



Ecological and Socio-Economic Contribution of Artificial Reefs to Small-Scale Fisheries in Palk Bay, Southeast India

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Abstract

Artificial reefs (ARs) are increasingly deployed as a non-destructive tool for enhancing marine habitat and supporting small-scale coastal fisheries. This study assessed the ecological development and socio-economic contribution of 300 artificial reef modules deployed at three nearshore stations off eight fishing villages in Palk Bay, southeast India, over two consecutive years. Following a six-month post-deployment period without fishing, reef modules underwent progressive colonization by algae and sessile invertebrates, increasing habitat complexity and establishing localized fish aggregations. Monitoring recorded 6,173 individuals across 37 genera in the first year (Shannon diversity $H' = 3.36$, evenness $J' = 0.93$), rising to 27,756 individuals in the second year, an increase of approximately 350%, while genus richness and diversity indices remained largely stable ($H' = 3.33$, $J' = 0.92$), indicating that reef maturation enhanced fish abundance without altering community composition. Seasonal abundance peaked during post-monsoon and summer periods in both years, and station-wise catch patterns converged as the reef matured, suggesting a spatially uniform aggregation effect. Local fishermen exploited the reefs almost exclusively using low-impact trap fishing, generating monthly incomes of ₹2,000–₹15,000. These findings indicate that the artificial reefs functioned as effective, low-disturbance fish aggregation structures that concentrated fishing effort in accessible nearshore grounds, potentially reducing pressure on adjacent natural coral reefs while supporting livelihood diversification. The results support artificial reefs as a viable complementary strategy for biodiversity conservation and sustainable fisheries management in heavily utilized coastal waters, while highlighting the need for long-term monitoring to confirm associated coral reef recovery benefits.

Keywords: Artificial reef, Palk Bay, coral reef conservation, small-scale fisheries, and livelihood.

Introduction

Artificial reefs (ARs) are a non-destructive technique for enhancing marine life in the ocean (Rofallski et al., 2020). Deliberately engineered and deployed around the world, ARs create new marine habitats that counter the escalating global problem of declining marine biodiversity and fish stock abundance. The colonization of ARs by algae, oysters, and corals draws fish seeking food, shelter, and refuge from predators, allowing marine species to flourish around these structures (Carr and Hixon, 1997; Florisson et al., 2018). By mimicking natural reef formations, ARs provide stable habitats that enhance biodiversity, support spawning and feeding for benthic species, promote ecological balance, and integrate into the broader marine ecosystem and overall fish populations, ultimately contributing to the sustainability of marine resources (Carral et al., 2022). They also contribute to nutrient cycling and help reduce eutrophication and pollution in coastal waters (Yong et al., 2013), while offering settlement surfaces for coral larvae that support the conservation and restoration of degraded coral reef systems (Knoester et al., 2023). By replicating coral reef structures, ARs sustain fish populations and strengthen the wider marine food web (Wu et al., 2019), and in doing so contribute to the overall resilience of ocean ecosystems. Beyond their ecological function, these installations have become drivers of coastal tourism, generating new diving destinations and attracting a diverse array of marine life for recreational use (Hammond et al., 2020).

The relevance of ARs to local fisheries, however, extends well beyond ecology into the socio-economic fabric of coastal communities. In economically vulnerable coastal regions, ARs concentrate fish stocks closer to shore, allowing local fishers to operate within short distances, at lower fuel cost, and with less risk than offshore fishing (Brochier et al., 2021). This proximity reduces pressure toward overexploitation and illegal fishing practices, though the success of any given AR programme remains closely tied to socio-economic factors such as governance structures and prevailing fishing practices (Brochier et al., 2021; Wehner, 2018). Field evidence from Malaysia illustrates this dynamic: research in Terengganu found that AR deployment measurably increased fish abundance, reduced the effort required to fish, and improved the socio-economic standing of artisanal fishers, with many households diversifying income sources as a result (Sanusi et al., 2024). AR programmes generated direct use-benefits for local fishing communities and the surrounding economy, though the authors cautioned that such gains require a clear exploitation strategy to avoid overfishing around the reefs in southern Portugal (Whitmarsh et al., 2008).

The Food and Agriculture Organization has similarly reported that, in degraded marine areas, ARs can raise fish production considerably. These socio-economic benefits do not operate in isolation from conservation goals: by concentrating fishing effort onto engineered structures near shore, ARs can serve as a strategic conservation tool, easing pressure on natural fish stocks while creating accessible new environments for marine species (Leitão, 2013; Pioch et al., 2010), and thereby fostering the kind of economic stability and resilience that helps coastal communities withstand external shocks (Syddall et al., 2021).

Materials and Method

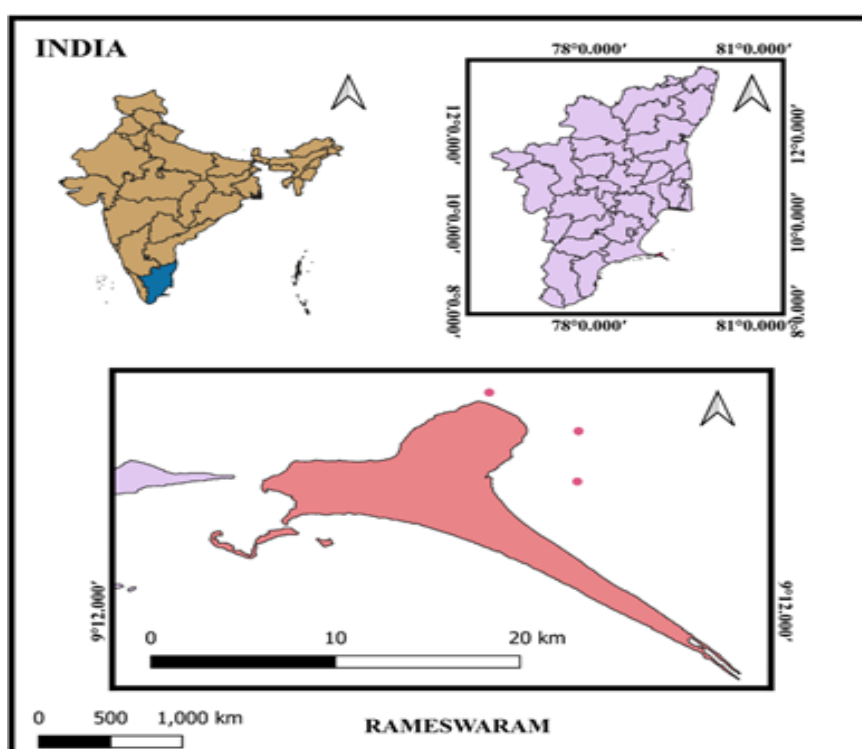
Underwater surveys were conducted using SCUBA to identify suitable locations for artificial reef deployment. Potential sites were assessed based on seabed characteristics, habitat condition, depth, accessibility, and the absence of established natural reef habitats. Three sites were selected along the Rameswaram coastal region of Palk Bay, representing nearshore areas associated with the surrounding fishing villages, for artificial reef deployment. The selected locations were predominantly non-reef areas and were characterized by the absence of coral communities, extensive seaweed beds, and seagrass meadows. Selection of these sites ensured that the artificial reef structures were deployed in areas without existing major natural habitats, thereby minimizing direct disturbance to coral reef, seaweed, and seagrass ecosystems. The geographic coordinates of each selected deployment site were recorded using a handheld Global Positioning System (GPS) and used to document the precise locations of the artificial reef installations.

Mangadu, Sembai, and Vadakadu shores from Artificial Reef Site-1 (AR-S1) 2.07 km, located at latitude 9.333939°N, longitude 79.316486°E, and a depth of 6 m. Olakuda, Kudiiruppu, and Erakadu shores from Artificial Reef Site-2 (AR-S2) 3.03 km, located at latitude 9.310308°N, longitude 79.360494° E, and a depth of 6.6m. Serankotai and Karaiyur shores from Artificial Reef Site-3 (AR-S3) 5.18 km, located at latitude 9.279421°N, longitude 79.359907° E, and depth of 6.1m (Figure 1). On each site three type of modules (Ring Ornamental, Ferro Concrete Triangle Reef, and Triangular Grouper Modules), 100 reefs are planted using small tradition craft and marine vessel or barge vessel (Wu et al., 2019).

Photographic and underwater video surveys were conducted using an Olympus Tough TG-7 underwater camera to directly assess the condition and development of the artificial reef structures. Underwater observations were used to document reef condition, fish aggregation, biological colonization, and the ecological role of the artificial reefs. Photographic and video records were collected during field surveys to monitor changes in reef-associated communities and to provide visual documentation of fish abundance and habitat utilization. The survey approach followed the underwater visual observation procedures described by English et al. (1997).

Local fishermen used small baited traps to collect fish associated with the artificial reef structures. Shrimp heads were used as bait, and traps were generally retrieved after 2–3 days, depending on sea conditions. Catch data, including catch quantity and Genus of the species, were recorded through direct observations and information obtained from local fishermen. These data were used to assess fishery utilization of the artificial reefs and their contribution to local fishing activities and fishermen's livelihoods. A socio-economic survey was conducted among local fishermen to assess the livelihood benefits of artificial reefs, including changes in fishing activity, catch, income, and perceived benefits from reef-associated fisheries.

Figure 1. Map showing the study area and artificial reef sites along the southeastern coast of India



Result

A total of 300 artificial reef modules were deployed at three reef stations located adjacent to the coastal villages of Erakadu, Karaiyur, Kudiyiruppu, Mangadu, Olaikuda, Serankottai, Vadakadu, and Sambai in Palk Bay. Following deployment, the modules underwent progressive colonization by benthic algal assemblages, which subsequently provided substrata for the establishment of sessile and mobile invertebrates. The development of these associated communities contributed to an increase in habitat complexity around the reef modules and created additional shelter and feeding areas for reef-associated fishes. The artificial reef structures also provided suitable habitat for juvenile fishes, thereby contributing to the formation of localized nursery areas.

The nearshore placement of the artificial reef stations provided an additional advantage for small-scale fishing communities by reducing the distance between the fishing grounds and the adjacent fishing villages. Consequently, local fishermen were able to reach the artificial reef sites with relatively shorter travel distances, requiring less time and fuel compared with fishing grounds located farther offshore. Fishing activity around the artificial reefs was primarily undertaken by local fishermen using small-scale traditional gear, particularly trap fishing, locally referred to as “**koondu**” fishing, and rarely hook-and-line fishing. The relatively simple fishing methods used at these sites enabled fishermen to exploit the aggregated fish resources without the need for large fishing vessels or intensive fuel consumption. During trap deployment and retrieval, fishermen used aluminium plates as fins and wore snorkel masks for underwater access and handling of the traps. A small **polystyrene foam float** was used to temporarily support the trap during retrieval. After bringing the trap to the surface and securing it with the floating device, the catch was transferred to the fishing boat. The trap was then reset and redeployed at the artificial reef site for the next fishing cycle (Figure 2).



Figure 2. (a) Fisherman diving using a steel plate and snorkelling mask to deploy and retrieve the trap; (b) securing the trap to a polystyrene foam float; (c) collecting trapped fish and transferring them into a plastic container; and (d) fishes captured in a single trap

Fish diversity and assemblage structure

Local fishermen commenced fishing at the three nearshore stations (AR-S1, AR-S2, AR-S3) after six-month installation of the artificial reef, end of the monsoon season in the first year. Consequently, no catch data were recorded for the pre-monsoon period of 2024–2025, and total catch for that year was correspondingly low: 6,173 individuals across 37 genera were recorded over the monsoon, post-monsoon, and summer seasons (Shannon diversity index $H' = 3.36$; evenness $J' = 0.93$) (Table 1).

In the second year (2025–2026), following establishment of the reef, fishing yields increased substantially across all four seasons. Total catch rose to 28,876 individuals an increase of approximately 350% over the first year with every one of the 37 genera recorded showing higher abundance than in Year 1. Genus's richness remained unchanged between the two years ($S = 37$ in both), and the Shannon diversity index showed only a marginal decline ($H' = 3.33$; $J' = 0.92$), indicating that the increase in catch reflected greater numerical abundance of the resident fish community rather than a change in its taxonomic composition. These results indicate that the artificial reef functioned as an effective fish aggregating structure: rather than altering species diversity, it

substantially enhanced local fish abundance and established the site as a productive fishing ground within a single year of installation.

The fish assemblage exhibited low dominance and high diversity during both study years. Simpson's dominance index increased only slightly from 0.0419 in 2024-2025 to 0.0439 in 2025-2026, while Simpson's diversity remained high at 0.9581 and 0.9561, respectively. Pielou's evenness remained high at 0.932 and 0.923, indicating a relatively even distribution of individuals among the recorded genera. *Otolithes* spp. was the most abundant genus in both years, contributing 7.16% and 8.29% of annual abundance, respectively. These findings indicate that the marked increase in total fish abundance was not accompanied by strong numerical dominance by a single genus.

Table 1. Annual fish assemblage diversity indices recorded at three nearshore fishing stations (AR-S1, AR-S2 and AR-S3) in Palk Bay during 2024-2025 and 2025-2026.

Diversity parameter	2024-2025	2025-2026
Total abundance (N)	6,173	27,756
Genus's richness (S)	37	37
Shannon-Wiener diversity index (H')	3.364	3.334
Simpson's dominance index (D)	0.0419	0.0439
Simpson's diversity index (1-D)	0.9581	0.9561
Margalef's species richness index (d)	4.125	3.519
Pielou's evenness index (J')	0.932	0.923

Seasonal Variation fish abundance

Seasonal fish abundance at the three nearshore stations (AR-S1-AR-S3) showed a consistent increasing pattern across the four seasons between the two study years (Figure 2). During 2024-2025, no catch was recorded during the pre-monsoon period because fishing was intentionally withheld for the first six months following artificial reef installation. This initial six-month no-fishing period was implemented to allow sufficient time for the newly deployed reef structures to undergo colonization and for associated fish assemblages to establish and increase in diversity and abundance. Following this initial development period, fishing commenced, and catches increased progressively from 918 individuals during the monsoon to 1,916 individuals in the post-monsoon and 3,339 individuals during summer, indicating the early development of fish reef associations around the newly established artificial reef habitat (Figure 3).

In 2025-2026, the seasonal pattern was retained but occurred at a substantially higher magnitude. Pre-monsoon abundance reached 5,862 individuals, a season for which no comparable catch was available in 2024-2025 because of the initial six-month fishing restriction (Figure. 4). Monsoon, post-monsoon, and summer catches subsequently increased to 6,377, 7,951, and 7,566 individuals, respectively. Post-monsoon and summer represented the periods of highest abundance in both study years, together accounting for a major proportion of the annual catch. This pattern suggests increased fish aggregation and habitat utilization around the artificial reef as the reef community became progressively established, with seasonal environmental conditions potentially further influencing fish abundance and aggregation (Figure 5). The increase between study years was evident across all comparable seasons, with the smallest relative increase occurring during summer. Overall, the marked increase in fish abundance during the second year indicates progressive development of the artificial reef as a functional fish habitat following the initial six-month establishment period.

Station-wise seasonal trends in fish abundance are presented in Figure 5. In 2024-2025, the three stations showed a degree of divergence during the middle of the season: at monsoon, catch ranged from 209 individuals at AR-S1 to 422 at AR-S2, and at post-monsoon, from 499 at AR-S2 to 758 at AR-S3. By summer, however, the stations had largely converged, with AR-S2 and AR-S3 both reaching approximately 1,170 individuals and AR-S1 reaching 997. In 2025-2026, this convergence was evident from the start of the sampling year and sustained throughout. Pre-monsoon catch across the three stations ranged narrowly from 1,893 (AR-S1) to 2,022 (AR-S2), and this close tracking continued through monsoon (2,094-2,151) and post-monsoon (2,492-2,773), before a modest divergence in summer, when AR-S1 declined to 2,304 individuals while AR-S2 and AR-S3 remained higher at 2,694 and 2,568, respectively (Figure 6).

Overall, the seasonal trajectories of all three stations followed the same underlying pattern in both years a rise from pre-monsoon/monsoon toward a post-monsoon or summer peak with the amplitude of that pattern far higher in the second year. The tighter clustering of the three lines in 2025-2026 compared with 2024-2025 indicates that, as the reef matured, its aggregating effect became more spatially uniform across the three nearshore stations, rather than favouring any single site.

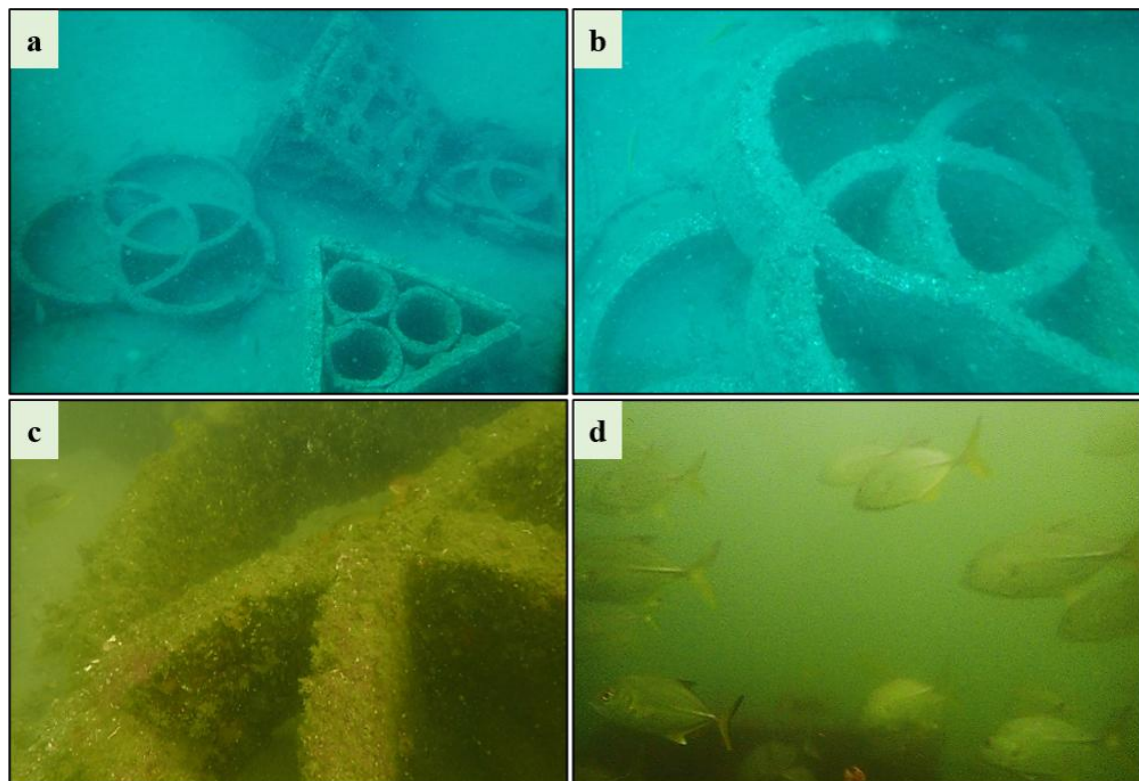


Figure 3. (a) Artificial reef modules after deployment; (b) surface of the artificial reef immediately after installation, showing no biological attachment; (c) surface of the artificial reef one year after installation, showing extensive algal colonization; and (d) aggregations of fish surrounding the artificial reef modules.

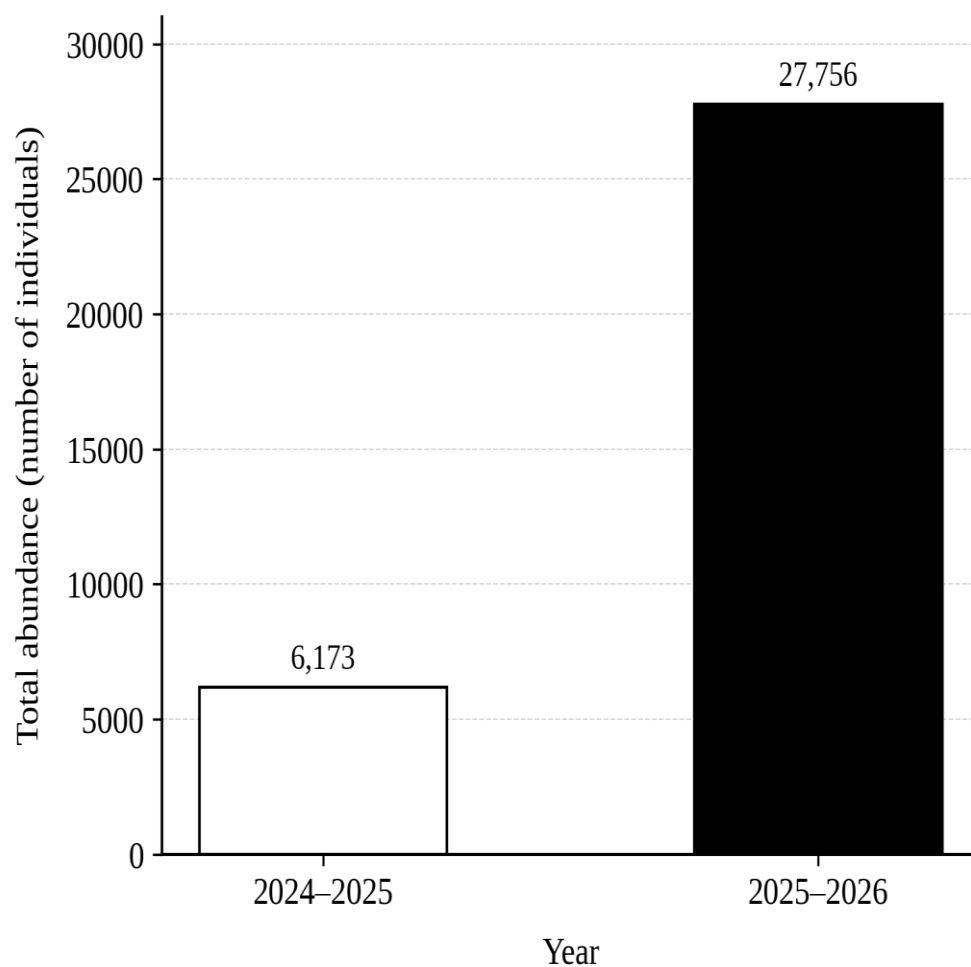


Figure 4. Total fish abundance at the artificial reef site during 2024-2025 and 2025-2026

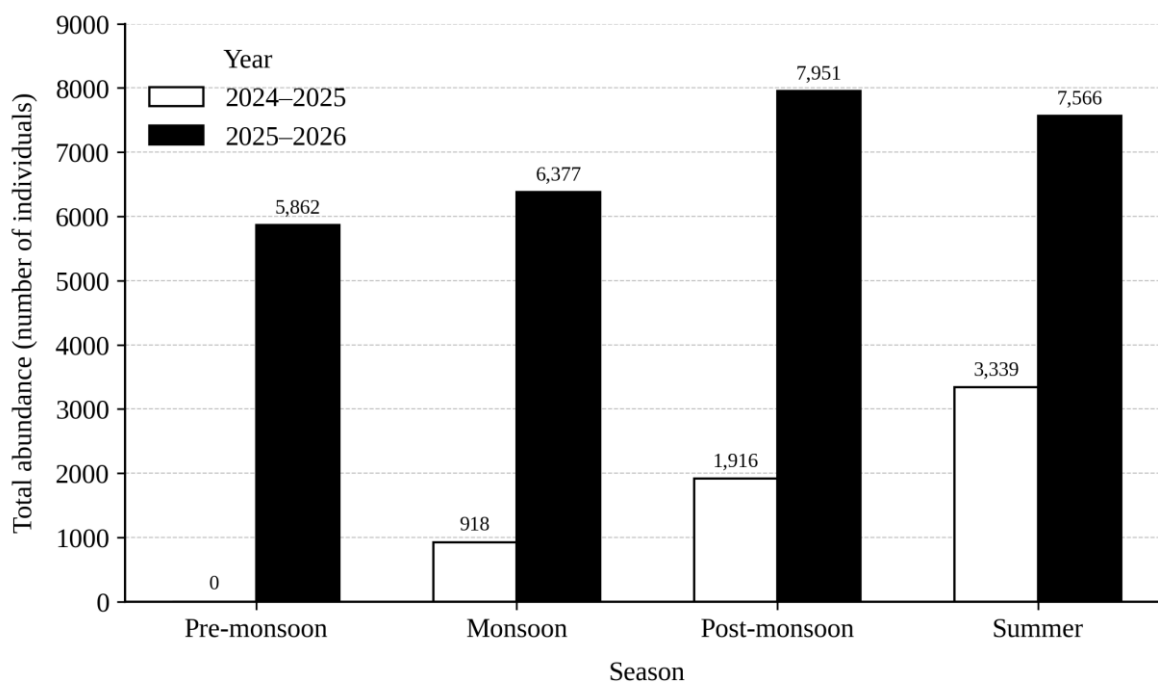
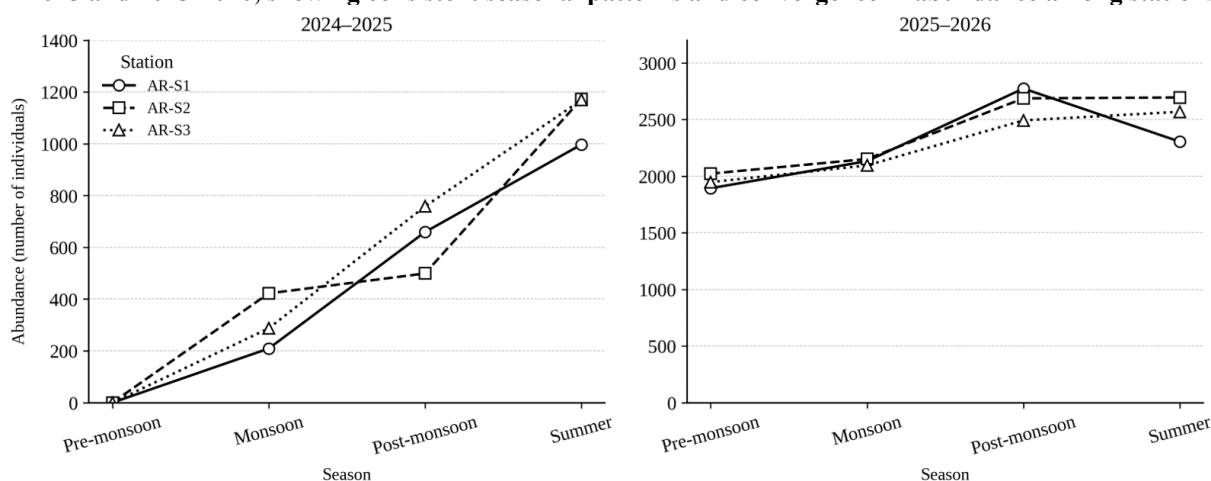


Figure 5. Seasonal variation in total fish abundance across AR-S1, AR-S2, and AR-S3 in Rameswaram villages of Palk Bay during 2024-2025 and 2025-2026.

Figure 6. Station wise seasonal abundance trends at AR-S1, AR-S2 and AR-S3 in Palk Bay during 2024-2025 and 2025-2026, showing consistent seasonal patterns and convergence in abundance among stations



as the reef matured.

Artificial reef contribution

Artificial reefs provide additional habitat in coastal areas by introducing stable three-dimensional structures into the marine environment. Following deployment, the reef surfaces are gradually colonized by algae, sponges, molluscs, Echinoderm, sessile invertebrates and other fouling organisms, increasing the biological complexity of the newly created habitat. These structures provide feeding areas, shelter, attachment surfaces and potential nursery habitats for a range of marine organisms (figure 7). As biological colonization progresses, artificial reefs can support the occurrence and aggregation of different fish species and other associated fauna, particularly species that utilize structurally complex habitats.

This function is particularly relevant in Palk Bay, where coastal habitats are exposed to considerable anthropogenic pressure and fishing activity. Natural coral reef areas are important fishing grounds for local communities, and continuous fishing activity can place additional pressure on reef-associated fish populations and the reef habitat itself. The establishment of artificial reef sites away from natural coral reef areas provides additional fishing grounds and alternative habitat for reef-associated fishes. Consequently, the development of productive fish assemblages around artificial reefs may help distribute fishing activity away from natural coral reef habitats. This can potentially reduce direct fishing pressure on coral reefs and provide greater opportunity for natural reef communities to recover and maintain their ecological functions.

In the present study, the increase in fish abundance between the first and second years indicates progressive utilization of the artificial reef habitat. The initial six-month period without fishing following reef deployment allowed the structures to remain relatively undisturbed while biological colonization and fish association developed. Following this establishment period, fish abundance increased across the monitored seasons, with

particularly high abundances during the post-monsoon and summer periods. The substantially greater abundance recorded during the second year suggests that the artificial reef environment became increasingly utilized as the associated biological community developed.

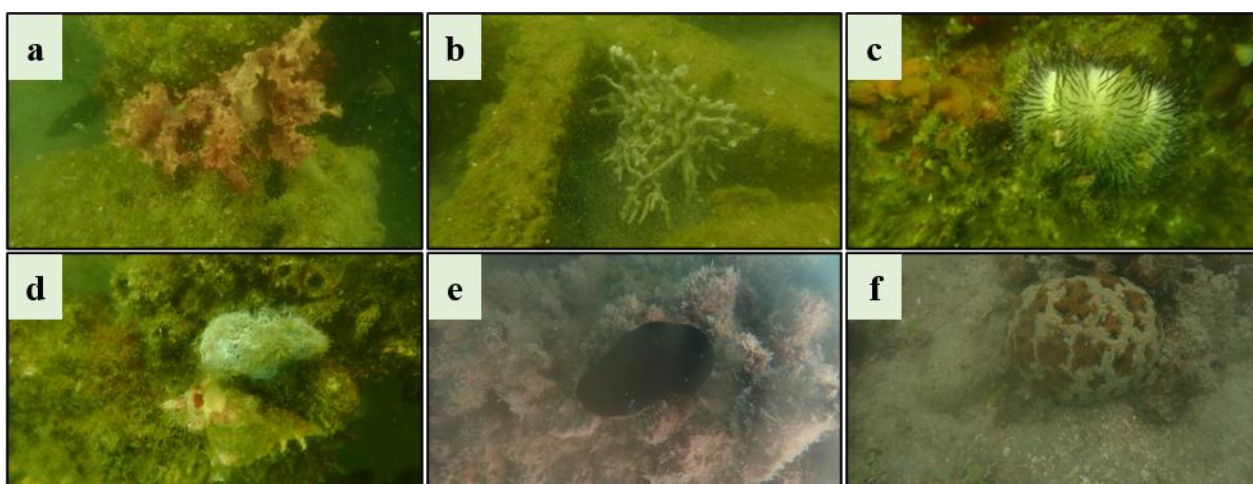


Figure 7. Biological attachments observed on the artificial reef modules: (a) seaweeds, (b) sponges, (c) echinoderms, (d) molluscs, (e) ascidians, and (f) other invertebrates

Economic impact

Socio-economic surveys conducted among local fishing communities indicated that the artificial reef sites were regularly exploited using traditional trap fishing methods. Fishermen reported that the artificial reefs functioned as productive fishing grounds supporting the capture of commercially important fish species throughout the year. Catch and fishing frequency varied according to seasonal and sea conditions. Income derived from fishing activities associated with the artificial reefs ranged from ₹2,000 to ₹15,000 per fisherman per month, depending on seasonal variability in catch, fishing intensity, and target species. These findings demonstrate that the artificial reefs provide both ecological habitat functions and measurable livelihood benefits for coastal fishing communities in the Rameswaram.

Discussion

The results of the present study demonstrate that artificial reef (AR) deployment in Palk Bay produced a substantial increase in fish abundance without a corresponding shift in community composition, a pattern that is broadly consistent with the ecological succession described for artificial reefs elsewhere. The colonization sequence observed here initial algal settlement, followed by the establishment of sessile and mobile invertebrates, and subsequent aggregation of reef-associated fishes was consistent with patterns reported by Carr and Hixon (1997) (Florisson et al., (2018). They emphasized that habitat complexity generated by epibenthic colonization is a primary driver of fish aggregation on artificial structures. The nearly 350% rise in total catch between the first and second year of the present study, occurring alongside stable genus richness ($S = 37$ in both years) and only marginal declines in Shannon diversity, suggests that the reef primarily enhanced the numerical abundance of an already-resident community rather than restructuring it (Knoester et al., 2023). For artificial reef designs deployed for coral reef restoration in Kenya, community recovery metrics similarly stabilized in composition even as biomass increased over the monitoring period. This distinction is directly relevant to the long-standing "attraction versus production" debate in artificial reef research (Bohnsack, 1989; Kasim et al., 2013), which asks whether reefs merely redistribute existing fish stocks toward new structures or genuinely increase regional biomass. The steady rise in abundance recorded across all 37 genera in the second year, without a decline in richness or evenness that would be expected under a purely redistributive scenario, lends some support to a production-oriented interpretation, consistent with the meta-analytic finding that well-designed artificial reefs can support fish density and biomass comparable to natural reef systems (Paxton et al., 2020).

The economic outcomes recorded in the present study, with monthly incomes of ₹2,000-₹15,000 per fisherman derived largely from nearshore trap fishing, align closely with earlier Indian evaluations of AR performance (Kasim et al., 2013). In a two-year economic assessment of artificial reefs deployed in India, Kasim et al. (2013) found that catch per unit effort and value per unit effort were consistently higher at AR sites than at comparable non-reef sites, and that the shorter distance to reef grounds substantially reduced fuel and labour costs for small-scale fishers (Vivekanandan et al., 2006). In an earlier case study of an artificial reef off Chennai, higher catch rates were reported for hook-and-line operations at reef sites than at non-reef grounds, owing to the aggregation of high-value species such as snappers, emperors, and carangids, a pattern broadly comparable to the dominance of commercially important genera such as *Otolithes*, *Carangoides*, and *Upeneus* observed at the Palk Bay stations in the present study. The reduced travel distance and fuel requirement reported by local fishermen in the present study are also consistent with findings from artificial reef programmes outside India. Sanusi et al. (2024) documented those artisanal fishers in Terengganu, Malaysia, diversified their income sources and reduced

fishing effort following AR deployment, while fishing revenue at AR sites off the Algarve coast of southern Portugal was reported to be 1.7 times higher than at non-reef control sites (Whitmarsh et al., 2008).

The reliance on traditional trap (**koondu**) fishing rather than intensive gear at the Palk Bay reef stations is notable in this context. Because trap fishing is comparatively low-effort and size-selective, it may reduce the risk that concentrated fish aggregations around the reef are rapidly overexploited (Islam et al., 2014). Cautioned that some AR programmes in Peninsular Malaysia appeared merely to redistribute existing catch among fishers rather than increase overall biomass. The convergence in seasonal abundance trends across the three Palk Bay stations by the second year, together with the sustained genus richness, suggests that fishing pressure at the present study sites had not yet reached a level capable of depleting the aggregated stock, although continued monitoring beyond the two-year window used here would be needed to confirm this trend. This is consistent with the view that AR sites require rational, well-planned site selection and ongoing management to remain sustainable (Devaraj, 1997; Kasim et al., 2013).

Overall, the present findings reinforce the view that artificial reefs, when appropriately sited in nearshore waters with historically degraded or featureless substrate, can function simultaneously as ecological habitat enhancement tools and as accessible, low-cost fishing grounds for small-scale coastal communities (Brochier et al., 2021). The scale of the abundance increase recorded in Palk Bay is broadly comparable to, and in some respects exceeds, benefits reported from other Indian AR programmes, underscoring the potential value of continued, well-monitored AR deployment along the Tamil Nadu coast.

Conclusion

The present two-year study demonstrates that artificial reef deployment in the nearshore waters of Palk Bay, Rameswaram, resulted in a marked increase in fish abundance, from 6,173 individuals in the first year to 27,756 individuals in the second, while genus richness and diversity indices remained largely stable. This pattern indicates that the reefs functioned primarily to enhance the resident fish community's abundance rather than to alter its structure, and that the modules had become an established, productive fish habitat within two years of deployment. The socio-economic data further confirm that these ecological gains translated into tangible livelihood benefits, with local fishermen earning between ₹2,000 and ₹15,000 per month through low-cost, nearshore trap fishing. Beyond these direct outcomes, the findings point to a dual ecological role for artificial reefs in Palk Bay. On one hand, the reefs provide additional physical habitat that supports biological colonization, fish aggregation, and broader marine biodiversity. On the other, by creating productive and accessible alternative fishing grounds away from natural coral reef areas, they may help redistribute fishing pressure spatially, reducing the reliance of local fishing communities on the region's coral reef habitats. Such a strategy could contribute to the wider conservation of Palk Bay's coral reef ecosystems by easing the continuous exploitation these natural habitats currently face. However, confirming whether this spatial redistribution translates into measurable coral reef recovery would require sustained, long-term monitoring that tracks coral cover, recruitment, and mortality, alongside fish community structure and fishing effort, at both artificial and natural reef sites in parallel.

The fishing practices observed around the artificial reef sites also carry conservation value in their own right. Local fishermen relied almost exclusively on trap (koondu) fishing, a low-impact, size-selective method that captures target species without damaging the surrounding habitat. The near-absence of net-based fishing at the artificial reef sites is particularly significant, as it substantially limits the generation of ghost gear and other marine litter, one of the more persistent threats to reef and benthic ecosystems in heavily fished coastal waters. In this sense, the artificial reefs are not only functioning as fish aggregation devices but are also indirectly shaping fishing behaviour toward more environmentally compatible methods.

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