed structures

Table 1. Fish Species assessed during Survey

Species assessed	Family	Status	Abundance after deployment and percentage increase*
Fistularia commersonii (Cornet fish)	Fistulariidae	Least Concern (LC)	12.5 (33.3)
Zanclus cornutus (Moorish Idol)	Zanclidae	Least Concern (LC)	56.25 (20)
Chlorurus Bleekeri (Parrot fish)	Labridae	Least Concern (LC)	18.75 (50)
Chaetodon decussatus (Butterfly fish)	Chaetodontidae	Least Concern (LC)	12.5 (30)

*Figures in parenthesis indicate the percentage increase *bleekeri* and *Zanclus cornutus* species were discovered to be extensively distributed in the waters of Tuhaha Bay, and Sahetapy et al. (2019) observed that these species were able to adapt to the biophysical environment of coral reefs. In areas where artificial reefs were implemented, increase in fish capture was observed (Fabi et al., 2015; Becker et al., 2016, Florisson et al., 2018; Wu et al., 2019).

The ecosystems of coral reefs are among the most productive and biologically diverse ecosystems on the planet. These systems have been shown to be negatively impacted by human activities (pollution, unjustified collection of coral and fishes, habitat destruction) as well as climate change (sea level rise, temperature change, ocean acidification, wave action and coastal erosion). As the planet continues to warm, further reef damage from climate change is certain; yet, there is plenty that communities can do to protect these sensitive ecosystems. Since the regeneration of damaged reefs can be initiated by creating supporting structures that can establish new reef regions to make up for the loss that has already happened. According to the study, artificial reefs are an effective operational adaptation approach for supporting corals and reef fishes. The region can be developed as a recreation area in future, as a refuge for biodiversity for educational reasons, a site for aquaculture, and a location for green waste collection for the aquarium business.

Acknowledgments

The first author is indebted to the whole team of LINI, Bali, Desa Les Indonesia and Gayathri Lilly in particular, for giving the opportunity to experience the ornamental fish industry from inside. Most of the technical support during the study was graciously contributed by Made and Yunaldi. The author would also like to extend warm regards to the Director of school of industrial fisheries for the support. We express gratefulness to the fishermen of Desa Les Indonesia. The first author would like to thank Sasya Shyamala Krishi Vigyan Kendra, Ramakrishna Mission Vivekananda Educational and Research Institute (RKMVERI) and Principal investigator of DST SEED project Dr. Swagat Ghosh for providing all the support for documentation of the work.

References

Alcala, A.C. and Gomez, E.D. (1987) Dynamiting coral reefs for fish: a resource-destructive fishing method. In: Human Impacts on Coral Reefs: Facts and Recommendations. French Polynesia: Antenne Museum. (Salvat, B., Eds), pp 52-60, E.P.H.E.

Ammar, M.S.A. (2009) Coral Reef Restoration and Artificial Reef Management, Future and Economic. Open Environ. Eng. J. 2(1): 37-49

Auberson, B. (1982) Coral transplantation- an approach to the reestablishment of damaged reefs. Kalikasan, Philipp. J. Biol. 11(1): 158-172

Becker, A., Taylor, M.D. and Lowry, M.B. (2016) Monitoring of reef associated and pelagic fish communities on Australia's first purpose built offshore artificial reef. ICES. J. Mar. Sci. 74(1): 277-285

Bell, J.D. and Galzin, R. (1984) Influence of live coral cover on coral-reef fish communities. Mar. Ecol. Prog. Ser. 15(3): 265-274

Borneman, E.H. and Lowrie, J. (2001) Advances in captive husbandry and propagation: an easily utilized reef replenishment means from the private sector? Bull. Mar. Sci. 69(2): 897-913

Bowden-Kerby, A. (2001) Low-tech coral reef restoration methods modelled after natural fragmentation processes. Bull. Mar. Sci. 69(2): 915-931

Bozec, Y.M., Doledec, S. and Kulbicki, M. (2005) An analysis of fish habitat associations on disturbed coral reefs: chaetodontid fishes in New Caledonia. J. Fish Biol. 66(4): 966-982

Brown, C.J., Fulton, E.A., Hobday, A.J., Matear R.J., Possingham, H.P., Bulman, C., Christensen, V., Forrest, R.E., Gehrke, P.C., Gribble, N.A. Griffiths, S.P., Lozano-Montes, H., Martin, J.M., Metcalf, S., Okey, T.A. and Watson, R. and Richardson, A.J. (2010) Effects of climate-driven primary production change on marine food webs: implications for fisheries and conservation. Glob. Change Biol. 16(4): 1194-1212

Cochrane, K., De Young, C., Soto, D. and Bahri T. (2009) Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge. 212 p, FAO Fish. Aquac. Tech. Rome

Edwards, A.J. and Clark, S. (1999) Coral transplantation: a useful management tool or misguided meddling? Mar. Pollut. Bull. 37: 474-487

English, S., Wilkinson, C. and Baker, V. (1997) Survey Manual for Tropical Marine Resources. Townsville. 378p, Australia: Australian Institute of Marine Science, Townsville Australia

Fabi, G., Scarcella, G., Spagnolo, A., Bortone, S.A., Charbonnel, E., Goutayer, J.J., Haddad, N., Lök, A. and Trommelen, M. (2015) Practical guidelines for the use of artificial reefs in the Mediterranean and the Black Sea. 84p, General Fisheries Commission for the Mediterranean. FAO, Rome, Italy

Florisson, J.H., Tweedley, J.R., Walker, T.H. and Chaplin, J.A. (2018) Reef vision: a citizen science program for monitoring the fish faunas of artificial reefs. Fish. Res. 206: 296-308

Fukasawa, M., Freeland, H., Perkin, R., Watanabe, T., Uchida, H. and Nishina, A. (2004) Bottom water warming in the North Pacific Ocean. Nature. 427(6977): 825-827

Grafton, R.Q. (2010) Adaptation to climate change in marine capture fisheries. Mar. Policy. 34(3): 606-615

Guzman, H. M. (1991) Restoration of coral reefs in Pacific Costa-Rica. Conserv. Biol. 5(2): 189-194

Harriott, V.J. and Fisk, D.A. (1988) Coral transplantation as a reef management option. In: Proceedings of the 6th International Coral Reef Symposium, pp 375-379, Australia

Harris, L.E. (2009) Artificial reefs for ecosystem restoration and coastal erosion protection with aquaculture and recreational amenities. Reef J.1(1): 235-246

Heeger, T. and Sotto, F. (2007) Eds. in Coral Farming: A Tool for Reef Rehabilitation and Community Ecotourism. pp 1-94, German Ministry of Environment (BMU), German Technical Cooperation and Tropical Ecology program (GTZ-TÖB), Philippines

Highsmith, R.C. (1982) Reproduction by fragmentation in corals. Mar. Ecol. Prog. Ser. 7(2): 207-226

IPCC. (2007) Climate change 2007: the physical science basis. In: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. 333 p, Cambridge University Press, Cambridge, United Kingdom, New York, NY

Korakandy, R. (2008) Fisheries Development in India: The Political Economy of Unsustainable, 683 p, Kalpas Publication, Satyavathy Nagar, Delhi

Lindahl, U. (1998) Low-tech rehabilitation of degraded coral reefs through transplantation of staghorn corals. Ambio. 27: 645-650

Lindahl, U. (2003) Coral reef rehabilitation through transplantation of staghorn corals: effects of artificial stabilization and mechanical damages. Coral Reefs. 22(3): 217-223

McCarthy, J.P. (2001) Ecological consequences of recent climate change. Conserv. Biol. 15(2): 320-331

McClanahan, T., Muthiga, N. and Mangi, S. (2001) Coral and algal changes after the 1998 coral bleaching: interaction with reef management and herbivores on Kenyan reefs. Coral Reefs. 19: 380-391

Mwaura, J.M., Murage, D., Karisa, J.F., Otwoma, L.M., Said, H.O. (2022). Artificial reef structures and coral transplantation as potential tools for enhancing locally-managed inshore reefs: a case study from Wasini Island, Kenya. WIO J. Mar. Sci. 21(2): 83-94

Sahetapy, D., Retraubun, A.S.W., Bengen, D.G. and Abrahamsz, J. (2019) Potency of reef fishes in Tuhaha bay waters, Central Maluku Regency, Maluku Province, Indonesia. Paper presented at the first Maluku International Conference on Marine Science and Technology, Ambon, Indonesia, IOP Conf. Ser.: Earth Environ. Sci. 339: 1-11, 24-26 October, 2018

Sano, M., Shimizu, M. and Nose, Y. (1984) Changes in structure of coral reef fish communities by destruction of hermatypic corals: Observational and experimental views. Pac. Sci. 38: 51-80

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J., Fromentin, J.M., Hoegh-Guldberg, O. and Bairlein, F. (2002) Ecological responses to recent climate change. Nature. 416(6879): 389-395

Wilson, S.K., Graham, N.A., Pratchett, M.S., Jones, G.P. and Polunin, N.V. (2006) Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient? Glob. Change Biol. 12(11): 2220-2234

Wu, Z., Tweedley, J.R., Loneragan, N.R. and Zhang, X. (2019) Artificial reefs can mimic natural habitats for fish and macroinvertebrates in temperate coastal waters of the Yellow Sea. Ecol. Eng. 139: p105579