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Leo Luricson

leoluricson76@gmail.com

Annamalai University

Vasanthan Koothan

Annamalai University

Keerthiga Ganesan

Annamalai University

Ayyaru Gopalakrishnan

Annamalai University

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Suspended Sedimentation Responses of Coral Reefs, Artificial Reefs and Non-Reef Areas in Palk Bay Southeast coast of India

Leo Luricson[1], Vasanthan Koothan[1], Keerthika Ganesan[1], Kapilan Kalimuthu[1], Ayyaru Gopalakrishnan[1]*.

Centre of Advanced Study in Maine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai - 608 502, Tamil Nadu, India

Corresponding author: aquagopal@gmail.com

Abstract

Sedimentation is a key stressor affecting coral reef health, yet comparative data on sediment dynamics across natural coral reefs, artificial reefs, and adjacent non-reef habitats remain limited for the southeast coast of India. This study examined suspended sedimentation rates, sediment grain size composition, and their ecological implications across coral reef, artificial reef, and non-reef habitats in Palk Bay, Rameswaram, over a 12-month period (August 2024–July 2025). Sediment traps were deployed monthly following English et al. (1997), and grain size fractions (sand, silt, clay) were analyzed in parallel. Overall mean sedimentation was significantly higher in the non-reef area (46.56 ± 13.37 mg cm^{-2} day^{-1}) than in the artificial reef (37.89 ± 12.31 mg cm^{-2} day^{-1}) or coral reef (35.62 ± 14.35 mg cm^{-2} day^{-1}) (Kruskal-Wallis H = 14.92, p = 0.001; ANOVA F = 6.71, p = 0.002), while coral reef and artificial reef sites did not differ significantly from each other. Sedimentation showed clear seasonality linked to the southwest and northeast monsoons, with significant seasonal variation in the artificial reef (F = 7.37, p = 0.013) and non-reef (F = 9.69, p = 0.006) areas. Sand was the dominant grain size fraction across all habitats (72.5–73.9%), with no significant inter-area differences in grain size composition; however, sedimentation rate was significantly negatively correlation with sand content in the coral reef area alone (Spearman r = −0.622, p = 0.031). Field observations linked sediment deposition to coral tissue stress, partial bleaching, and reduced photosynthetic potential in the natural reef, and to elevated turbidity and delayed biofouling colonisation on artificial reef modules. These findings indicate that habitat structure, rather than reef origin, is the primary determinant of sediment exposure in this system, and highlight the need for sediment-informed management strategies to protect coral health and guide the siting and design of future artificial reef installations in Palk Bay.

Keywords: Sedimentation, Coral reef, Artificial reef, Palk Bay

Introduction

Coral reefs support nearly one quarter of all known marine species and sustain the livelihoods of millions of coastal communities in tropical regions (Obura et al., 2017). In India, reef formations occur at five locations: the Gulf of Kachchh, the Gulf of Mannar, Palk Bay, Lakshadweep, and the Andaman and Nicobar Islands. Across these sites, reef health has declined measurably under the combined pressure of climate change and local anthropogenic stressors, with sedimentation recognised as one of the most persistent threats (Erftemeijer et al., 2012; Marimuthu et al., 2020). Sedimentation impairs coral physiology through two mechanisms. Suspended

particles reduce light penetration, lowering photosynthetic output of the symbiotic zooxanthellae, while settled material forces corals to divert energy toward sediment rejection rather than growth and reproduction (Erftemeijer et al., 2012; Tuttle and Donahue, 2022). Unlike bleaching, chronic sedimentation operates gradually and is often overlooked until degradation is advanced. Roy and Smith (1971) recorded live coral cover of only 31% in turbid conditions compared to 62% in clear water, while Risk and Edinger (2011) documented reduced calcification, colony mortality, suppressed larval settlement, and community shifts toward stress-tolerant species. A global meta-analysis by Zhang and Donahue (2022) established that adverse effects begin at deposited loads as low as 4.9 mg cm^{-2} day^{-1} in adult corals, placing many reef systems including Palk Bay under chronic sub-lethal stress.

Within Palk Bay, Wilson et al. (2005) recorded sedimentation rates from 1 to 42 mg cm^{-2} day^{-1} across five reef sites, peaking during the southwest monsoon, with elevated rates negatively associated with live coral cover, particularly Acroporidae. Long-term monitoring by Marimuthu et al. (2020) recorded a 37% decline in live coral cover at Rameswaram between 2002 and 2018, attributed partly to sustained sedimentation alongside trawling and boat disturbance (Kumaraguru et al., 2004). Palk Bay has been identified as a major permanent sediment sink, receiving year-round inputs via longshore currents from the Bay of Bengal and the Gulf of Mannar (Pillai et al., 1917). Reef restoration through artificial reef deployment has expanded in the region (Jha et al., 2022), yet how sedimentation dynamics differ across coral reef, artificial reef, and non-reef habitats over a full annual cycle remains unexamined.

The present study therefore quantified and compared suspended sedimentation rates and sediment grain size composition across these three habitat types in Palk Bay from August 2024 to July 2025, capturing variation across the southwest monsoon, northeast monsoon, and pre-monsoon seasons, to produce the most comprehensive sedimentation dataset yet assembled for this reef system and to contextualise findings within established global physiological thresholds and regional conservation priorities.

Methodology

Suspended Sedimentation Assessment

Suspended sediment deposition was quantified using passive sediment traps following the standardized protocol of English et al. (1997). Sediment traps were constructed from PVC cylinders with a height-to-diameter ratio of ≥5:1 to minimize hydrodynamic disturbance and resuspension of trapped particles. At each study site (Coral reef, Artificial reef, and non-reef area), three replicate sediment traps were deployed vertically with the openings facing upward at approximately 0.5–1.0 m above the reef substrate at 9°19'34.56"N 79°19'26.00"E, 9°20′02.18″ N, 79°18′59.35″ E, and 9°19'53.98"N 79°19'16.67"E (Fig 1). Traps remained in situ for one month to ensure sufficient sediment accumulation.

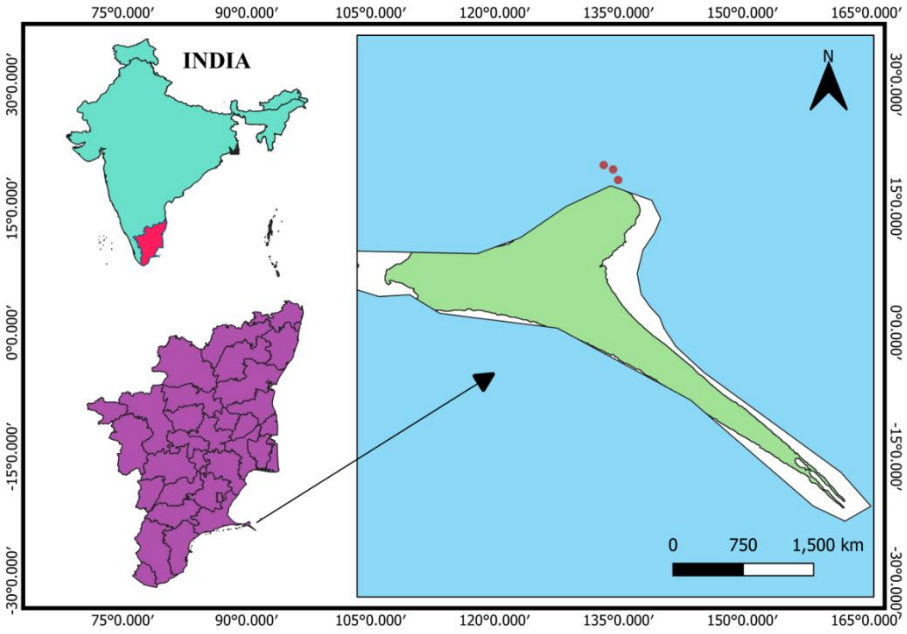


Figure 1. Study area map showing the coral reef, artificial reef, and non-reef habitats in Palk Bay, southeast coast of India

Upon retrieval, each trap was sealed underwater to prevent sediment loss during recovery. Sediment samples were transferred into labelled containers and transported to the laboratory under cool, dark conditions. Samples were filtered through pre-weighed Whatman GF/C glass fibre filters and rinsed with distilled water to remove residual salts. Filters were subsequently dried at 60°C for a minimum of 24 h until a constant weight was achieved and then reweighed using an analytical balance (±0.1 mg).

Sediment dry mass was determined as the difference between the final and initial filter weights. Sedimentation rates were calculated following English et al. (1997) using the equation

$$\text{Sedimentation Rate (mg cm}^{-2}\text{ day}^{-1}) = \frac{\text{Sediment weight (mg)}}{\text{Trap opening area (cm}^2) \times \text{Number of deployment days}}$$

where sediment dry weight represents the net dry mass retained on the filter, trap opening area corresponds to the cross-sectional area of the sediment trap, and deployment period denotes the duration of field exposure in days.

Sedimentation rates were expressed as mg cm^{-2} day^{-1}. Procedural blanks consisting of pre-weighed filters subjected to the same drying and weighing protocol without sediment were included for quality assurance. Mean sedimentation rates were calculated from the three replicate traps at each sampling site and used for subsequent statistical analyses

Statistical Analysis

Normality Testing:

Prior to statistical analyses, the normality of sedimentation rate and sediment grain-size data was evaluated using the Shapiro–Wilk test (Shapiro and Wilk, 1965). Statistical significance was assessed at $\mathbf{p < 0.05}$. Variables conforming to normality were analysed using parametric tests, whereas non-normally distributed data were analysed using non-parametric approaches.

Differences in mean suspended sedimentation rates among the three habitat types (coral reef, artificial reef, and non-reef) and among seasonal periods were initially evaluated using one-way analysis of variance (ANOVA) (Sokal and Rohlf, 2012). When significant differences were detected, pairwise comparisons were performed using Tukey's Honestly Significant Difference (HSD) test (Tukey, 1949).

Because sedimentation data deviated significantly from normality, as indicated by the Shapiro–Wilk test, comparisons among habitats and seasons were subsequently conducted using the Kruskal–Wallis rank-sum test (Kruskal and Wallis, 1952), which does not require normally distributed data. Test statistics (H) and corresponding probability values were reported for all comparisons.

Relationships between suspended sedimentation rates and sediment grain-size fractions (sand, silt, and clay) were examined using Spearman's rank correlation coefficient (Spearman, 1904), owing to the non-normal distribution of the variables. Correlation coefficients (ρ) and associated *p*-values were calculated separately for each study area. Pearson's product-moment correlation coefficient (Pearson, 1895) was additionally computed for datasets that approximated normality to facilitate comparison between linear and monotonic relationships.

The annual sampling period was classified into three hydroclimatic seasons following the regional monsoon regime of the southeastern coast of Tamil Nadu, India: **Southwest Monsoon (June–September), Northeast Monsoon (October–January), and Pre-monsoon (February–May)** (Shetye and Gouveia, 1998). This seasonal classification formed the basis for all temporal analyses. All statistical analyses were performed using **R version 4.4.2**. Data are presented as **mean ± standard deviation (SD)** unless otherwise stated. Figures, including line graphs, box plots, scatter plots, and stacked bar charts, were generated to illustrate monthly variability, seasonal trends, habitat-wise differences, and sediment grain-size composition.

Results

Suspended sedimentation rates

Suspended sedimentation rates were recorded monthly across three habitat types coral reef, artificial reef, and non-reef areas over a 12-month period from August 2024 to July 2025, following the methodology of English et al. (1997). The overall mean sedimentation rate was highest in the non-reef area (46.56 ± 13.37 mg cm^{-2} day^{-1}), followed by the artificial reef area (37.89 ± 12.31 mg cm^{-2} day^{-1}) and the coral reef area (35.62 ± 14.35 mg cm^{-2} day^{-1}) (Table 1).

Monthly mean sedimentation rates in the coral reef area ranged from a minimum of 22.21 ± 9.89 mg cm^{-2} day^{-1} in February to a maximum of 50.43 ± 27.40 mg cm^{-2} day^{-1} in October. In the artificial reef area, the lowest rate was recorded in November (30.99 ± 14.09 mg cm^{-2} day^{-1}) and the highest in July (48.89 ± 9.12 mg

cm^{-2} day^{-1}). The non-reef area showed the least monthly variation, with rates ranging from 42.08 ± 21.28 mg cm^{-2} day^{-1} in April to 54.43 ± 9.62 mg cm^{-2} day^{-1} in September (Fig. 2, Fig. 3).

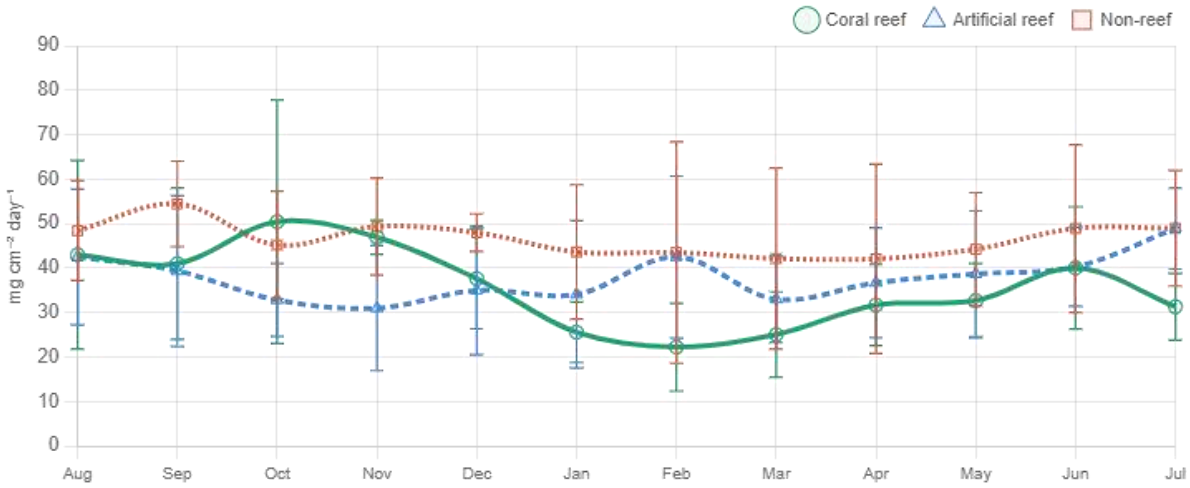


Figure 2. Temporal variation in monthly mean suspended sedimentation rates (mg cm^{-2} day^{-1}) across coral reef, artificial reef, and non-reef habitats. Values are expressed as mean ± standard deviation (SD).

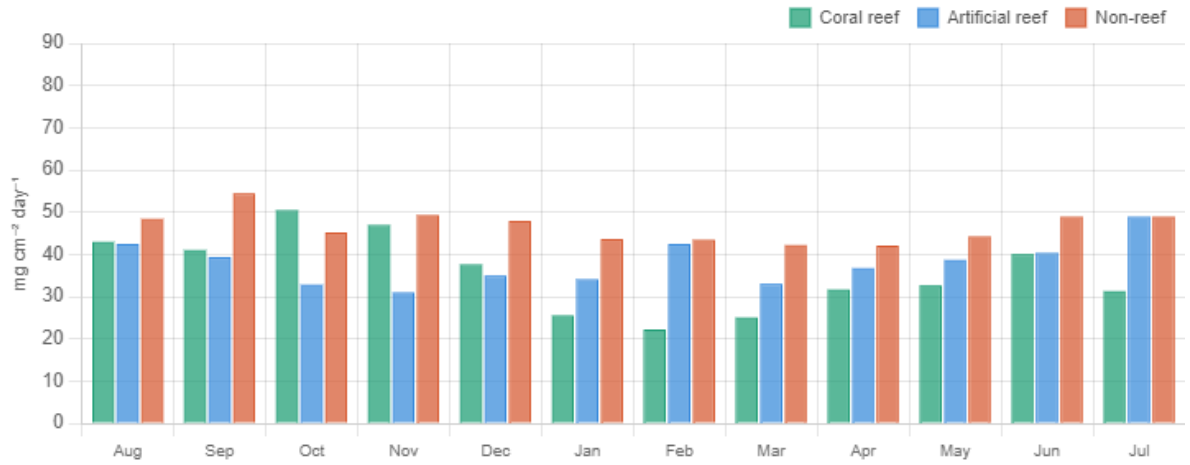


Figure 3. Comparative monthly variation in suspended sedimentation rates (mg cm^{-2} day^{-1}) among coral reef, artificial reef, and non-reef habitats.

Prior to statistical comparison, the Shapiro-Wilk test indicated that sedimentation data for all three areas deviated significantly from a normal distribution (coral reef: $W = 0.929$, $p = 0.024$; artificial reef: $W = 0.939$, $p = 0.046$; non-reef: $W = 0.918$, $p = 0.011$). Given this departure from normality, the Kruskal-Wallis test was applied as a non-parametric alternative to one-way ANOVA. The test revealed a statistically significant difference in sedimentation rates among the three habitat types ($H = 14.92$, $p = 0.001$). Supporting this, a one-way ANOVA also confirmed a significant difference among areas ($F = 6.71$, $p = 0.002$). Post-hoc analysis using Tukey's HSD indicated that the non-reef area differed significantly from both the coral reef area (mean difference = 10.94 mg cm^{-2} day^{-1}) and the artificial reef area (mean difference = 8.67 mg cm^{-2} day^{-1}), while no significant difference was detected between the coral reef and artificial reef areas (mean difference = 2.27 mg cm^{-2} day^{-1}). Monthly variation within each area was not statistically significant (coral reef: $F = 1.28$, $p = 0.291$; artificial reef: $F = 0.43$, $p = 0.925$;

non-reef: F = 0.17, p = 0.998), suggesting that sedimentation remained relatively stable across months within each habitat type (Fig. 4).

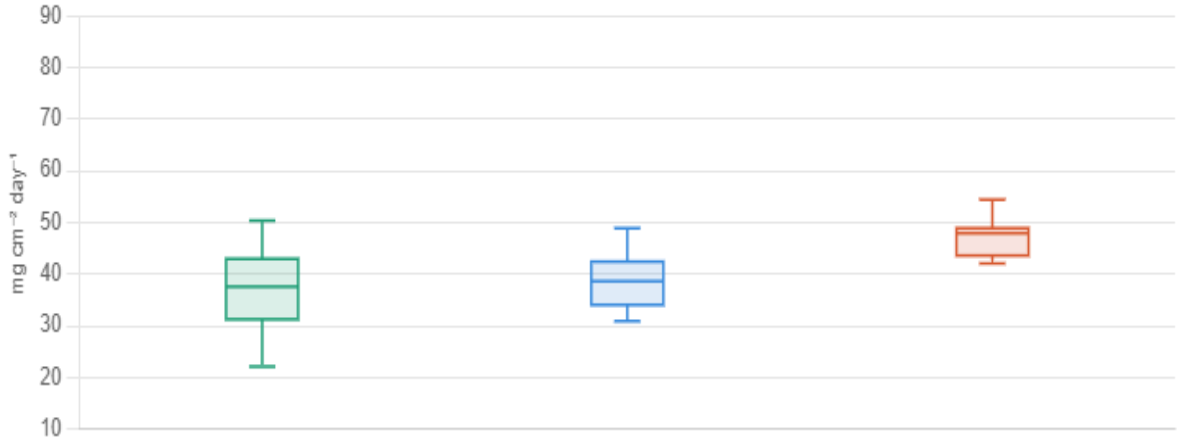


Figure 4. Distribution of suspended sedimentation rates (mg cm^{-2} day^{-1}) across 12 months among coral reef, artificial reef, and non-reef habitats.

Table 1. Overall mean ± SD suspended sedimentation rates and range values recorded across the three study areas over the 12-month monitoring period (August 2024 – July 2025).

Area	Mean ± SD (mg cm^{-2} day^{-1})	Min	Max
Coral reef	35.62 ± 14.35	13.94	80.12
Artificial reef	37.89 ± 12.31	14.97	58.34
Non-reef	46.56 ± 13.37	14.85	65.35

Seasonal variation in suspended sedimentation rates

To assess seasonal patterns in suspended sedimentation at Palk Bay, Rameswaram, the 12-month monitoring period (August 2024 – July 2025) was divided into three seasons based on the regional monsoon calendar of the southeastern coast of India: The Southwest Monsoon (SWM; June–September), the Northeast Monsoon (NEM; October–January), and the pre-monsoon period (February–May).

In the coral reef area, mean sedimentation rates were highest during the NEM season (40.13 ± 11.12 mg cm^{-2} day^{-1}), closely followed by the SWM (38.82 ± 5.17 mg cm^{-2} day^{-1}), while the lowest rates were recorded during the pre-monsoon period (27.89 ± 5.08 mg cm^{-2} day^{-1}). The peak monthly rate in this area was observed in October (50.43 ± 27.40 mg cm^{-2} day^{-1}), which falls within the early NEM season, while the minimum was recorded in February (22.21 ± 9.89 mg cm^{-2} day^{-1}). One-way ANOVA showed that seasonal differences within

the coral reef area were not statistically significant (F = 3.07, p = 0.096), though a declining trend toward the pre-monsoon period was evident (Fig. 5).

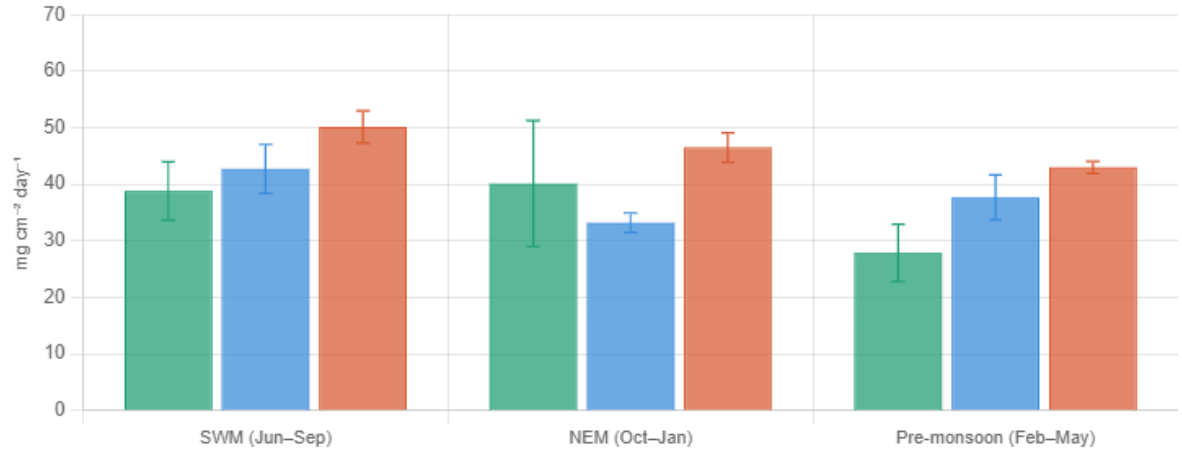


Figure 5. Seasonal sedimentation rates (mg cm⁻² day⁻¹) per unit area across coral reef, artificial reef, and non-reef habitats; values are expressed as mean ± standard deviation (SD).

In the artificial reef area, sedimentation rates were highest during the SWM (42.75 ± 4.30 mg cm⁻² day⁻¹), with a peak recorded in July (48.89 ± 9.12 mg cm⁻² day⁻¹). Rates declined during the NEM (33.21 ± 1.72 mg cm⁻² day⁻¹) before recovering slightly during the pre-monsoon season (37.70 ± 3.95 mg cm⁻² day⁻¹). Seasonal variation in the artificial reef area was statistically significant (F = 7.37, p = 0.013), with the Kruskal-Wallis test confirming this result (H = 7.54, p = 0.023).

The non-reef area showed consistently elevated sedimentation across all seasons, with the highest rates during the SWM (50.17 ± 2.85 mg cm⁻² day⁻¹) and a gradual decline through the NEM (46.52 ± 2.59 mg cm⁻² day⁻¹) to the pre-monsoon period (42.99 ± 1.06 mg cm⁻² day⁻¹). This declining seasonal trend was statistically significant (F = 9.69, p = 0.006; Kruskal-Wallis: H = 7.65, p = 0.022), and the notably low standard deviation during the pre-monsoon season suggests that sedimentation in the non-reef area was particularly stable and uniform during this period (Fig. 6).

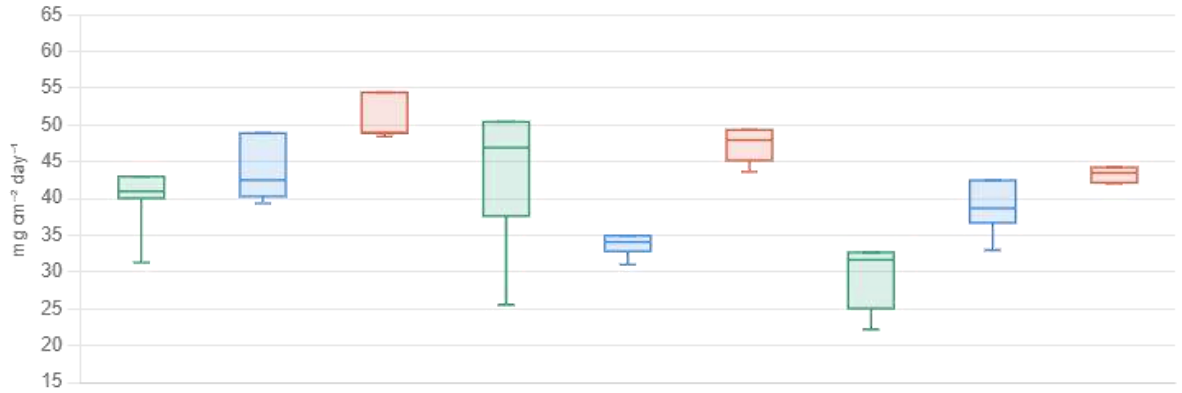


Figure 6. Seasonal comparison of sedimentation rates (mg cm⁻² day⁻¹) across coral reef, artificial reef, and non-reef sites, highlighting spatial differences in sediment deposition.

Comparison of sedimentation rates among the three habitat types within each season revealed significant differences during the SWM (Kruskal-Wallis: H = 6.73, p = 0.035) and pre-monsoon periods (H = 8.77, p = 0.013), with the non-reef area consistently recording the highest values. During the NEM, inter-area differences were not statistically significant (H = 4.77, p = 0.092), indicating a degree of convergence in sedimentation activity across habitat types during this season.

Table 2. Mean ± SD suspended sedimentation rates (mg cm^{-2} day^{-1}) recorded across three seasons in coral reef, artificial reef, and non-reef areas at Palk Bay, Rameswaram (August 2024 – July 2025).

Season	Coral reef	Artificial reef	Non-reef
Southwest monsoon (Jun–Sep)	38.82 ± 5.17	42.75 ± 4.30	50.17 ± 2.85
Northeast monsoon (Oct–Jan)	40.13 ± 11.12	33.21 ± 1.72	46.52 ± 2.59
Pre-monsoon (Feb–May)	27.89 ± 5.08	37.70 ± 3.95	42.99 ± 1.06

Sediment grain size composition

Sediment grain size analysis revealed that sand was the dominant fraction across all three study areas throughout the monitoring period (Fig. 7). The overall mean sand content was comparable among areas, recorded at 72.63% in the coral reef, 72.49% in the artificial reef, and 73.89% in the non-reef area. Silt contributed 20.49%, 21.53%, and 20.45%, while clay accounted for 6.88%, 5.98%, and 5.66% in the coral reef, artificial reef, and non-reef areas, respectively (Figs. 8–10).

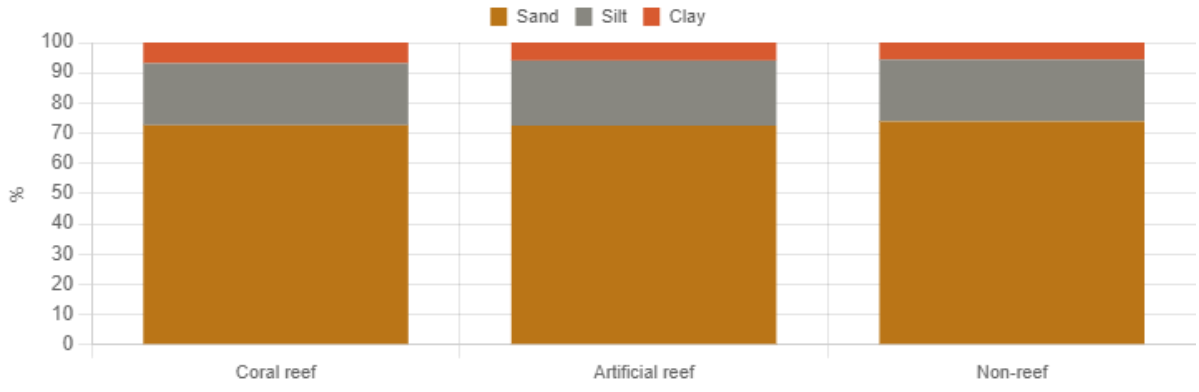


Figure 7. Sediment grain size composition (%) across coral reef, artificial reef, and non-reef habitats, including sand, silt, and clay fractions.

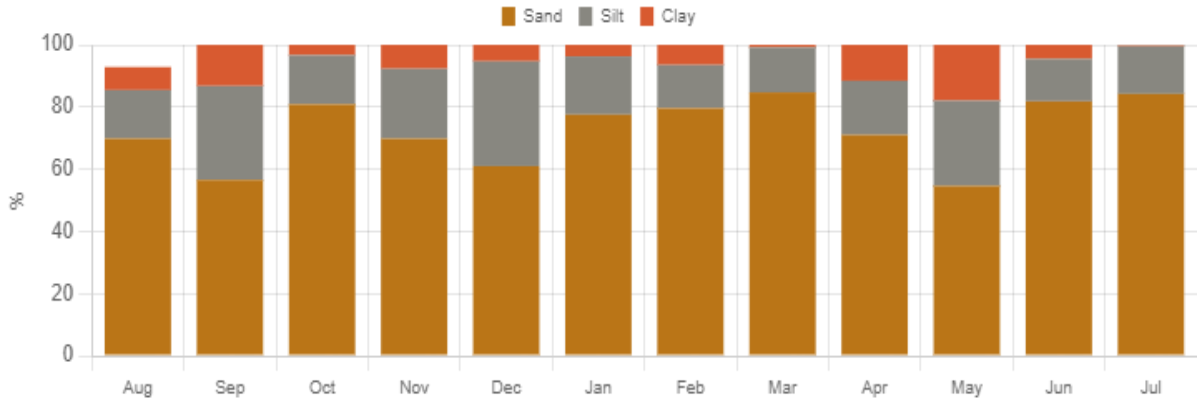


Figure 8. Monthly distribution of sediment grain size fractions (%) at the coral reef site, highlighting temporal variability in sediment composition.

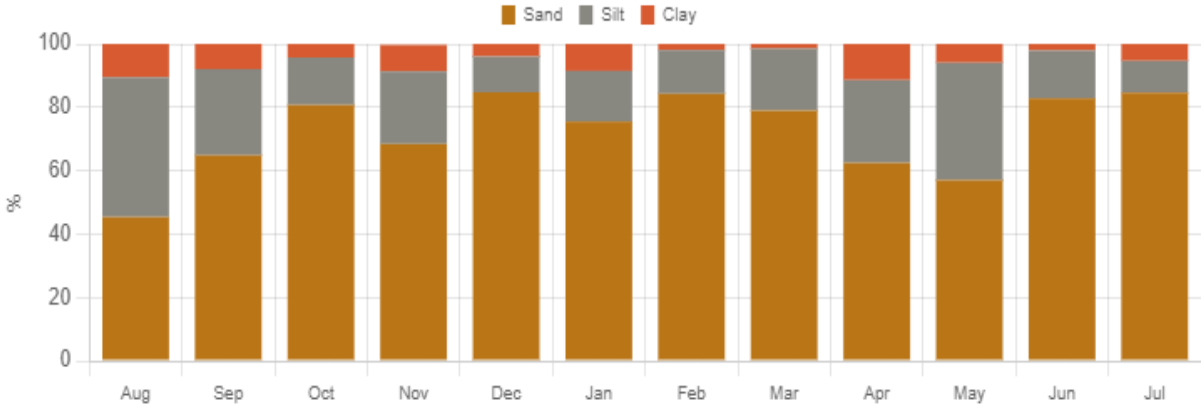


Figure 9. Monthly distribution of sediment grain size fractions (%) at the artificial reef site, highlighting temporal variability in sediment composition.

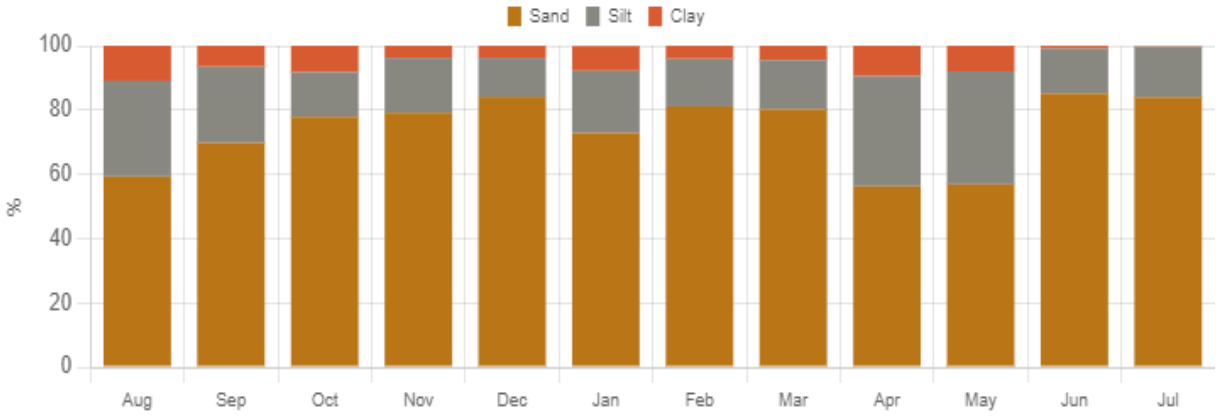


Figure 10. Monthly distribution of sediment grain size fractions (%) at the non-reef site, highlighting temporal variability in sediment composition.

One-way ANOVA tests showed no statistically significant differences among the three areas for sand ($F = 0.054$, $p = 0.947$), silt ($F = 0.060$, $p = 0.942$), or clay ($F = 0.292$, $p = 0.748$), indicating a broadly similar grain size composition across habitat types. Spearman's rank correlation analysis found no significant relationship between

monthly sedimentation rates and silt content in any of the three areas (coral reef: r = 0.399, p = 0.199; artificial reef: r = −0.042, p = 0.897; non-reef: r = −0.077, p = 0.812). Similarly, no significant correlation was found between sedimentation rate and clay content (coral reef: r = 0.266, p = 0.404; artificial reef: r = 0.000, p = 1.000; non-reef: r = −0.413, p = 0.183).

Correlation between suspended sedimentation rates and sediment grain size

Prior to correlation analysis, the Shapiro-Wilk test was applied to assess the normality of grain size data. Sand and silt fractions in the non-reef area showed significant departures from normality (sand: W = 0.847, p = 0.033; silt: W = 0.823, p = 0.018), while grain size data from the coral reef and artificial reef areas were approximately normally distributed (p > 0.05 for all fractions). Given that sedimentation rate data for all three areas also deviated from normality (as reported previously), Spearman's rank correlation was selected as the primary correlation test, with Pearson's correlation conducted in parallel for comparison.

The relationship between suspended sedimentation rate and sand content in the coral reef area yielded the only statistically significant correlation observed in this study. Spearman's rank correlation revealed a significant negative relationship between sedimentation rate and sand content in the coral reef area (r = −0.622, p = 0.031), indicating that months with higher sedimentation rates tended to coincide with a lower proportion of sand in the deposited material. Pearson's correlation for the same relationship was negative but did not reach significance (r = −0.389, p = 0.212), likely reflecting the non-normal distribution of the data. No significant correlations between sedimentation rate and silt or clay content were found in the coral reef area (silt: r = 0.469, p = 0.125; clay: r = 0.224, p = 0.485). In the artificial reef area, Spearman's correlation showed no significant association between sedimentation rate and any grain size fraction (sand: r = 0.049, p = 0.880; silt: r = −0.042, p = 0.897; clay: r = 0.000, p = 1.000). Pearson's correlation similarly produced no significant results (sand: r = −0.024, p = 0.942; silt: r = 0.044, p = 0.892; clay: r = −0.036, p = 0.911), suggesting that fluctuations in sedimentation rate in this area were largely independent of grain size composition throughout the monitoring period. In the non-reef area, no statistically significant correlations were detected between sedimentation rate and any grain size fraction under either Spearman's (sand: r = 0.259, p = 0.417; silt: r = −0.077, p = 0.812; clay: r = −0.413, p = 0.183) or Pearson's tests (sand: r = 0.193, p = 0.548; silt: r = −0.144, p = 0.655; clay: r = −0.271, p = 0.395). The moderate negative Spearman correlation between sedimentation and clay content (r = −0.413), while not significant, may suggest a weak tendency for lower clay proportions during periods of elevated sedimentation in open-water conditions (Fig. 11, Table 3).

Table 3. Spearman's rank correlation coefficients (r) and p-values for the relationship between monthly suspended sedimentation rates and sediment grain size fractions across the three study areas.

Area	sedimentation vs Sand	sedimentation vs Silt	sedimentation vs Clay
Coral reef	r = −0.622, p = 0.031*	r = 0.469, p = 0.125	r = 0.224, p = 0.485
Artificial reef	r = 0.049, p = 0.880	r = −0.042, p = 0.897	r = 0.000, p = 1.000
Non-reef	r = 0.259, p = 0.417	r = −0.077, p = 0.812	r = −0.413, p = 0.183

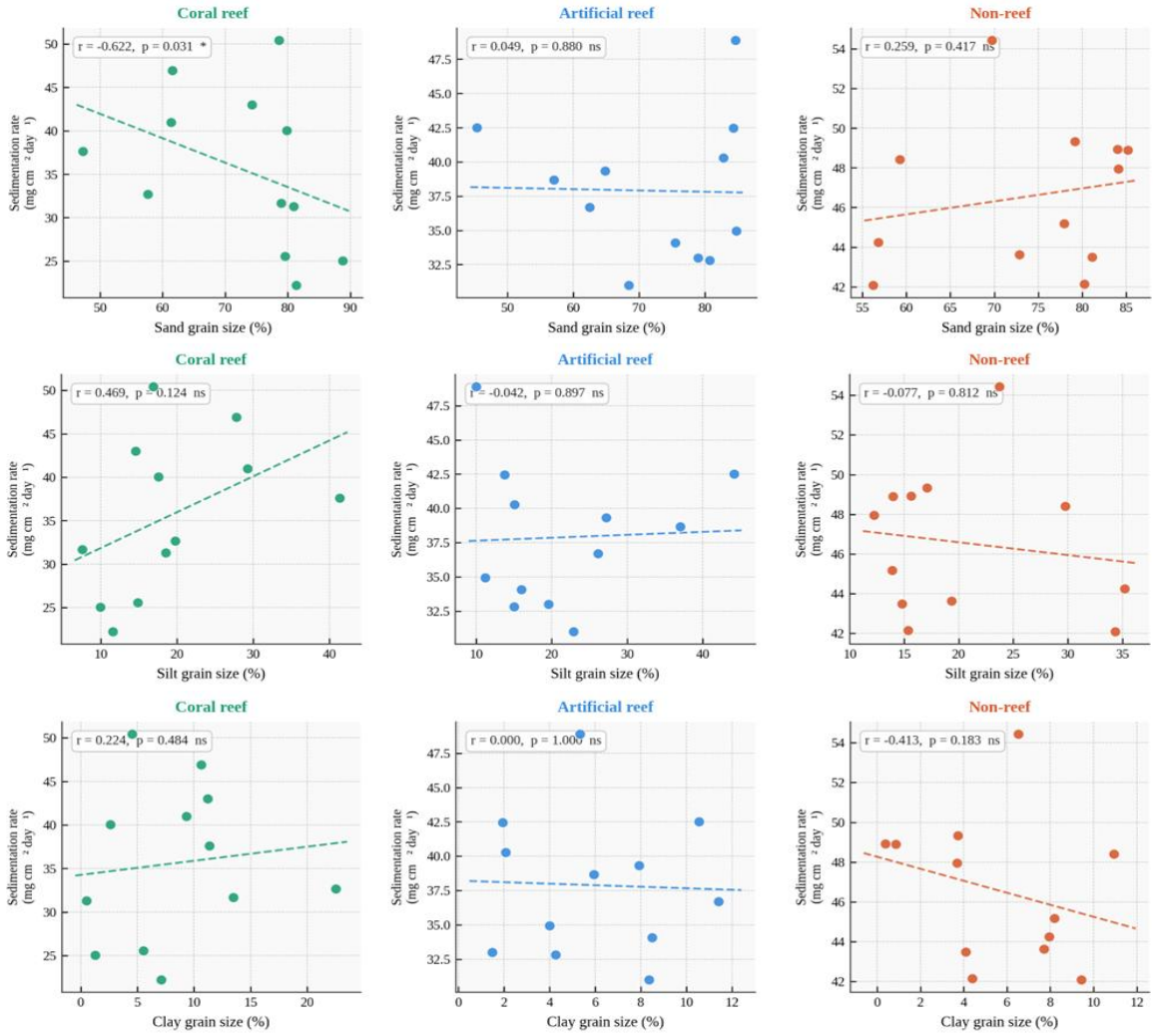


Figure 11. Relationship between monthly suspended sedimentation rate and sediment grain size (%) across coral reef, artificial reef, and non-reef areas.

Sedimentation Impact

Sedimentation varied among the study habitats and had a measurable influence on the ecological condition of the reef communities. In the natural coral reef environment, excessive sediment deposition was observed on coral colonies, covering living tissues and reducing light penetration. This sediment accumulation is likely to impair photosynthetic activity of the symbiotic zooxanthellae, resulting in physiological stress, partial bleaching, and, in heavily affected colonies, tissue mortality (fig. 12). At the artificial reef sites, sediment deposition was moderate but sufficient to increase local water turbidity. Elevated turbidity reduced underwater visibility and limited light availability, potentially affecting the growth of photosynthetic benthic organisms. In addition, the accumulation of fine sediments on the reef modules created a temporary barrier to the attachment and settlement of biofouling organisms, including algae, sessile invertebrates, and coral recruits. Consequently, ecological succession on newly deployed reef structures may be slower in areas experiencing higher sediment loads (fig. 13).

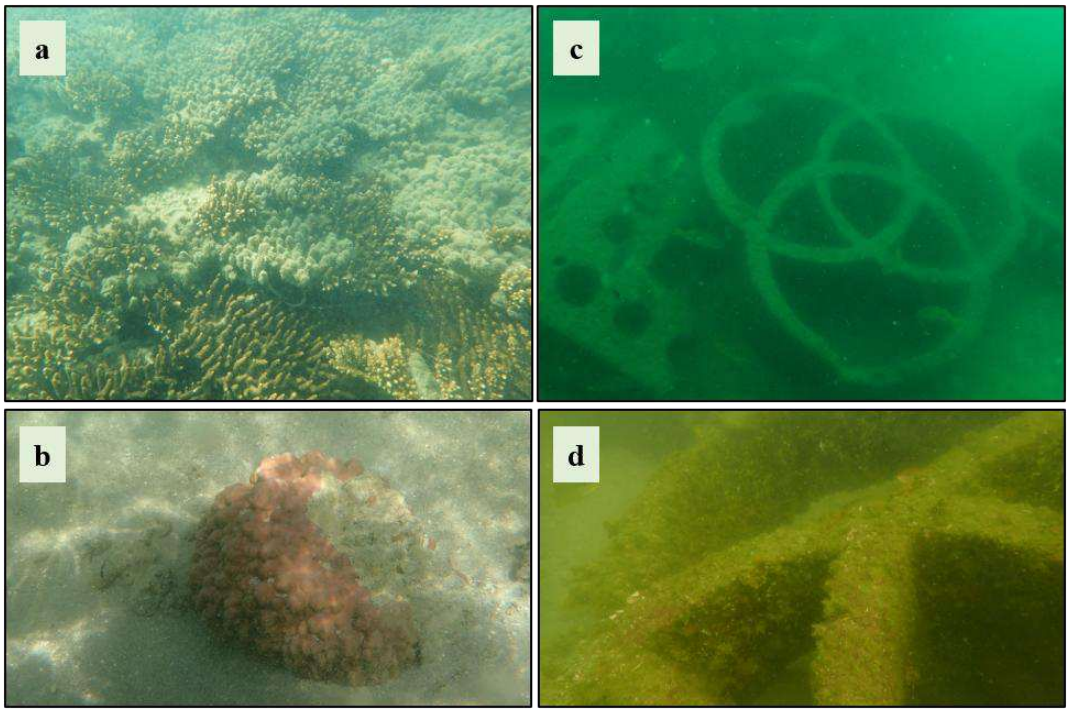


Figure 12. Effects of sediment deposition on natural and artificial reef habitats. (a) Sediment accumulation covering living coral tissues and reducing light penetration; (b) sediment deposition on coral colonies causing physiological stress; (c) increased water turbidity surrounding the artificial reef due to suspended sediments; and (d) accumulation of fine sediments on the artificial reef surface, potentially delaying the settlement and colonization of benthic organisms.

Discussion

The overall pattern observed in this study, non-reef > artificial reef > coral reef, is consistent with the general understanding that reef framework and associated biological communities act as natural sediment traps and current-attenuating structures, reducing net accumulation of fine particulate matter compared to open, unstructured substrates. The mean rates recorded here (35.62–46.56 mg cm^{-2} day^{-1}) fall within a range previously reported for reef systems on the southeast coast of India. Sedimentation rates measured across Palk Bay and Gulf of Mannar reef ecosystems have been reported between 14.6 and 38.54 mg cm^{-2} day^{-1}, with Palk Bay showing roughly twice the sedimentation rate of the Gulf of Mannar (National Centre for Sustainable Coastal Management [NCSCM]. Similarly, an earlier rapid assessment in the Palk Bay coral reef environment found sedimentation ranging from 1 to 42 mg cm^{-2} day^{-1}, with rates greatest around the onset of the southwest monsoon and areas of higher sedimentation showing reduced live coral cover (Wilson et al., 2005). The values recorded in the present study, particularly the elevated rates in the non-reef and artificial reef zones, are therefore comparable to, and in places exceed, historical baselines for this region. Set against global coral-stress thresholds, early work on reef sedimentation reported mean rates of 1 to 21 mg cm^{-2} day^{-1} under relatively undisturbed conditions (Rogers, 1990), while a recent meta-analysis found that adverse effects in corals can occur at deposited-sediment loads as

low as 1 mg cm^{-2} day^{-1} for larvae and 4.9 mg cm^{-2} day^{-1} for adult tissue mortality (Tuttle & Donahue, 2022). Against these benchmarks, even the lowest monthly mean recorded in the coral reef area here (22.21 mg cm^{-2} day^{-1}, February) substantially exceeds thresholds associated with sub-lethal and lethal effects elsewhere, reinforcing the ecological relevance of the sediment stress documented in the Sedimentation Impact section, and is further supported by a Guam-based study showing that coral richness dropped exponentially with increasing sedimentation rate, with richness nearly three times greater below 10 mg cm^{-2} day^{-1} than between 10 and 50 mg cm^{-2} day^{-1}, and no corals present above roughly 110 mg cm^{-2} day^{-1} (Minton et al., 2022). The absence of a significant difference between the coral reef and artificial reef areas (Tukey's HSD, mean difference = 2.27 mg cm^{-2} day^{-1}) suggests both hard-substrate habitats experience a broadly similar hydrodynamic sediment regime despite differences in structural complexity and biological cover, with the non-reef area the primary driver of the overall significant result.

The seasonal patterns identified here, elevated sedimentation during both monsoons and reduced rates pre-monsoon, align with long-documented monsoon-driven sediment dynamics of the Palk Bay and Gulf of Mannar region. Along the seaward side of the Gulf of Mannar islands, high-velocity waves breaking against the reef edge lose velocity and generate wave-induced currents that carry littoral sediment onto the reef (Pillai, 1971). Wave- and current-driven resuspension of this kind is consistent with the elevated sedimentation recorded here during both monsoon seasons, when wind- and wave-energy inputs to the bay are highest, and is corroborated by post-disturbance surveys showing that corals located closer to the shore across the Gulf of Mannar and Palk Bay islands were disproportionately affected by sedimentation following major shoreline disturbance events (Kumaraguru et al., 2005), underlining that near-shore, shallow reef zones such as the coral reef area of the present study are structurally predisposed to episodic sediment loading. The particularly strong SWM-season signal in the non-reef and artificial reef areas is likewise consistent with broader regional findings that coral reef ecosystems of the Gulf of Mannar and Palk Bay have undergone degradation linked in part to high sedimentation rates occurring specifically during the southwest monsoon (Koushik et al., 2021).

The dominance of sand across all three habitats (72.5–73.9%), with comparatively minor silt and clay fractions, is typical of reef-associated sediment systems where coarse, largely biogenic particles dominate the local budget. The significant negative correlation between sedimentation rate and sand content in the coral reef area ($r = -0.622$, $p = 0.031$) suggests that periods of higher total sediment flux were associated with a proportionally greater contribution of fine material, consistent with findings that fine-grained silt-clay sediment accumulating on reefs can show marked spatial and temporal variation, often increasing following heavy rainfall or land-use disturbance events (Otaño-Cruz et al., 2017). The absence of an equivalent significant correlation in the artificial reef and non-reef areas may reflect a more locally uniform, current-driven resuspension process at those sites, where sediment supply is less episodically pulsed by terrigenous fine input.

The observed sediment accumulation on coral colonies, reduced light penetration, and associated physiological stress are consistent with a substantial body of sediment-stress literature. Adverse effects from suspended sediment exposure have been documented at levels as low as 10 mg/L for reduced juvenile growth and 3.2 mg/L for bleaching and tissue mortality in adults, with corals generally taking longer to show mortality from suspended than from deposited sediment, though physiological changes appear more rapidly under suspended exposure (Tuttle & Donahue, 2022). This distinction is relevant here, since the coral reef area experienced both

chronic deposited sedimentation and, presumably, elevated suspended loads during peak months such as October, a combination likely to compound stress on zooxanthellae-bearing tissue. For the artificial reef, the observed turbidity increases and apparent delay in biofouling and coral-recruit settlement align with findings that low colonisation on artificial substrates has been linked to sedimentation of suspended particulate matter on the substrate surface, an effect more pronounced on horizontal structures (Agostini & Ozorio, 2022). Given that the artificial reef modules here likely include horizontal surfaces, this mechanism may plausibly explain the slower successional development noted qualitatively in this study. At the same time, artificial reefs elsewhere have shown resilience to sediment stress: corals successfully colonised an artificial reef in a naturally turbid, dynamic nearshore environment subject to intermittent high turbidity and frequent cyclones (Blakeway et al., 2013), indicating that sedimentation may slow but not necessarily preclude longer-term reef development on artificial substrates.

Collectively, these findings reinforce that sedimentation in Palk Bay is a chronic, monsoon-modulated stressor that differentially affects natural and artificial reef habitats, with the coral reef area, despite receiving statistically comparable sediment loads to the artificial reef, likely bearing a disproportionate ecological cost given the sensitivity of live coral tissue to both deposited and suspended sediment exposure. Placement of future artificial reef modules in areas of naturally lower ambient sedimentation, or orientation to minimise horizontal, sediment-trapping surfaces, may improve early colonisation success. Some limitations should be acknowledged: the single 12-month sampling window cannot capture inter-annual monsoon variability, and the sediment-trap method integrates both resuspended local material and any terrigenous input without fully partitioning these sources; complementary analyses of sediment provenance, such as organic content or $CaCO_3$ percentage, would strengthen future interpretations of the drivers behind the observed grain-size sedimentation relationships.

Conclusion

This 12-month study demonstrates that suspended sedimentation in Palk Bay, Rameswaram is a chronic, habitat-structured, and monsoon-modulated process. Non-reef areas recorded significantly higher sedimentation (46.56 ± 13.37 mg cm^{-2} day^{-1}) than either the coral reef (35.62 ± 14.35) or artificial reef (37.89 ± 12.31), while the two reef habitats did not differ significantly from each other indicating that reef structure, rather than reef origin (natural vs. artificial), is the primary factor governing sediment exposure. Seasonally, sedimentation peaked during the southwest and northeast monsoons and declined pre-monsoon, with the artificial reef and non-reef areas showing statistically significant seasonal cycles and the coral reef following a similar, non-significant trend.

Sediment composition was sand-dominated and statistically uniform across all three habitats, but the coral reef alone showed a significant negative correlation between sedimentation rate and sand content ($r = -0.622$, $p = 0.031$), suggesting its sediment peaks are driven by episodic fine-particle pulses rather than steady sand deposition a pattern unique to that habitat. Ecologically, sediment accumulation on coral tissue coincided with reduced light penetration and physiological stress, while sediment-driven turbidity at the artificial reef appeared to delay, rather than prevent, biofouling and coral recruitment. Overall, the results indicate that the coral reef habitat bears a disproportionate ecological cost relative to the artificial reef despite comparable sediment loads, underscoring the need for sediment-informed siting of future artificial reef deployments and broader catchment-level sediment management to protect the region's remaining natural coral habitat.

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