FINAL REPORT

Tracing in-water debris accumulation on coral reefs

In Zamboanguita, Southern Negros Oriental, Philippines

Lars Peters

Marine Conservation Philippines (MCP)

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Student Number: 540338168

Supervisor (MCP): Naomi Westlake

Supervisor (HAS): Harm Van Kuppevelt

Institution: HAS Green Academy

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Summary

Marine debris accumulating on coral reefs poses an increasing threat to reef health, fisheries, and the coastal communities of Southern Negros Oriental that depend on them. While surface-floating debris has received considerable research attention, debris that becomes lodged within the reef causes more damage through smothering and elevated disease rates, yet there has been no previous analysis on this problem within this region.

This study analysed Marine Conservation Philippines' long-term reef monitoring dataset (March 2018 to early 2026, over 13,000 records) to identify spatial and temporal patterns of in-water debris accumulation across fifteen reef sites in Zamboanguita, Siaton, and Santa Catalina, twelve of which had sufficient survey history to be included in the statistical analysis. Non-parametric statistical methods (Kruskal-Wallis, Dunn's post-hoc, Scheirer-Ray-Hare, Spearman correlation) were combined with multivariate techniques (PERMANOVA, SIMPER, NMDS) and Generalized Linear Models to test the influence of depth, current strength, rainfall, wind speed, and proximity to rivers, markets, coastal infrastructure and fishing pressure.

Debris density varied significantly between sites ($p < 0.001$), differing by up to a factor of ten between the highest sites (Salag MPA, Dalakit MPA) and the lowest (Andulay MPA), with a significant Site × Depth interaction showing that the relationship between depth and debris depends on local site conditions rather than following one regional pattern. Distance to the nearest river mouth was the strongest factor overall ($\rho = -0.218$, $p < 0.001$), followed by distance to Malatapay Market ($\rho = -0.098$), coastal infrastructure ($\rho = 0.074$), and fishing pressure ($\rho = 0.138$); current strength was also significant ($\chi^2 = 15.593$, $p < 0.001$), while short-term weather variables showed no effect.

These results point to land-based input as the dominant driver of debris accumulation, concentrated in hotspots close to rivers and markets rather than distributed evenly, and shaped further by depth and current strength once debris enters the water. Fishing gear followed a distinct pattern, accumulating more with depth regardless of local fishing intensity, most likely due to the physical settling of heavier gear into deeper, calmer zones.

In conclusion, in-water debris accumulation on the reefs of Southern Negros follows clear, detectable spatial patterns driven mostly by proximity to land-based sources, reef topography, and hydrodynamic conditions. Based on these findings, it is recommended that MCP and local Government Units (LGUs) concentrate cleanup and monitoring resources around identified hotspots such as river mouths and Malatapay Market, prioritise fishing gear recovery in deeper zones, and continue building survey history at recently added monitoring sites to allow their inclusion in future analyses.

1. Introduction

Marine debris has become one of the most pressing environmental problems facing reef ecosystems worldwide, and the numbers make it easy to see why. Global plastic production and consumption have grown continuously for decades, and large amounts end up in the ocean every year breaking down into microplastics, drifting across ocean currents, and eventually ending up in some of the most ecologically important habitats on the planet, including coral reefs.

Coral reefs matter enormously in the Philippines. They support food security, sustain fisheries, and provide a foundation for the livelihoods of millions of coastal people (UNEP, 2021). Philippine reefs are already under pressure from multiple directions: climate change, overfishing, sedimentation, and pollution. Marine debris adds a direct and measurable layer to this. Unlike debris floating at the surface, material that reaches the reef can become lodged within the coral structure, where it is difficult to remove and continues to cause damage through smothering, abrasion, and entanglement. Research has shown that corals in contact with plastic are up to 89% more likely to show signs of disease compared to 4% in areas without plastic (Lamb et al., 2018). That is not a small effect.

Marine Conservation Philippines (MCP) is a non-profit organisation based in Zamboanguita, Southern Negros Oriental, working to ensure that the reefs in this municipality and others continue to provide food and livelihoods for the communities that depend on them. MCP runs a long-term reef monitoring programme across fifteen sites in Zamboanguita, Siaton, and Santa Catalina, covering substrate composition, fish populations, invertebrates, and in-water debris. Since March 2018, every piece of debris found during predation surveys has been recorded. That dataset now has over eight years of data and with more than 13,000 records that have never been properly analysed. A structured analysis of what has accumulated, where, and how it got there could give MCP and the LGUs of Zamboanguita, Siaton, and Santa Catalina the insight needed to direct cleanup efforts more effectively, identify the most likely debris sources, and make the case for targeted action at the municipal level.

This study is built on exactly that idea. It analyses MCP's monitoring dataset to identify spatial and temporal patterns of in-water debris accumulation across the fifteen reef sites, covering March 2018 to early 2026, and explores what environmental factors (rainfall, tidal state, current strength) and human factors (proximity to settlements and rivers, fishing activity) might help explain those patterns. The work runs in two phases: first a description of the data, followed by statistical test to explore the underlying trends. The central research question is:

What patterns of in-water debris accumulation occur on coral reefs in Southern Negros, and what factors help explain these patterns?

Three sub-questions structure the analysis:

- How does in-water debris accumulation vary across reef sites and depth zones, and how have these patterns changed over time?
- To what extent can differences in debris accumulation be explained by environmental factors such as current strength, seasonal rainfall, and proximity to rivers or estuaries?
- To what extent can differences in debris accumulation be explained by human factors such as proximity to coastal settlements, fishing activity, or land-based waste sources?

2. Literature Review

2.1 Organisational context: Marine Conservation Philippines

Marine Conservation Philippines (MCP) is a registered non-profit organisation founded in 2015 and based in Zamboanguita, Southern Negros Oriental. Its mission is to ensure that coral reefs continue to provide food security and livelihoods for the coastal communities that depend on them, working through a combination of long-term scientific monitoring, community engagement, education, government capacity building and research projects such as this one (Marine Conservation Philippines, 2025a).

MCP's monitoring programme covers fifteen reef sites across Zamboanguita, Siaton, and Santa Catalina. Surveys follow standardised protocols across three depth zones and record coral cover and composition, fish abundance and commercial biomass, invertebrate communities, and the presence of coral predating organisms and in-water debris through predation belt transects (Marine Conservation Philippines, 2025b). Results are published in biannual MPA status reports and through an open-source data dashboard accessible to government agencies, researchers, and local fisherfolk (Marine Conservation Philippines, 2025c). Beyond monitoring, MCP runs school education programmes, trains government dive teams, partners with ProOcean on coastal cleanups and ocean plastics collection, and supports fishing communities through dive tourism development and a lost gear reporting network.

The debris records produced through MCP's predation belt surveys represent one of the few long-running, standardised in-water reef debris datasets in the Philippines. Their value lies not only in the quantity of records but in the consistency of the protocol: the same depth zones, survey methods, and debris categories have been used across all fifteen sites since 2018, making it possible to compare accumulation meaningfully across sites and through time.

2.2 Marine debris on coral reefs: Mechanisms and ecological impacts

Marine debris is defined as any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine environment (UNEP, 2021). Plastic is by far the most studied and ecologically problematic component (Rochman et al., 2016). Unlike organic waste, plastic does not biodegrade in any meaningful timeframe. Instead, it photodegrades slowly under UV exposure, fragmenting into progressively smaller particles that persist in the environment for decades and concentrate in marine food webs (Andrady, 2011). Gall and Thompson (2015) reviewed evidence of debris impacts across a wide range of marine taxa and found documented harm at every level of the food chain. From direct ingestion and entanglement in megafauna to chemical contamination through microplastic uptake in invertebrates.

On coral reefs, the mechanisms of harm are both physical and biological. Loose debris smothers coral tissue, reduces light availability for symbiotic algae, and creates anaerobic conditions beneath larger objects (Nama et al., 2023). Lamb et al. (2018) produced the most comprehensive quantification of this risk to date: across 159 reef sites in the Asia-Pacific region, corals in contact with plastic showed disease rates of up to 89%, compared to a background rate of approximately 4% in plastic-free areas. The authors estimated that around 11 billion plastic items are currently entangled with reefs across the region, with this figure projected to increase by 40% by 2025. Fishing gear poses a distinct but equally serious threat. Richardson et al. (2019) estimated that between 5.7% and 8.6% of all fishing gear produced globally is lost or abandoned each year, translating to over 500,000 tonnes of gear entering the ocean annually. On reef systems, abandoned lines, nets, and rope fragments can abrade and break coral colonies through repeated contact over months or years.

Within MCP's monitoring framework, the relevance of the debris dataset is shaped by a deliberate recording protocol: all debris encountered during a survey is recorded, but not all of them are removed. During a survey, divers take some accessible debris that aren't overgrown, Larger or more difficult items, such as a ghost net or a big pile of debris that needs more effort to remove, are instead left in place and dealt with later during a separate cleanup dive. Items colonised by benthic invertebrates such as sponges and ascidians are also left in place, since removing them would damage those organisms. This means the dataset reflects the debris present in the water at the time of each survey, not a complete record of everything ever found there, since some of it gets removed along the way.

2.3 The Philippines plastic pollution context

The Philippines is one of the largest contributors of ocean plastic globally, generating an estimated 2.7 million tonnes of plastic waste per year, with approximately 20% estimated to enter the ocean (World Bank Group, 2021). Several Philippine rivers rank among the highest plastic-emitting waterways in the world, driven by the combination of dense coastal populations and waste management infrastructure that is unable to keep pace with the volume of waste produced (Lebreton et al., 2017).

A structural dimension of this problem is the ‘sachet economy’. For a large proportion of lower-income households across the Philippines, purchasing everyday goods such as shampoo, condiments, or washing powder in small single-use sachets is the only financially feasible option, with bulk quantities being unaffordable. An estimated 163 million sachets are consumed daily nationwide (World Bank Group, 2021). The abundance of small soft plastic packaging items on Philippine reefs is therefore not primarily a product of individual carelessness but of income constraints and the near-total absence of reusable or affordable alternative packaging options for lower-income consumers.

The legislative framework nominally addresses solid waste management. Under the Ecological Solid Waste Management Act (Republic Act 9003, 2000), Local Government Units (LGUs) are required to establish collection systems and material recovery facilities. In practice, national compliance is highly uneven: only around 9% of plastic waste is recycled and approximately 33% is formally collected, with the majority burned or dumped (World Bank Group, 2021). In coastal municipalities like those of Southern Negros, uncollected waste reaches drainage channels, rivers, and ultimately coastal waters. This is the structural backdrop against which MCP's debris data must be interpreted, and it helps explain why debris continues to accumulate on the reefs despite ongoing removal during every survey cycle and through periodic cleanup dives at individual sites.

2.4 Environmental drivers of debris accumulation on reefs

The amount and type of debris found at any given reef site is shaped by physical transport processes operating at multiple scales. At the regional scale in Southern Negros, the monsoon system is the dominant driver of seasonal variability. The southwest monsoon (Habagat) brings heavy rainfall, strong onshore winds, and rough sea conditions from approximately June to October, while the northeast monsoon (Amihan) marks the calmer, drier period from November to May (Licuanan et al., 2019). Crucially, wind direction reverses between seasons, meaning the coastline from which floating debris approaches shifts substantially throughout the year. Sites exposed to southwest winds during the Habagat may receive far more wind-driven debris during those months, while the same sites may be partially sheltered during the Amihan.

Rainfall drives land-to-sea debris transfer more directly through runoff and river discharge. Heavy rainfall during the wet season flushes accumulated terrestrial waste from land surfaces into drainage channels and rivers, which carry it into coastal waters (Lebreton et al., 2017). The magnitude of this effect depends on catchment size, land cover, and the density of upstream human settlements. In the MCP monitoring network, two sites are particularly exposed to this process: Basak Can-Unsang South MPA which will be referred to as Basak Can-Unsang MPA from now on, sits adjacent to a river mouth capable of delivering debris pulses during intense rainfall events.

At the local site level, hydrodynamic conditions determine whether debris accumulates or is redistributed. Sheltered sites with low current activity (such as Dalakit MPA, Latason MPA, and Salag MPA) may retain debris for longer between survey visits. More exposed sites (such as Guinsuan MPA and the Santa Catalina sites during the Habagat) may show more variable accumulation, with debris arriving in pulses and being redistributed again by wave action and currents. Tidal state at the time of each survey adds a further layer: tidal movement influences both the depth at which floating material settles and whether items recorded in shallow zones have been transported from elsewhere. This study accounts for this using the tidal current strength recorded by divers during each survey, rather than a modelled tidal height, since survey times were not consistently logged (see Section 3.3). It is worth noting that surveys were, by default, conducted less often during periods of stronger current, since diving conditions become harder, which may introduce a slight bias toward calmer-water surveys in the dataset.

2.5 Human drivers and site-level differences

Human activity shapes reef debris accumulation through both marine and land-based pathways, and the relative contribution of each pathway varies by site. Marine-based activity introduces fishing-related debris (line, rope, net fragments, abandoned gear) directly onto the reef. At several MCP sites, fishing pressure is a regular and observable feature: Kookoos is an unprotected reference site where fishing within and adjacent to the survey area is frequently observed. Similarly, Latason MPA and Malatapay MPA both experience regular boat traffic. At Malatapay, a Wednesday market brings additional concentrations of human activity close to the reef, likely elevating land-based waste inputs on market days specifically.

The influence of MPA status on debris accumulation is worth examining but cannot be assumed. MPAs restrict fishing and anchoring within their boundaries, which might be expected to reduce fishing-related debris at protected sites relative to unprotected reference sites. However, enforcement effectiveness varies considerably across the MCP network, and MPA designation does not necessarily prevent all fishing activity from occurring at or near a site. Whether MPA status is reflected in lower fishing-gear debris counts is therefore an empirical question this study can address directly, by comparing debris composition between MPA and reference sites.

Proximity to land-based waste sources is a further site-level variable. Sites closer to coastal settlements, markets, or river mouths are more exposed to the land-based plastic pathways described in Section 2.3. Mapping these site-level attributes against debris composition can help identify which sites are primarily receiving land-based material versus fishing-related debris, which in turn points toward whether cleanup and management responses should focus on community-level waste reduction or on fishing gear programmes.

2.6 Stakeholder overview

Several groups have a direct interest in, or influence over, how this study's findings are used. Understanding their roles helps clarify why this analysis matters beyond the scientific findings themselves.

Marine Conservation Philippines (MCP) is the project's direct stakeholder and data owner. As the organisation running the monitoring programme, MCP has both the greatest interest in the outcomes and the greatest influence over how recommendations are implemented, since any proposed changes to survey protocols or cleanup prioritisation depend on MCP's operational capacity and staffing.

Local Government Units (LGUs) of Zamboanguita, Siaton, and Santa Catalina hold formal authority over municipal waste management and MPA enforcement (under Republic Act 9003 and Republic Act 8550, respectively). Their interest lies in evidence that can justify enforcement priorities or budget allocation; their influence on the project's real-world impact is high, since they are the only stakeholder with legal authority to act on land-based waste infrastructure or fishing regulation.

Coastal fishing communities are both a contributing factor in the debris patterns studied, and a group directly affected by reef degradation, since reef health upholds their long-term food security and income. Their influence over the project is indirect, but their cooperation is essential for any recommendation involving fishing gear management or MPA compliance to succeed in practice.

HAS Green Academy, as the academic institution supervising this research, has an intern in the study's academic standards and research design, but limited direct influence over its real-world implementation.

Together, these groups define the boundaries of what this study's recommendations can realistically achieve: findings are only as useful as the willingness and capacity of MCP and the LGUs to act on them, and the cooperation of local fishing communities to except any possible actions.

3. Methodology

3.1 Research design

This research utilises an existing long-term monitoring dataset from MCP rather than collecting new field data. This approach aligns with what the study is trying to do: find patterns in years of accumulated records and translate those into practical recommendations. It also means MCP's ongoing monitoring programme did not need to be altered in any way to support this research.

The analysis runs in two phases. The first describes what the data shows: where debris accumulates, at what depths, in what quantities, how that has changed over time and what debris is present it which site. The second takes those patterns and tests whether environmental or human factors can help explain them. The project followed the timeline established in the original planning phase (Appendix A).

3.2 The MCP debris dataset

The primary dataset comes from MCP's predation belt transect surveys, covering fifteen reef sites across Zamboanguita, Siaton, and Santa Catalina, twelve of which met the survey-history requirements for inclusion in the statistical analyses (see Appendix B and Section 3.4). It runs from 30 March 2018 to the present and follows a standardised protocol across three depth zones: shallow (3-7 m), medium (9-13 m), and deep (15-19 m). Table 1 shows what the dataset looks like.

Table 1. Example records from the MCP debris dataset illustrating column structure.

Date	*Site*	*Depth*	*Current*	*Group*	*Size (cm)*	*Total*
2018-03-30	Basak Can-Unsang MPA	Shallow	1	Trash - Fishing Line	10-20	10
2019-06-14	Guinsuan MPA	Deep	3	Trash - Soft Plastic Wrapper	5-10	4
2023-11-02	Kookoos	Medium	0	Trash - Plastic Bag	20-30	7

The predation belt survey records more than just trash. Surveyors also record biological predation activity, such as the presence of organisms like ‘Drupella ssp’. snails that feed on coral polyps. Rather than only working with the trash records, the full dataset including those biological observations was used as the starting point. This matters because a survey where divers found ‘Drupella ssp’, but no trash is still useful information: it tells you that the site was checked and nothing was there. An R script was written to identify those surveys and give them a 'No Trash Found' entry with a count of zero, so they are included in the density calculations rather than simply missing from the data.

A few additional data cleaning steps were applied (the complete cleaning log is provided in Appendix C). Records from six older sites that are no longer part of the active monitoring network were removed, along with entries as 'Fish Cage - In Use', which were treated differently depending on whether the site is an MPA or not. For MPA sites (where all fishing activities are illegal), these entries were renamed, whereas for non-MPA sites (where these entries may reflect active, legal fishing), they were excluded altogether. This distinction is explained further in Section 5.4. Other categories were also combined where appropriate; for example, 'Fishing Net' and 'Ghost Net' were combined into one category.

To make site- and depth-level comparisons possible, a unique survey ID was created for each individual survey. The ID uses the first three letters of the site name, followed by S, M, or D for the depth zone. For the three Lutoban sites, which would otherwise share the same first three letters, distinct abbreviations were used instead: LUN (Lutoban North), LUS (Lutoban

South), and LUP (Lutoban Pier). A sequential number is added at the end; ANDS151, for example, refers to the 151st Shallow survey at Andulay MPA. These IDs are used to calculate debris density per survey, which is simply the number of items found per survey (150m2), and this becomes the main response variable used throughout the analysis.

3.3 Secondary data sources

To see if environmental factors like rain, wind, or tide had any influence on debris patterns, additional data was needed alongside the MCP records. After assessing several options, ERA5 was considered to be the most complete and reliable source for this region. It features continuous daily rainfall, wind speed, and wind direction data spanning from the year 1940 to the present day. This uninterrupted coverage makes it a more suitable choice than local PAGASA (Philippine Atmospheric, Geophysical and Astronomical Services Administration) station records, which contain significant data gaps over the study period (Zippenfenig, 2023). Tidal height could not be modelled directly, because the exact time of each survey was only recorded from 2024 onwards. This lack of complete historical time data prevented the precise inputs required by the FES2014 tidal model via the 'oceantide' package (Oceanum Ltd., 2024). Instead, tidal current strength was recorded by divers during each survey, on a scale from 0 (no current) to 4 (strong current), and used as the tidal variable throughout the analysis.

Seasonal classification was straightforward to describe. The wet season (Habagat) runs from June to October and the dry season (Amihan) from November to May, so it was derived directly from the date column using the ‘lubridate’ package in R, following the standard Philippine monsoon classification (Licuanan et al., 2019).

The Coastal Infrastructure Score and Fishing Pressure Index used during this study were originally developed as a single combined "Human Activity Index," scored by the research supervisor and MCP staff across three sub-metrics (commercial/infrastructure activity, legal fishing pressure, and illegal/destructive fishing), before being split into the two separate indices used in the analyses below.

3.4 Data analysis

Statistical analyses were carried out using R version 4.4.2 (R Core Team, 2024), using the 'tidyverse' package for data handling and visualisation, 'rstatix' for non-parametric testing, and 'rcompanion' for the Scheirer-Ray-Hare test.

Three sites (Mojon MPA, Santa Catalina Cawitan MPA, and Santa Catalina Manalongon MPA) were excluded from the statistical analyses. These sites have only been monitored by MCP since 2024, giving them approximately two years of survey history compared to the rest of the network, which has been monitored since 2019 or earlier. This resulted in too few surveys per depth zone to support reliable statistical comparison.

Phase 1: Descriptive Analysis
Debris density per survey was calculated by dividing the total number of trash items by the total surveyed area (items / 150m2). Surveys where no debris was encountered were assigned a value of zero. Mean density (± standard error) was then calculated per site and depth zone (Figure 4.1).

For temporal trend, mean density was calculated per site per year. Data from the years 2020 and 2021 were excluded because survey effort dropped sharply during the COVID-19 pandemic. Consequently, these years are represented as a temporal gap in all time-series figures. Because some sites started monitoring later than others, the trend is split into two figures: sites monitored since 2018 (Figure 4.2) and sites monitored from 2019 or later (Figure 4.3).

To see the potential sources of the marine debris, items were classified into two primary categories. Fishing-related debris covers fishing line, rope, fishing net, and fish cages. Land-based covers all remaining items. The relative proportion of each category per survey is shown in Figure 4.4.

Phase 2: Statistical Analysis
To determine the appropriate statistical tests for the dataset, data normality was assessed using a Shapiro-Wilk test. The data were not normally distributed ($p = 0.007$); therefore, non-parametric tests were used throughout the study. A Levene's test confirmed that variance was homogeneous across sites and depth zones. Statistical tests were run on individual survey totals rather than site-and-depth mean values, since aggregating to means reduced the number of data points too far to detect reliable differences between sites and depths.

To test whether debris density differed between sites and depth zones, a Kruskal-Wallis test was run for each factor. Where results were significant, a Dunn's test with Bonferroni correction identified which pairwise comparisons were driving these significant differences. A Scheirer-Ray-Hare test was then run with both site and depth together, adding an interaction term that assesses whether the depth-density relationship is the same at every site, or varies between them. For debris composition, a Kruskal-Wallis test was performed on the per-survey fishing percentage, assessing variations in the balance of fishing-related and land-based debris across sites, while a second test examined seasonal shifts.

To test for site-specific seasonal effects, a Kruskal-Wallis test was run on total debris counts by season within each site, followed by Dunn's post-hoc comparisons with Benjamini-Hochberg correction.

To move beyond simple single-factor testing, a Generalized Linear Model (GLM) was deployed. This allowed for the simultaneous testing of multiple environmental (e.g., rainfall, current strength) and human drivers (e.g., local infrastructure scores) to see how they may collectively influence total trash density.

Additionally, the structure of the debris was evaluated using two ecological community tools. First, the Simpson’s Diversity Index was calculated for each site. Instead of just looking at the total amount of trash, this index quantifies the composition and diversity of the recorded debris. A low index score indicates that a site is heavily dominated by one specific type of waste, while a higher score points to a heterogeneous mix of multiple debris categories.

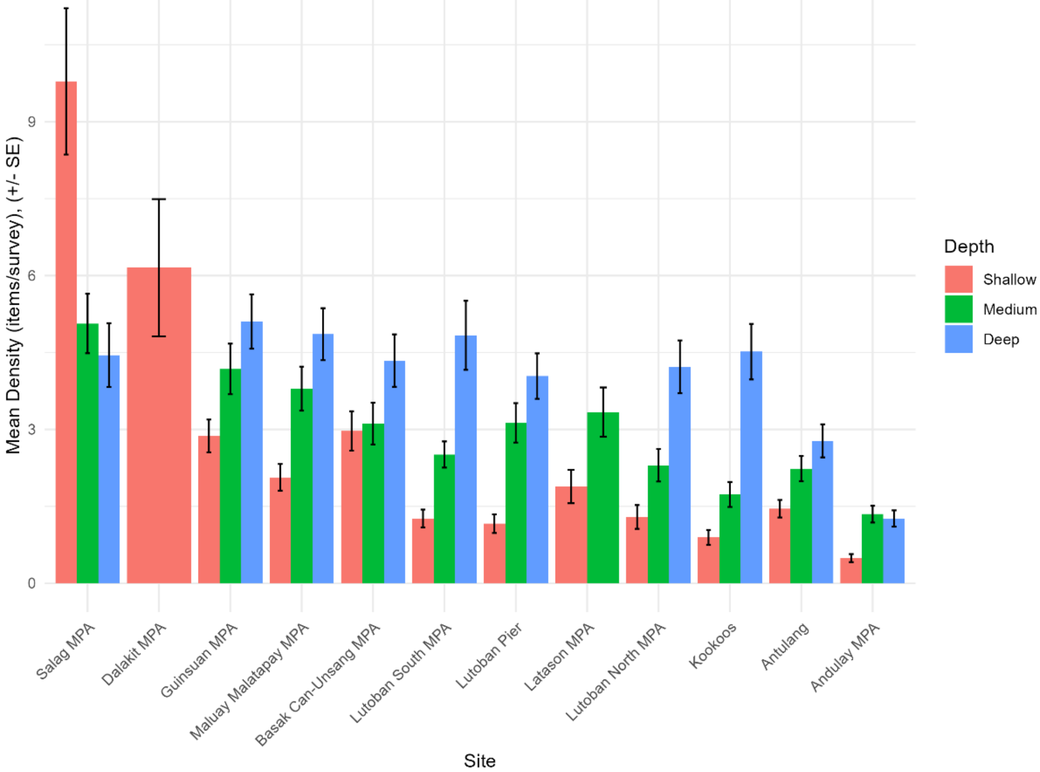
Second, a multivariate analysis using Non-Metric Multidimensional Scaling (NMDS) and Permutational Multivariate Analysis of Variance (PERMANOVA) was completed to visualise and test differences in overall debris profiles across sites. To determine exactly which trash items (e.g., fishing lines, plastic bags, or diapers) were driving the statistical differences between locations, a Similarity Percentages (SIMPER) analysis was conducted. This step translates the complex multivariate clusters into a clear list of specific target items for local management.

4. Results

4.1 Spatial and temporal debris patterns

To understand the distribution of marine pollution along the coastline, baseline debris density was evaluated across all survey zones and depths. Distinct spatial variations in mean debris density were observed across the study sites. A Kruskal-Wallis rank sum test shows that the differences in average debris density between the twelve monitored locations are highly significant ($\chi^2 = 273.43$, df = 11, $p < 0.001$). While most surveyed locations shared a comparable, lower baseline density, a small number of sites show higher accumulation. A post-hoc Dunn's test revealed that Salag MPA and Dalakit MPA exhibited significantly higher accumulation compared to the lowest-density site, Andulay MPA ($p < 0.001$; full pairwise results in Appendix E).

To determine whether these spatial patterns were consistent across depths, a Scheirer-Ray-Hare test was applied. The test revealed a highly significant interaction effect between site and Depth (H = 64.415, df = 19, $p < 0.001$), alongside significant main effects of both Site ($p < 0.001$) and Depth ($p < 0.001$). This interaction indicates that the relationship between depth and trash accumulation is not the same at every site: at some reefs, debris concentrates heavily in one depth zone, while at others, it is distributed more evenly from shallow to deep. Salag MPA illustrates the first pattern, with debris density concentrated almost entirely in the shallow zone (Figure 4.1). Latason MPA illustrates the opposite pattern: debris there is dominated by fishing gear, which increases significantly with depth (GLM estimates: Medium = 0.490, $p < 0.001$; Deep = 0.947, $p < 0.001$; Appendix F, Table F1).

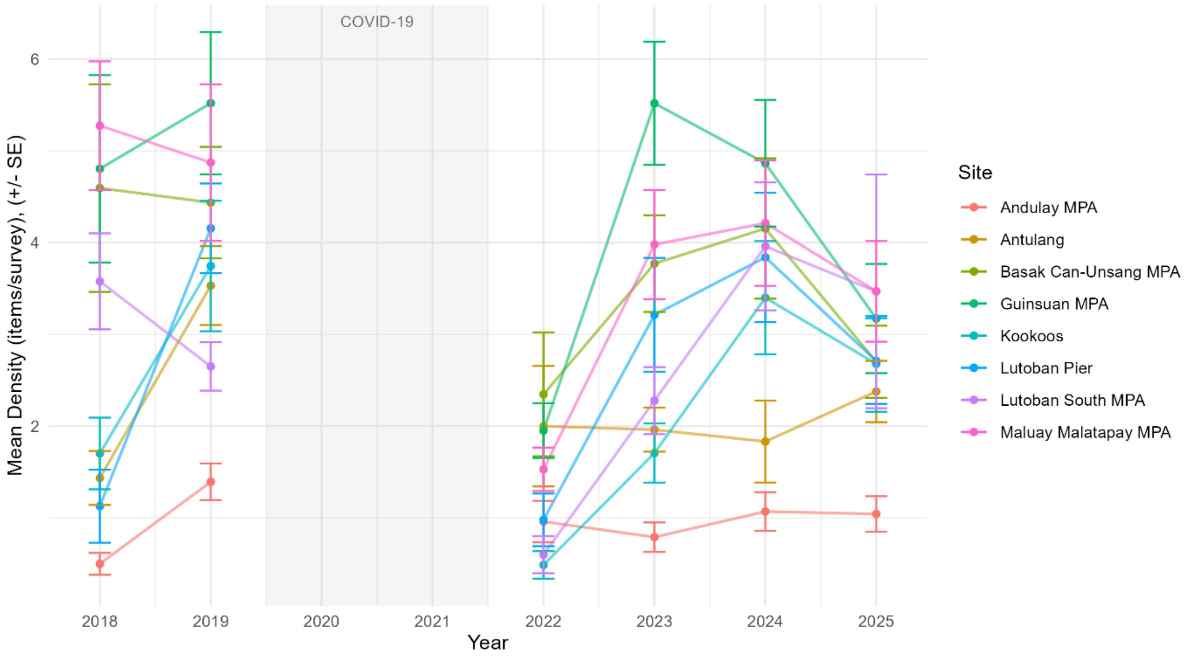


[Figure 4.1: Average marine debris density (items per survey, ± SE) across the twelve monitored reef sites, split by depth (Shallow, Medium, Deep). Bars represent the mean of all individual survey counts collected between 2018 and 2025 (n = 3,856 surveys), excluding Mojon MPA, Santa Catalina Cawitan, and Santa Catalina Manalongon. Debris density varies by up to a factor of ten between the highest sites (Salag MPA, Dalakit MPA) and the lowest (Andulay MPA), with the effect of depth differing by site.]

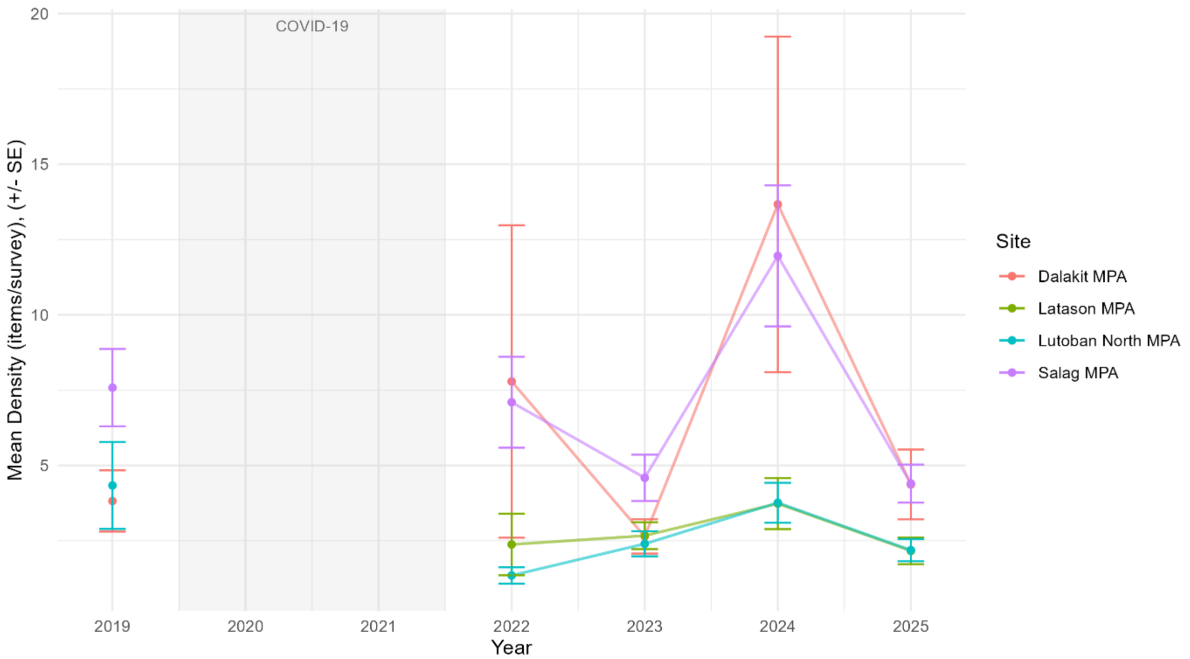
Note: The full pairwise significance matrix comparing all sites (Dunn's test) is in Appendix E.

4.2 Temporal trends (2018–Present)

Having identified key areas of debris accumulation, subsequent analyses examined temporal shifts in baseline debris density. Because monitoring began at different times depending on the site, locations are split into two groups: sites monitored since 2018, and sites monitored since 2019 or later.



[Figure 4.2: Yearly average debris density (items per survey, ± SE) for the eight reef sites monitored since 2018. The 2020–2021 gap reflects the suspension of MCP's monitoring programme during COVID-19. Debris density dropped to its lowest point in 2022, immediately after monitoring resumed, before rising through 2023–2024 and declining again in 2025.]



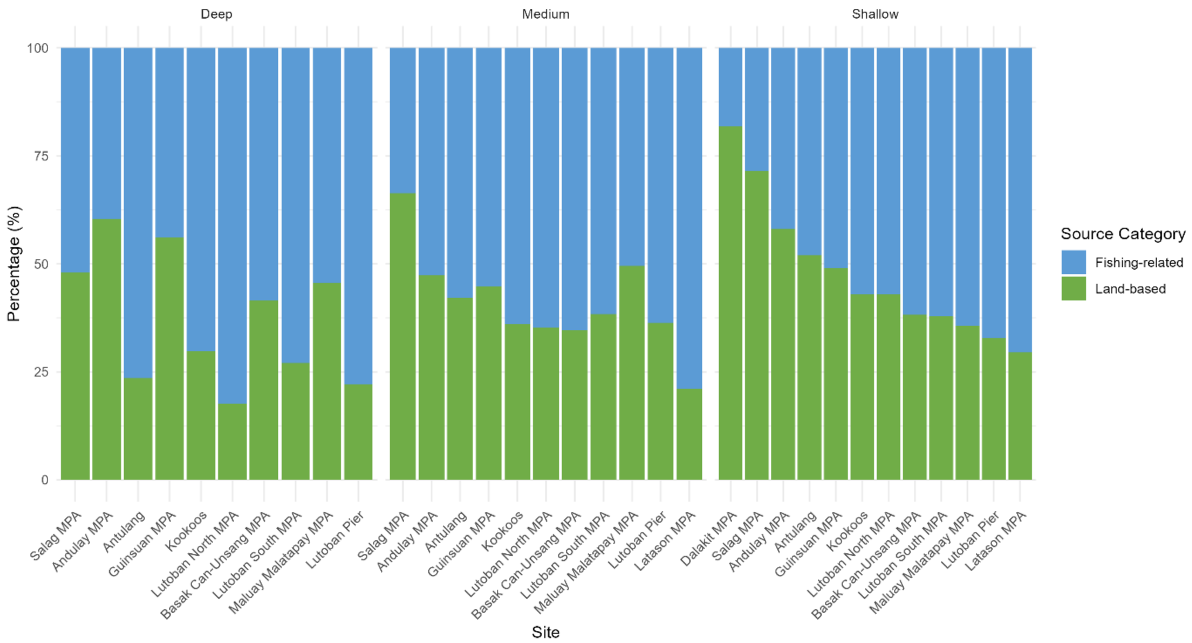
[Figure 4.3: Yearly average debris density (items per survey, ± SE) for the four reef sites monitored since 2019 or later (Dalakit MPA, Latason MPA, Lutoban North MPA, Salag MPA). These sites follow the same overall pattern as the longer-monitored network (Figure 4.2), with a low point in 2022 followed by a rise through 2023–2024.]

Across both groups, recorded debris density drops to its lowest point in 2022, immediately following the COVID-19 monitoring gap. From 2022 onward, most sites show an increase in debris density through 2023 and 2024, followed by a decline again in 2025 across nearly all tracked sites. A Kruskal-Wallis test confirmed that debris density differs significantly between years ($\chi^2 = 382.39$, df = 8, $p < 0.001$), supporting this temporal pattern.

A Dunn's post-hoc test confirmed that debris density in 2022 was significantly lower than in every subsequent year across the longer-monitored site group ($p < 0.01$ for all comparisons with 2023–2026), and that the decline recorded in 2025 was itself significant compared to 2024 ($p = 0.017$). A similar pattern held for sites monitored since 2019, where 2025 differed significantly from both the earliest recorded years (2019, 2020; $p < 0.05$) and from 2024 ($p = 0.002$), while differences between 2024 and the intermediate years (2022–2023) were not statistically significant.

4.3 Debris dispersion: Fishing vs. Land-based

To identify what is driving these temporal and spatial variations, recorded debris was categorised by origin: fishing-related waste (e.g. nets, lines, ropes, fish cages) and land-based consumer waste (e.g. everything else like, plastic bags, food wrappers, textiles, and diapers).

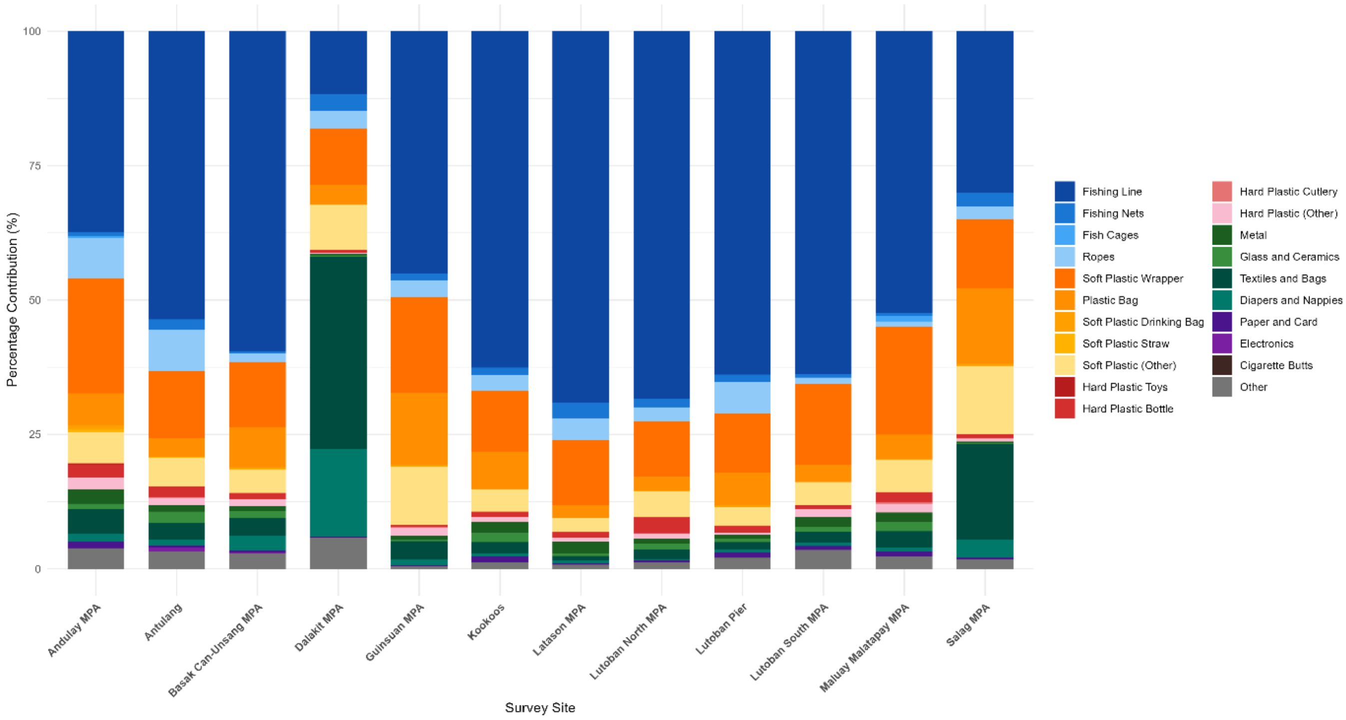


[Figure 4.4: Relative contribution of fishing-related versus land-based debris (%) per site, split by depth zone. The ratio between the two source categories varies substantially across the twelve sites: land-based debris makes up the largest share in shallow zones at most sites, while fishing-related debris becomes more dominant with increasing depth.]

A Wilcoxon signed-rank test comparing paired land-based and fishing-related item counts per survey confirmed a significant overall difference between the two categories ($V = 1{,}021{,}858$, $p < 0.001$). This difference is not consistent across sites, however: Dalakit MPA, for example, is dominated almost entirely by land-based waste, while Latason MPA shows the opposite pattern, with debris composition driven almost entirely by fishing gear. A detailed profile of the site-specific characteristics behind this variation is provided in Appendix D.

4.4 Detailed item breakdown and heterogeneity

Since broad source categories only show part of the profile, a further breakdown of individual debris items was conducted to identify the specific waste signature of each reef.



[Figure 4.5: Detailed breakdown (%) of individual debris categories (e.g. fishing line, plastic bags, soft plastic wrappers, textiles) recorded at each of the twelve sites. Latason MPA shows the most homogeneous composition (Simpson Diversity = 0.4478, dominated by fishing gear), while Andulay MPA shows the most heterogeneous mix (Simpson Diversity = 0.6643).]

To measure how mixed or concentrated debris types are at each location, the Simpson's Diversity Index was calculated for each site. A lower score indicates debris dominated by one or two specific items; a higher score indicates a more varied mixture of categories. The average Simpson's Diversity Index across all sites is (0.5472), indicating that most reefs are exposed to a mix of debris types rather than a single dominant source. Andulay MPA records the highest diversity score (0.6643), while Latason MPA records the lowest (0.4478), indicating that site is more dominated by a small number of specific items.

A PERMANOVA test (adonis2, Bray-Curtis dissimilarity, 199 permutations) found that overall debris composition differs significantly between the twelve sites when accounting for both Site and Depth ($F = 24.109$, $R^2 = 0.075$, $p = 0.005$). A separate PERMANOVA testing seasonal effects (Dry vs. Wet season) found no significant difference in debris composition ($F = 1.012$, $p = 0.345$). A test for homogeneity of multivariate dispersion (betadisper) found that dispersal also differs significantly between sites ($F = 24.463$, $p = 0.001$); this is explored further in the discussion, as it affects how the PERMANOVA result should be interpreted.

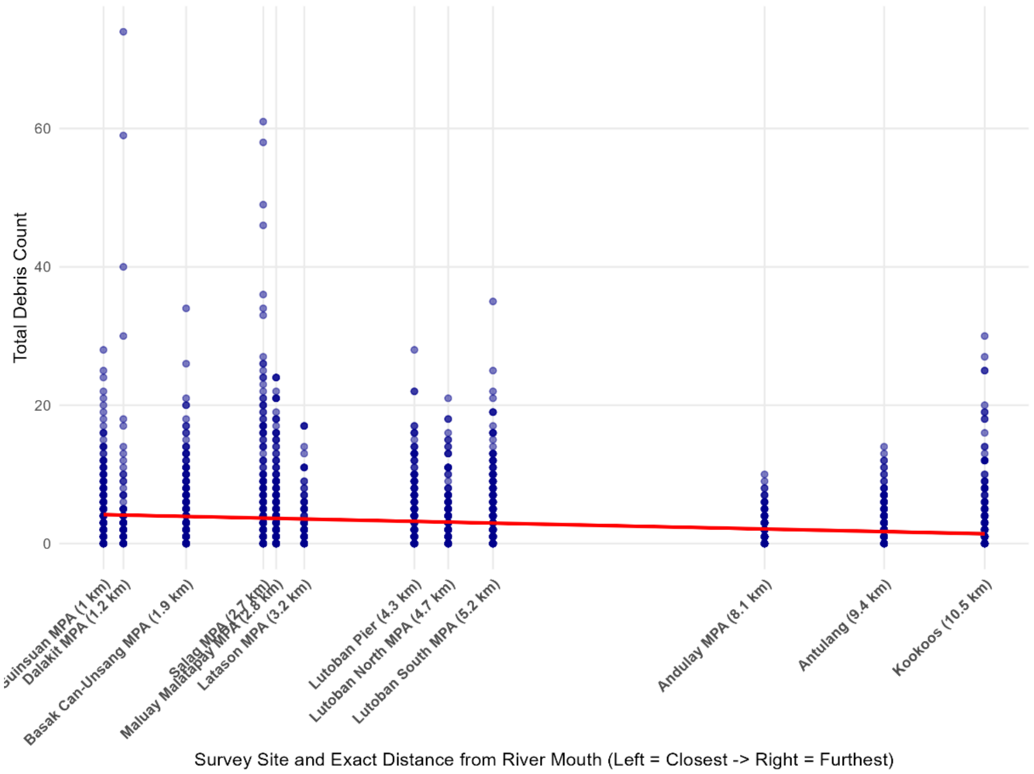
4.5 Environmental and human drivers (univariate factor assessment)

To identify which physical and human factors relate with debris levels, multiple factors were tested individually using Spearman's rank correlation, except for current strength, which was categorical and tested using a Kruskal-Wallis test.

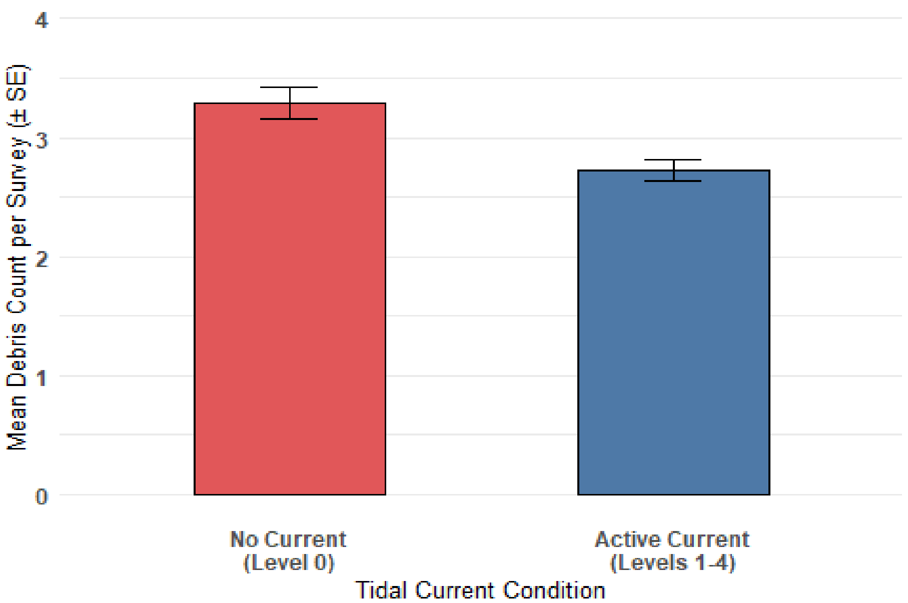
The correlation coefficient (ρ) shows the direction of the relationship: positive values indicate that debris increases as the factor increases, negative values indicate the opposite. The full overview is shown in Table 4.2.

Table 4.2: Statistical overview of individual spatial, human, and environmental drivers on total debris density

Category	***Tested Factor (Predictor)***	***Correlation Coefficient (ρ)***	***Statistical Significance (p-value)***	***Model Status / Outcome***
Human	Fishing Pressure Index	$\rho = 0.138$	$p < 0.001$	Highly Significant (Kept)
Human	Coastal Infrastructure Score	$\rho = 0.074$	$p < 0.001$	Highly Significant (Kept)
Geography	Distance to Nearest River Mouth	$\rho = -0.218$	$p < 0.001$	Highly Significant (Kept)
Human	Distance to Malatapay Market	$\rho = -0.098$	$p < 0.001$	Highly Significant (Kept)
Oceanographic	Combined Tidal Current (No Current vs. Active Current)	(categorical variable, tested with Kruskal-Wallis)	$\chi^2 = 15.593$, $p < 0.001$	Highly Significant (Kept)
Weather	Daily Rainfall (Precipitation)	$\rho = -0.002$	$p = 0.8775$	Not Significant (Excluded)
Weather	Maximum Wind Speed	$\rho = -0.007$	$p = 0.6520$	Not Significant (Excluded)
Temporal	Season (Dry vs. Wet)	Non-parametric	$p > 0.05$	Not Significant (Excluded)



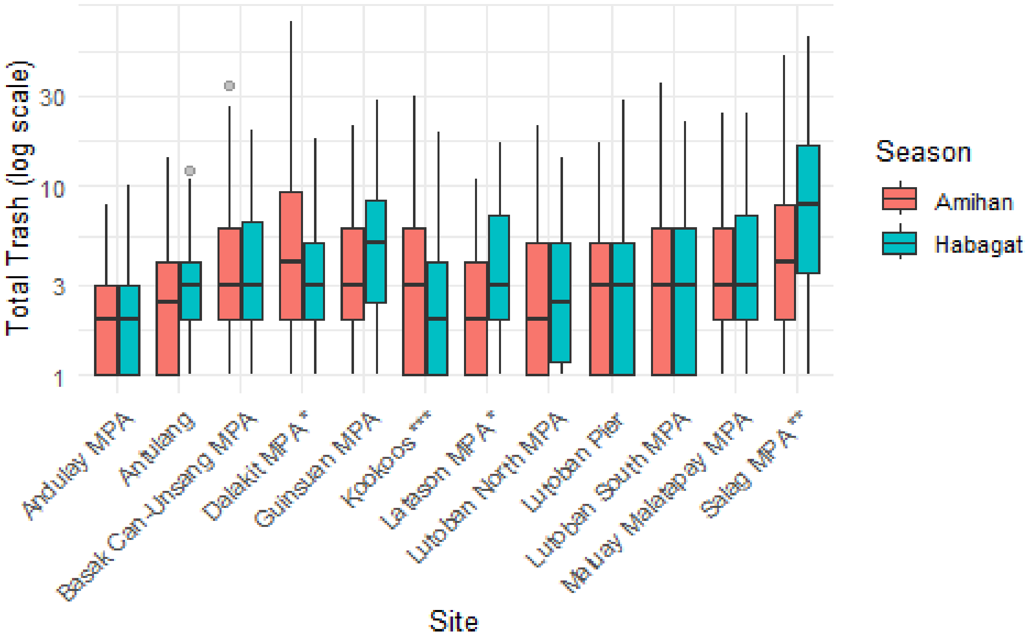
[Figure 4.6: Total debris count per survey plotted against distance to the nearest river mouth (km) for all twelve sites, with a linear trend line indicating the overall negative relationship (Spearman ρ = -0.218, $p < 0.001$). Each point represents one individual survey; sites are ordered from closest (left) to furthest (right) from the river mouth.]



[Figure 4.7: Mean debris count (± SE) compared between surveys with no tidal current (Level 0) and surveys with active tidal current (Levels 1-4). Debris counts are significantly higher during periods of no current than during active current (Kruskal-Wallis, χ^2 = 15.593, df = 1, $p < 0.001$).]

Short-term weather variables (daily rainfall, maximum wind speed) and season showed no statistically significant relationship with total debris counts ($p > 0.05$), indicating that conditions on the day of the survey do not measurably change the trash levels on the seafloor. These variables were excluded from further modelling.

While season alone showed no significant relationship with total debris counts, a Kruskal-Wallis test followed by Dunn's post-hoc comparisons with Benjamini-Hochberg adjustment revealed a significant site-specific interaction between season and debris accumulation ($p < 0.001$). Dalakit MPA and Kookoos recorded significantly higher trash loads during the Amihan (northeast monsoon) season, whereas Salag MPA and Latason MPA recorded significantly higher accumulation during the Habagat (southwest monsoon) season ($p.adj < 0.05$ for all four). Other sites, including Andulay MPA and Antulang, showed no significant seasonal difference, maintaining a stable baseline year-round (Figure 4.9, Table 4.3).



[Figure 4.9: Total trash count per survey (log scale) by site, split by season (Amihan = northeast monsoon; Habagat = southwest monsoon). Boxes show the interquartile range with the median; whiskers show the full range excluding outliers. Salag MPA and Latason MPA show higher accumulation during Habagat, while Dalakit MPA and Kookoos peaked during Amihan. Asterisks indicate statistical significance of the seasonal difference (Dunn's post-hoc, Benjamini-Hochberg adjusted): *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.]

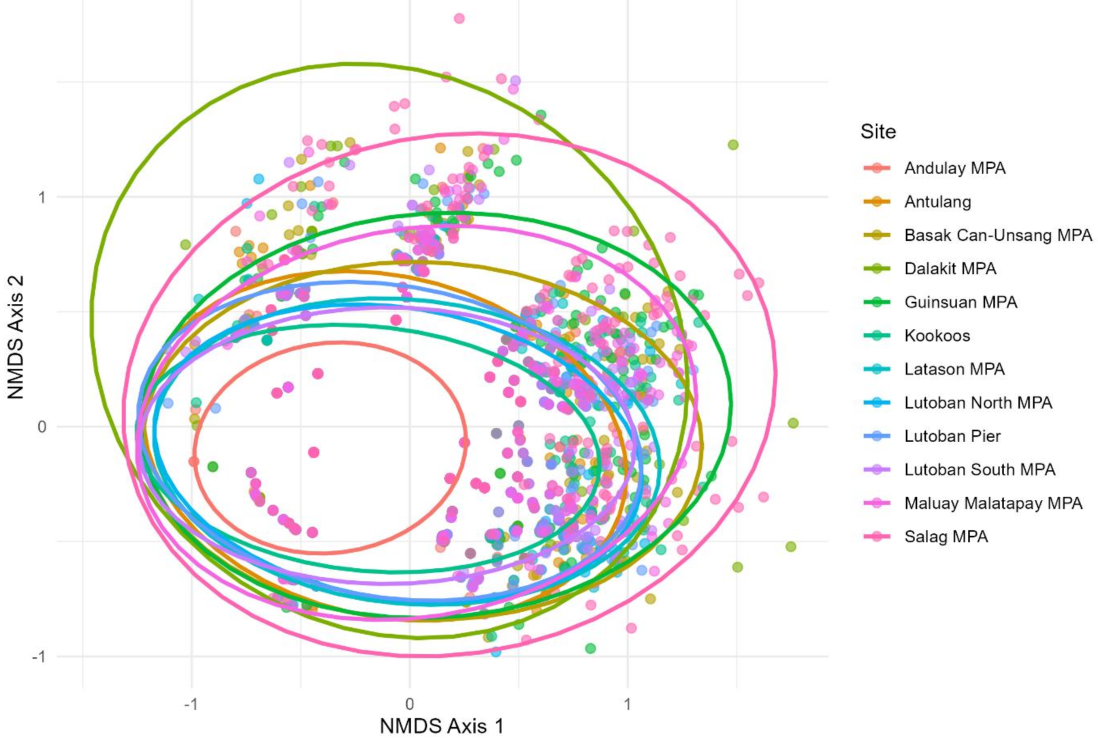
Table 4.3: Site-specific seasonal patterns in total debris accumulation (Amihan vs. Habagat).

Site / Category	***Seasonal Pattern***	***Statistical Significance***	***Key Observation***
Salag MPA	Habagat > Amihan	High	Highest overall trash burden
Latason MPA	Habagat > Amihan	Moderate	Clear increase during Habagat
Dalakit MPA, Kookoos	Amihan > Habagat	High	Higher trash load during Northeast Monsoon
Andulay MPA, Antulang, Lutoban South MPA	Amihan ≈ Habagat	Not Significant	Stable baseline year-round
Basak Can-Unsang MPA, Guinsuan MPA, Lutoban North MPA, Lutoban Pier, Maluay Malatapay MPA	Amihan ≈ Habagat	Not Significant	No meaningful seasonal difference detected

In contrast, spatial and human factors showed stronger relationships. Distance to the nearest river mouth was negatively correlated with debris density ($\rho = -0.218$, $p < 0.001$), indicating that reefs closer to river mouths accumulate more debris. Distance to Malatapay Market showed the same pattern ($\rho = -0.098$, $p < 0.001$). Both the Fishing Pressure Index ($\rho = 0.138$, $p < 0.001$) and Coastal Infrastructure Score ($\rho = 0.074$, $p < 0.001$) were positively correlated with debris density, indicating that sites with higher fishing activity or heavier coastal development accumulate more debris. Tidal current strength also showed a significant effect ($\chi^2 = 15.593$, df = 1, $p < 0.001$): sites surveyed during periods of no current recorded higher debris counts than those surveyed during active current. The complete Generalized Linear Model outputs combining these factors are in Appendix F.

4.6 SIMPER analysis and NMDS ordination

To identify the specific debris items driving structural differences between sites, a Similarity Percentages (SIMPER) analysis was conducted. To visualise how site-level debris profiles relate to one another, a Non-Metric Multidimensional Scaling (NMDS) ordination was produced (stress = 0.173).



[Figure 4.8: Non-metric multidimensional scaling (NMDS) ordination of debris composition across all twelve sites, based on Bray-Curtis dissimilarity with a dummy variable added to accommodate zero-count surveys (stress = 0.173). Each point represents one survey, and ellipses indicate the spread of survey profiles per site. Sites with overlapping ellipses share a broadly similar debris composition, while more distinctly separated ellipses (e.g. Andulay MPA) indicate a more unique profile.]

On an NMDS plot, distance between points reflects structural dissimilarity: sites with similar debris profiles are positioned close together, while sites with dissimilar profiles are positioned further apart. With a stress value of 0.173, the ordination provides a fair and acceptable two-dimensional representation of the data, falling below the standard 0.20 threshold.

5. Discussion

5.1 Interpretation of spatial and temporal patterns

The spatial differences between sites are the largest source of variation found in this study (Figure 5.1). Debris density did not vary randomly across the twelve reefs; it varied substantially, with sites such as Salag MPA and Dalakit MPA recording densities several times greater than low-accumulation sites like Andulay MPA. This fits the idea that marine debris does not spread out evenly, but accumulates in response to local, site-specific factors (Lebreton et al., 2017). This also apparent in the pairwise comparisons (Appendix E): Andulay MPA differs significantly from nearly every other site, while several mid-range sites show no significant difference from each other. This points to a small number of specific local pressures driving the pattern, rather than one set of big regional influences.

[Figure 5.1: Location of the four highest debris-density sites (Salag MPA, Dalakit MPA, Guinsuan MPA, and Maluay Malatapay MPA) along the Zamboanguita–Siaton coastline. Base map adapted from Marine Conservation Philippines' (MCP's) online database (Appendix B).]

The significant Site × Depth interaction adds critical context to this dynamic. If depth affected every site similarly, this would imply a shared regional mechanism, such as gravity pulling debris down evenly everywhere. Instead, the interaction shows that the relationship between depth and debris is site specific. This aligns with the site-level profiles in Appendix D: at sites characterised by strong currents and rocky, canyoning terrain (such as Salag MPA), debris seems to get trapped mostly in the shallows. On the contrary at sites dominated by fishing-related trash, debris density tends to increase with depth. This fits the pattern that heavier fishing gear, like hooks and lines, sinking and settling in deeper, calmer zones as opposed to staying near the surface. The GLM output supports this trend (Appendix F, Table F1): both Medium (Estimate = 0.490, $p < 0.001$) and Deep zones (Estimate = 0.947, $p < 0.001$) showed significantly higher fishing gear counts than Shallow zones. A lack of clear boundary demarcation in deeper water at sites such as Basak Can-Unsang MPA and Guinsuan MPA may also contribute to elevated fishing debris in the Deep zone, since poorly marked boundaries make illegal fishing in deeper water harder to detect and enforce (Appendix D).

The temporal pattern (Figures 4.2 and 4.3) is likely closely tied to MCP's operational history. MCP's monitoring programme was paused for approximately two years due to COVID-19, and survey activity remained low immediately after reopening in 2022, while operations gradually returned to full capacity. This lower survey effort in 2022 likely explains the low debris values recorded that year: with fewer dives and less consistent coverage, less debris was documented overall, as opposed to less debris being physically present. As survey frequency and coverage returned to normal through 2023 and 2024, the recorded debris density rose accordingly, giving a more accurate picture of what had actually built up on the reefs during and after the closure. The drop recorded in 2025 might then represent a genuine reduction, as accumulated debris was gradually removed through resumed cleanup activities. Since February 2023, MCP has partnered with ProOcean, which collects an estimated 400–600 kg of coastal debris daily, and may have contributed to the increased detection and removal of debris from 2023 onward. This partnership has not specifically targeted Dalakit MPA or Salag MPA, both of which were only added to broader cleanup efforts more recently.

5.2 Environmental and human drivers: What the data suggests

Of all the factors tested, distance to land-based sources had the greatest effect on debris levels. Distance to the nearest river mouth was the strongest driver of any factor tested ($\rho = -0.218$, $p < 0.001$), and distance to Malatapay Market showed a similar trend ($\rho = -0.098$, $p < 0.001$). Both results align with what the literature says: rivers are a well-known route for land-based plastic reaching coastal waters (Lebreton et al., 2017; Jambeck et al., 2015), and markets bring a lot of human activity and packaging waste together in one place. Given the information from Section 2.3 (an estimated 163 million sachets used every day in the Philippines, driven by income limits rather than personal choice (World Bank Group, 2021)), is logical that proximity to these land-based sources matters more than short-term weather conditions.

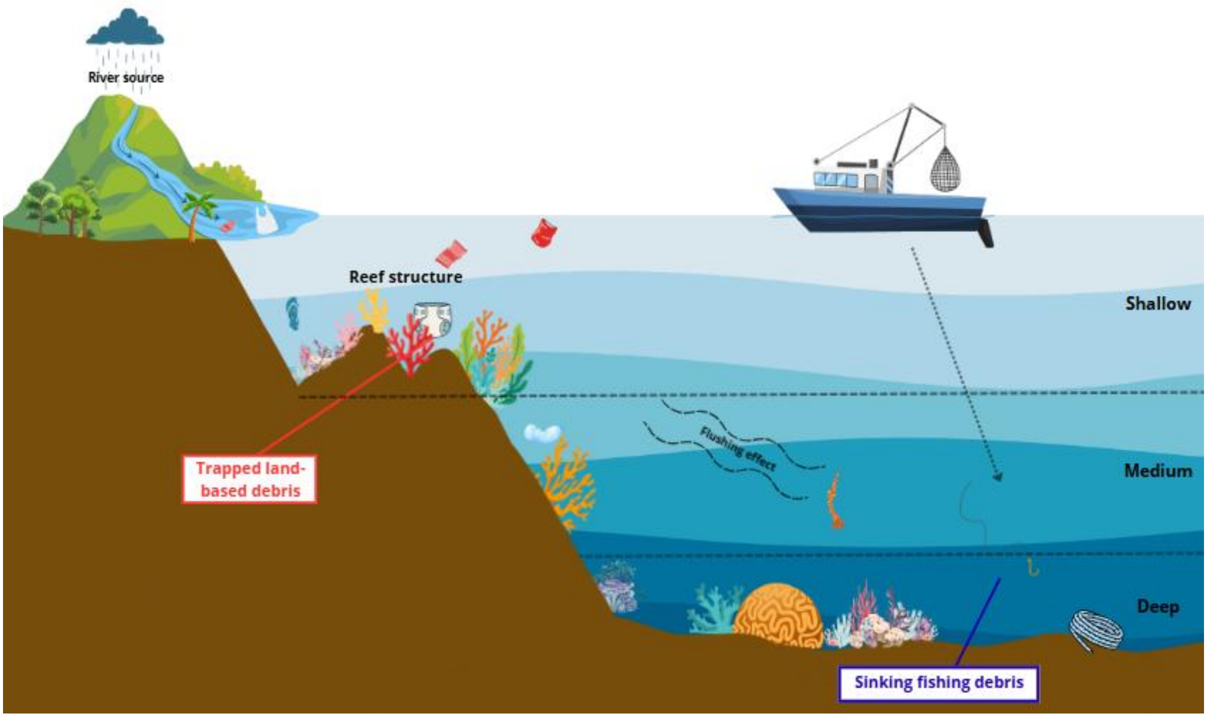
This same pattern explains why GLM Model 1 (land-based/consumer plastics) did not produce usable results (Appendix F). This is not really a mistake in the model, because land-based debris does not spread out evenly across the area; it shows up in sudden, concentrated bursts near specific sources, with minimal presence elsewhere. A standard regression model expects a smoother, more gradual relationship between a factor and the outcome, and this clustered pattern does not fit that. This matches what the Spearman's correlations showed: land-based debris in this dataset behaves like it comes from specific points, not from a spread across the region.

Fishing-related debris follows a different pattern. In GLM Model 2, distance to the nearest river mouth was still a significant negative predictor of fishing gear counts ($p < 0.001$). This is likely because river mouths also work as harbours and launch points for fishing boats, which brings gear loss close to the same spots as land-based waste, not because the two travel through the water in the same way. Depth was the strongest driver of fishing gear buildup: both Medium and Deep zones had significantly more gear than Shallow zones ($p < 0.001$ for both). This makes sense, given with what we discussed in the previous section about the debris density tending to increase with depth. Current strength also made a difference: sites and surveys recorded during periods without current had higher debris counts than those recorded during active current ($p = 0.0146$ in the GLM; $p < 0.001$ in the separate Kruskal-Wallis test). This points towards a "flushing effect", where moving water clears loose debris off the reef, while calm water allows it to settle and accumulate (Ríos-Bonilla, n.d.). The Integrated Fishing Pressure Index itself was not a significant predictor in the GLM ($p = 0.219$), despite showing a significant positive correlation on its own ($\rho = 0.138$, $p < 0.001$), suggesting that once depth and river distance are accounted for, the environmental characteristics that determine where the gear physically ends up matter more than the amount of fishing pressure a site experiences.

One surprising result is that short-term weather (daily rainfall, wind speed) showed no significant link with debris density, which goes against what the literature in Section 2.4 suggests, since rainfall and monsoon patterns are usually seen as a key way land-based debris gets transported (Licuanan et al., 2019; Lebreton et al., 2017). The most likely explanation is a mismatch in timing: this study only looked at weather on the exact day of each survey, while the debris found on a reef usually accumulates over weeks, months, or even years. A single dry survey day does not mean it hadn't rained or that debris hadn't already been transported at some point before the survey was carried out. This points to a limitation in the method rather than proof that rainfall has no effect at all.

Interestingly, while season showed no effect when tested across the whole dataset, it did have a significant effect at specific sites (Section 4.5). Dalakit MPA and Kookoos accumulated more debris during Amihan, while Salag MPA and Latason MPA accumulated more during Habagat. This site-specific pattern may reflect local differences in monsoon exposure, current direction, or seasonal fishing and tourism activity, though this study cannot confirm the exact mechanism. It suggests that season does matter, just not uniformly across the whole coastline showing the same pattern already seen for depth in Section 5.1, where one factor's effect depends entirely on the specific site.

Taken together, these drivers point to two separate debris pathways operating on these reefs, each shaped by a different combination of factors (figure 5.2). Land-based debris follows a source-to-sink pathway: it originates at fixed points on land (rivers, markets) and settles wherever it first reaches the reef, which is why proximity to these sources outweighs every other factor tested. Fishing gear follows a different, depth-driven pathway: it enters the water more broadly across a site rather than from one fixed point, and its final position is shaped mainly by physical settling and current strength rather than by how much fishing occurs locally. This distinction matters for management: interventions aimed at land-based debris (e.g. waste infrastructure, river-mouth cleanups) will not address fishing gear accumulation, and vice versa, since the two problems are driven by different mechanisms as opposed to a single shared cause.



[Figure 5.2: Diagram of the two debris draft pathways in this study. Land-based debris enters via rivers and settles in the shallower reef zone, while fishing-related debris enters more broadly from fishing activity and settles with depth, moderated by current strength (flushing effect).]

5.3 Methodological evaluation

Non-parametric tests used in this study (Kruskal-Wallis, Dunn's post-hoc, Scheirer-Ray-Hare, Spearman correlation) were needed because the debris count data was not normally distributed (Shapiro-Wilk, $p = 0.007$; Zar, 2010). This must be considered when comparing these results to studies that use standard parametric tests, since the numbers aren't directly comparable between the two approaches.

Two results need a careful interpretation before drawing strong conclusions from them. The PERMANOVA test found that debris composition differs significantly between sites (F = 24.109, p = 0.005), but a separate test (betadisper) showed that sites also differ in how consistent their debris composition is from survey to survey (F = 24.463, p = 0.001). This means part of the significant PERMANOVA result likely reflects some sites simply being less predictable, rather than every site having a fully distinct debris signature. The NMDS ordination (Figure 4.8, stress = 0.173; Bakker, 2026) points to a something similar: the broad pattern it shows can be trusted, but small differences in how close specific points sit to each other shouldn't be over-interpreted, given the moderate stress value.

The GLM results show a similar boundary for what this analysis could capture. Model 1 (land-based debris) failed to produce usable coefficients, because most surveys recorded zero debris so “No Trash Found”, with only a small number of very high counts near hotspots. A standard regression model isn't built to handle data with highly curved, zero-inflated distributions. A model designed specifically for data with lots of zeros would likely handle this pattern better, and is recommended for anyone continuing this analysis in the future.

Fishing gear at non-MPA sites could only be classified as debris when clearly abandoned, since active legal fishing at these sites made it impossible to distinguish lost gear from gear currently in use. This means fishing gear counts at non-MPA sites should be read as a conservative estimate rather than the full picture. Tidal height also couldn't be modelled directly, since survey timestamps were only logged consistently from 2024 onward, so current strength was used as the tidal variable instead. It captured a similar effect, but a future version of this dataset with complete timestamps would allow tidal height to be tested directly, alongside the zero-inflated modelling approach mentioned above.

6. Conclusion and Recommendations

6.1 Conclusion per sub question

This study set out to answer one central question: *What patterns of in-water debris accumulation occur on coral reefs in Southern Negros, and what factors help explain these patterns?*

Spatial and temporal patterns:
Debris accumulation is not evenly spread across the monitoring network. Density differs strongly between sites, by as much as a factor of ten between the highest and lowest sites, and these differences are statistically significant. Andulay MPA illustrates this well: it recorded consistently low debris density across every depth zone, which directly matches its distance from both the nearest river mouth and Malatapay Market, and makes these the two strongest factors identified in this study. Depth also plays a role, but not in the same way at every site. At Latason MPA, for example, debris accumulation clearly increases with depth and is dominated almost entirely by fishing gear, aligning with the expectation that heavier gear sinks and settles into deeper, calmer zones over time. At Salag MPA, on the other hand, debris concentrates in the Shallow zone rather than the deep zone, which fits given its position directly next to a river mouth combined with a shallow, canyoning and rocky terrain that appears to trap debris coming from the river close to shore.

Environmental factors:
Distance to river mouths was the strongest single factor of debris density, and Salag MPA (the site closest to an active river mouth in the dataset) Also recorded the highest overall trash density of any site, directly reflecting this relationship. Tidal current strength followed the same logic: sites and surveys recorded during calm, low-current conditions showed higher debris counts, supporting a ‘flushing effect’ where active water movement clears loose debris. Short-term weather conditions on the day of a survey, such as rainfall and wind speed, showed no link to debris levels in this analysis.

Human factors:
Coastal infrastructure and market proximity did show a clear link to debris levels, illustrated well by Dalakit MPA, which sits along a busy resort strip with dense coastal housing. Despite strong marine enforcement, Dalakit's debris profile is dominated by land-based items such as textiles, bags, and diapers rather than fishing gear, pointing to a source that marine patrols cannot address: waste seeping in from the shore itself rather than from the water. This land-based pattern was consistent across the dataset: land-based debris tends to concentrate in a small number of hotspots close to rivers and markets, as opposed to spreading evenly, while fishing gear debris is more closely linked to depth and river proximity than to fishing activity itself, as also seen at Latason MPA.

Taken together, these findings answer the central research question: clear, measurable patterns of debris accumulation exist across the reefs of Southern Negros, and a large part of the variation between sites can be explained by a specific set of environmental and human factors, rather than by chance or an even regional spread.

6.2 Recommendations for MCP and Local Government Units (LGUs)

1. **Prioritise cleanup and monitoring resources near river mouths and coastal markets (e.g., Malatapay Market).** These were the strongest predictors of debris density found in this study, so concentrating effort here is likely to have a greater impact than distributing resources evenly across all sites.

2. **Target fishing gear removal efforts in Medium and Deep zones** rather than Shallow zones, since fishing gear consistently accumulates more with depth. Dive cleanups should prioritise these zones, particularly at sites already identified as fishing-gear hotspots in Appendix D (such as Latason MPA).

3. **Time cleanup and monitoring efforts at seasonally-driven hotspots to match their peak season.** This means prioritising cleanups at Dalakit MPA and Kookoos during Amihan, and at Salag MPA and Latason MPA during Habagat.

4. **Increasing survey frequency at Mojon MPA, Santa Catalina Cawitan MPA, and Santa Catalina Manalongon MPA**, rather than simply waiting for more time to pass. Since these three sites were excluded from the statistical analysis due to having too few surveys per depth zone (not too few survey years), running more surveys per year at these specific sites would build up a comparable sample size faster, allowing them to be included in future analyses sooner.

5. **Future statistical work on this dataset should consider a model designed for data with many zero counts**, since a standard model struggled to handle the large number of surveys with no land-based debris combined with a small number of very high counts near hotspots.

6. **Address land-based waste management specifically at Dalakit MPA, where debris is dominated almost entirely by land-based items (e.g. textiles, diapers)** despite strong marine enforcement. Since this pattern likely originates from coastal resorts and settlements rather than fishing activity, effective intervention here depends on LGU-level waste management and drainage infrastructure rather than additional MPA patrol effort.

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Appendices

Appendix A: Project planning (Gantt Chart)

This appendix contains the original project timeline and operational Gantt chart covering the full 20-week research internship period at Marine Conservation Philippines (MCP), running from 2 March 2026 to 20 July 2026.

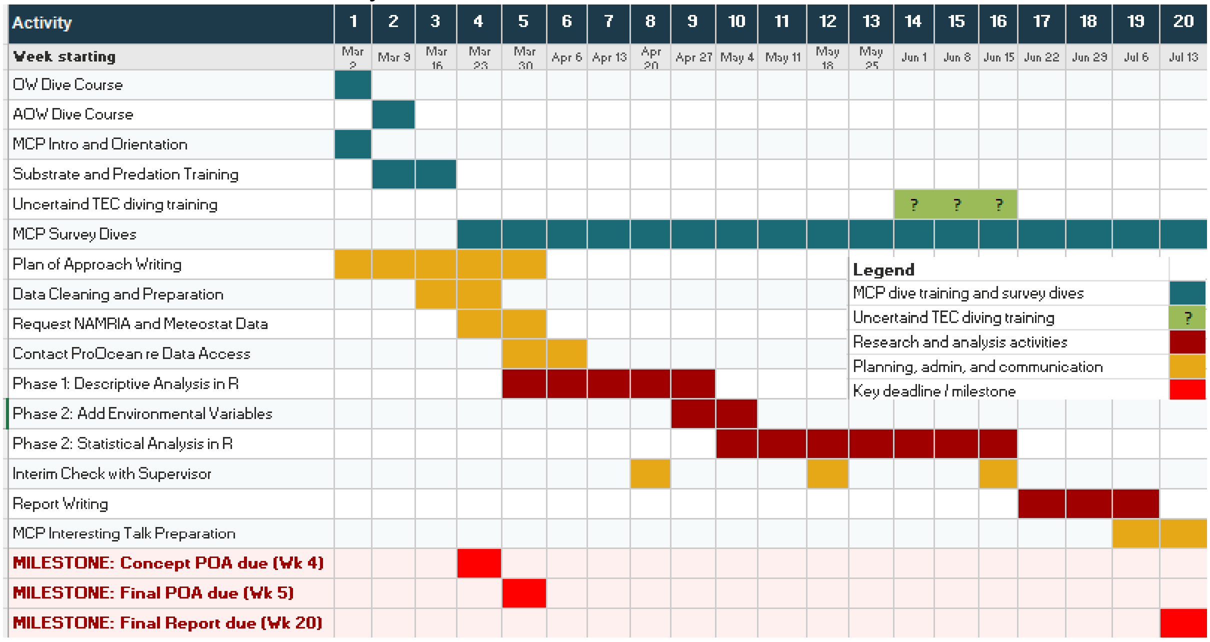

Figure A1: 20-week operational research planning and milestone tracking.

Appendix B: Map of MCP survey sites

The map below illustrates the spatial distribution of the twelve monitored coral reef stations across Zamboanguita, Siaton, and in Southern Negros Oriental, Philippines.

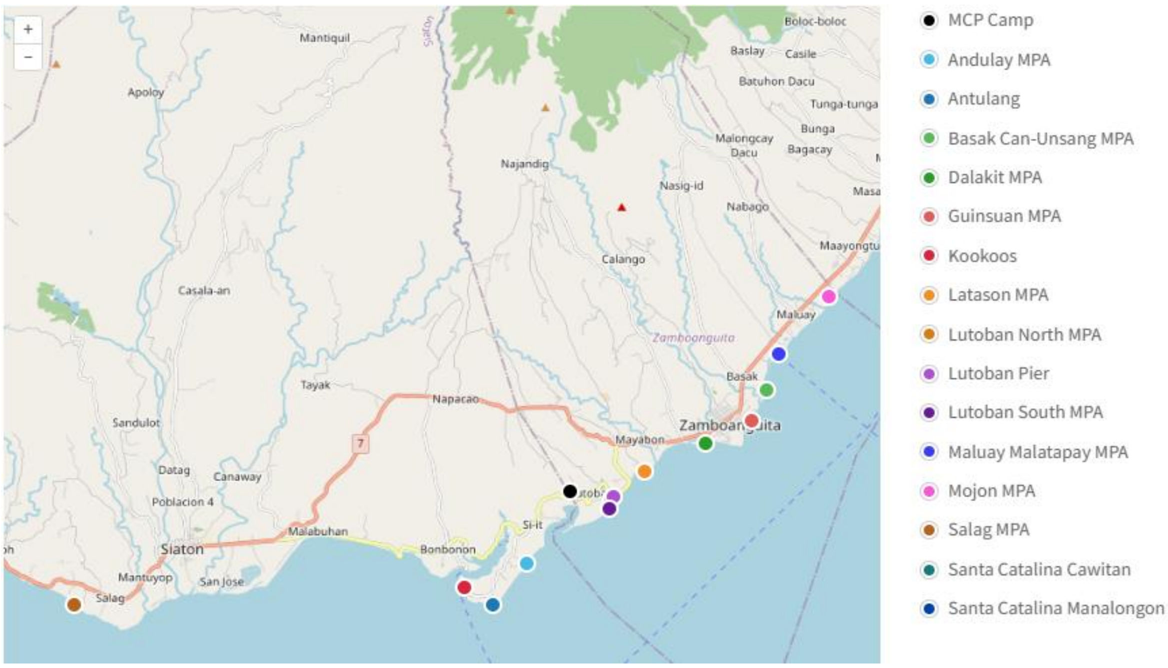

Figure B1: Map of the fifteen MCP reef monitoring sites in Southern Negros Oriental, plus the location of MCP. Due to limited data, Mojon MPA and the two sites in Santa Catalina (Cawitan, and Manalongon; location not included) were excluded from this study.

Appendix C: Data cleaning and dataset preparation log

To ensure statistical validity, data integrity, and reproducibility, the raw MCP historical dataset was processed using R. A total of 13,376 raw records across 15 initial sites from March 2018 to the present were screened and cleaned before executing the statistical framework.

Table C1: Chronological Data Cleaning and Filtering Steps

Step	*Process / Operation*	*Action Taken & Justification*	*Remaining Rows*
1	Raw Database Import	Consolidated all historical monitoring logs from March 2018 to present.	13,376
2	Regional Site Filtering	Excluded Mojon MPA, Santa Catalina Cawitan, and Santa Catalina Manalongon due to insufficient survey history (monitored only since 2024, compared to 2019 or earlier for the rest of the sites)	11,420
3	Pre-Standardization Cleanup	Removed unique, historical debris categories recorded before the monitoring protocol was fully standardized across the organization.	*10,355*
4	'Trash Only' Transformation	Isolated surveys containing marine debris. Surveys that originally logged only biological data (with zero initial debris records) were systematically converted to 'No Trash Found' baselines to prevent data skewing.	5,264
5	Multivariate Matrix Adjustment	Removed incomplete survey headers and restricted the final dataset specifically to the twelve core stations required for deep multivariate and pairwise testing.	3,856

Appendix D: Site profiles

Table D1: Simpson's Diversity Index per Monitored Site

Site Name	*Simpson's Diversity Index*
Andulay MPA	0.6643
Kookoos	0.5858
Lutoban South MPA	0.5648
Salag MPA	0.5481
Antulang	0.5354
Maluay Malatapay MPA	0.5336
Dalakit MPA	0.5183
Lutoban Pier	0.5145
Guinsuan MPA	0.5124
Lutoban North MPA	0.5068
Basak Can-Unsang MPA	0.5042
Latason MPA	0.4478

Note: Simpson's Diversity values closer to 1 indicate a highly mixed, heterogeneous debris composition, while values closer to 0 indicate a uniform profile dominated by a specific item type.

Detailed Site Profiles

1. Andulay MPA

Andulay is located far from active river mouths, limiting land-based plastic runoff, and has low to medium infrastructure development. The local community enforces strict boundary demarcation, and illegal poaching within the MPA is well managed, while regular legal artisanal fishing continues just outside the boundary. This context matches the statistical profile: exceptionally low baseline trash density combined with the highest Simpson Diversity Index in the dataset (0.6643). Rather than pointing to one dominant pollution source, this suggests Andulay receives a low, unpredictable mix of drifting regional debris rather than being targeted by a specific local input. The active guardhouse and clear boundaries appear effective at preventing both dumping and heavy localised poaching.

2. Antulang (Non-MPA Site)

Antulang is remote and cliff-bound, difficult to access by land, and has no MPA status, guardhouse, or physical demarcation. Fishing pressure is weather-dependent but boat traffic increases sharply during tourist and fishing peak seasons. Despite its geographic isolation, the SIMPER analysis shows a marked surge in fishing line debris compared to Andulay. This indicates that the absence of any formal protection or monitoring allows Antulang to become an unmonitored hotspot for seasonal maritime activity, showing that open access can outweigh the protective effect of remoteness.

3. Basak Can-Unsang MPA

This site experiences very high water movement and wave action, borders an active local community and public beach with seasonal dive tourism, and has legal fish traps operating daily just outside. A guardhouse is present but inconsistently staffed, and physical demarcation buoys are regularly destroyed by strong currents. The result is a high and highly variable trash density (confirmed by the dispersion test), with recurring spikes in both fishing line and domestic waste such as diapers. The likely mechanism is that the loss of visible boundaries during high-current periods facilitates illegal night fishing (including the destructive "Latak" stone method), while the same currents trap a mixed signature of both maritime and beach-sourced debris.

4. Dalakit MPA

Dalakit is a shallow, seagrass-dominated reef flat that physically restricts larger vessel access, located along a busy resort strip with dense coastal housing. Enforcement is strong, with a guardhouse close to the local police station and clear demarcation and signage; illegal fishing is rare since the shallow, visible terrain makes poachers easy to spot. Despite this strong marine enforcement, the SIMPER analysis shows a major, distinct surge in textiles, bags, and diapers. This points to land-based seepage from the adjacent resort strip and housing bypassing marine patrols entirely, with the dense seagrass beds acting as a physical trap that captures and retains terrestrial waste washed in from shore.

5. Guinsuan MPA

Guinsuan has a dense coastal village and high water movement, and its beach is associated with parties and drinking (local authorities have installed a physical barrier to reduce this). There is no guardhouse, no boundary demarcation (due to strong currents), and signage has reportedly been deliberately removed. Legal fish traps operate outside the boundary, alongside frequent sightings of illegal netting in the shallows. The debris profile is dominated by single-use plastic bags and wrappers combined with illegal netting signatures, consistent with a site where unmonitored recreational beach activity and the complete absence of physical boundary markers combine to allow both land-based littering and unhindered shallow-water net fishing.

6. Kookoos (Non-MPA Site)
Kookoos has one resort, a coastal community set back from the shore, and is a popular sunset viewing and fish-cooking spot with paid public beach access. It has no guardhouse or demarcation and lies close to Tambobo Port, which routes heavy large-vessel traffic through the area. The site shows a high Simpson Diversity Index (0.5858) alongside very high dissimilarity in the SIMPER analysis, driven by large volumes of fishing line and heavily weathered, mechanically broken macro-plastics. This composition is consistent with debris introduced by passing commercial and transit vessels, supplemented by recreational litter from tourists.

7. Latason MPA
Latason is bordered by a dense coastal community and an active, unregulated beachfront boat repair site. There is no official guardhouse, only residential huts, and no signage; the only demarcation is a cleared boat channel cutting through the reef. Enforcement is weak, and recent illegal fish cages have been recorded inside the MPA. This site records the lowest Simpson Diversity Index in the dataset (0.4478), and the SIMPER profile is dominated almost entirely by discarded fishing net fragments and cages. This points to a single, specific pollution source rather than a mixed input: the adjacent boat maintenance yard likely acts as a direct pipeline for gear and ghost nets that overwhelm the site's limited protective infrastructure.

8. Lutoban North MPA
Lutoban North is bordered by a dense coastal village with no resort or commercial tourism infrastructure. Human activity is dominated by heavy, widespread gleaning at low tide, and fishing pressure is regular but seasonal, with illegal poaching being low and largely accidental. There is no guardhouse, but a resident "Bantay Dagat" officer lives on the beach, and boundary demarcation is present but inconsistent. The site shows a moderate trash density, dominated by consumer packaging mixed with subsistence fishing items, reflecting a direct domestic footprint from local low-tide gleaning activity rather than commercial or tourism pressure. The continuous presence of the resident officer appears effective at limiting major intentional poaching.

9. Lutoban South MPA
Compared to Lutoban North, Lutoban South is more remote and has a smaller resident population, but receives high tourism impact from beachgoers visiting nearby Turtle Island. Legal gleaning, net use, and hook-and-line fishing are high-volume, and the site suffers frequent intentional illegal poaching inside the MPA. A guardhouse is located further south near Turtle Island, and boundary demarcation is present and strongest at the southern end. Despite lower housing density than Lutoban North, this site shows significantly higher counts of illegal fishing gear and targeted plastics. This spatial mismatch suggests that enforcement, concentrated near the southern guardhouse for tourism monitoring, leaves the northern boundary of the MPA relatively unmonitored and vulnerable to poaching.

10. Lutoban Pier (Non-MPA Site)
Lutoban Pier has no permanent residential community but functions as a hub for recreational beachgoers, group gatherings, and drinking. It has non-MPA open access, with intense legal fishing throughout the day and night and heavy daily low-tide gleaning, and no guardhouse or demarcation. Trash density here is very high, driven by heavy consumer packaging, recreational litter, and gleaning debris. This demonstrates that permanent housing is not required for a site to accumulate severe debris levels: the combination of round-the-clock open-access fishing and heavy recreational use is sufficient on its own.

11. Maluay Malatapay MPA
Malatapay is the highest-intensity impact zone in the dataset: it hosts an active marketplace, a dense residential village, a high-traffic tourist boat launch, and an active fish landing port, and is exposed to drifting waste from nearby Apo Island. Fishing pressure is high-intensity and year-round, with legal seine nets and cages operating just outside the boundary and occasional illegal poaching inside. Enforcement is strong, with a 24/7 Coast Guard station and well-maintained demarcation. Despite this, trash density is exceptionally high across all metrics, correlating strongly with the site's maximum coastal infrastructure score. The data suggests that even the highest level of official protection in the network is overwhelmed by the sheer scale of surrounding commercial, market, and transit activity.

12. Salag MPA
Salag sits directly adjacent to an active river mouth, and although the residential village is built back on a hill, the beachfront is popular with recreational visitors. The underwater topography features sharp rocky ridges and high-relief coral structures in the shallow zone. A "Bantay Dagat" guardhouse is present but not staffed 24/7, and boundary demarcation is incomplete. This site records the highest localised trash density in the dataset, concentrated heavily in the shallow zone, with a composition surprisingly low in fishing debris and dominated instead by land-based consumer plastics. The likely mechanism is that the high-relief shallow topography physically traps and anchors terrestrial debris carried in by river runoff, an effect made worse by the lack of continuous enforcement.

Appendix E: Spatial variation and Post-Hoc significance matrix

This appendix contains the detailed statistical outputs for the spatial analysis of debris density across the monitored sites and depth zones, supporting the findings in Section 4.1.

Table E1: Pairwise Comparisons of Debris Density Between Key Sites (Dunn's Post-Hoc Test)

Site Comparison	*Z-Value*	*Adjusted p-value*	*Statistical Significance*
Salag MPA vs. Andulay MPA	12.766	1.67e-35	Highly Significant (Outlier vs. Benchmark)
Guinsuan MPA vs. Andulay MPA	11.416	2.31e-28	Highly Significant (Outlier vs. Benchmark)
Malatapay MPA vs. Andulay MPA	9.631	3.92e-20	Highly Significant
Dalakit MPA vs. Andulay MPA	7.649	1.33e-12	Highly Significant
Latason MPA vs. Andulay MPA	5.509	2.39e-06	Significant
Other Baseline Site Contrasts	…	*variable*	*See full matrix, archived externally*

Note: This matrix displays the adjusted p-values (with Bonferroni correction) following the significant Kruskal-Wallis test ($p < 0.001$). Values of $p < 0.05$ indicate statistically significant differences in baseline trash levels between the two locations.

Table E2: Complete Pairwise Comparisons (Dunn's Post-Hoc Test, all 66 site contrasts)
Note: Adjusted p-values with Bonferroni correction, following the significant Kruskal-Wallis test (p < 0.001). NS = Not Significant.

Site Comparison	Z-Value	Adjusted p-value	Significance
Andulay MPA vs. Antulang	6.111	6.52e-08	p < 0.0001
Andulay MPA vs. Basak Can-Unsang MPA	9.489	1.55e-19	p < 0.0001
Andulay MPA vs. Dalakit MPA	7.649	1.33e-12	p < 0.0001
Andulay MPA vs. Guinsuan MPA	11.416	2.31e-28	p < 0.0001
Andulay MPA vs. Kookoos	4.275	0.00126	p < 0.01
Andulay MPA vs. Latason MPA	5.509	2.39e-06	p < 0.0001
Andulay MPA vs. Lutoban North MPA	5.974	1.53e-07	p < 0.0001
Andulay MPA vs. Lutoban Pier	6.655	1.87e-09	p < 0.0001
Andulay MPA vs. Lutoban South MPA	6.366	1.28e-08	p < 0.0001
Andulay MPA vs. Maluay Malatapay MPA	9.631	3.92e-20	p < 0.0001
Andulay MPA vs. Salag MPA	12.766	1.67e-35	p < 0.0001
Antulang vs. Basak Can-Unsang MPA	3.085	0.134	NS
Antulang vs. Dalakit MPA	3.833	0.00836	p < 0.01
Antulang vs. Guinsuan MPA	4.957	4.74e-05	p < 0.0001
Antulang vs. Kookoos	-2.101	1.000	NS
Antulang vs. Latason MPA	0.735	1.000	NS
Antulang vs. Lutoban North MPA	0.074	1.000	NS
Antulang vs. Lutoban Pier	0.196	1.000	NS
Antulang vs. Lutoban South MPA	-0.685	1.000	NS
Antulang vs. Maluay Malatapay MPA	2.924	0.228	NS
Antulang vs. Salag MPA	6.598	2.76e-09	p < 0.0001
Basak Can-Unsang MPA vs. Dalakit MPA	1.910	1.000	NS
Basak Can-Unsang MPA vs. Guinsuan MPA	1.922	1.000	NS
Basak Can-Unsang MPA vs. Kookoos	-5.404	4.30e-06	p < 0.0001
Basak Can-Unsang MPA vs. Latason MPA	-1.704	1.000	NS
Basak Can-Unsang MPA vs. Lutoban North MPA	-2.913	0.237	NS
Basak Can-Unsang MPA vs. Lutoban Pier	-3.037	0.158	NS
Basak Can-Unsang MPA vs. Lutoban South MPA	-4.225	0.00158	p < 0.01
Basak Can-Unsang MPA vs. Maluay Malatapay MPA	-0.293	1.000	NS
Basak Can-Unsang MPA vs. Salag MPA	3.736	0.0124	p < 0.05
Dalakit MPA vs. Guinsuan MPA	-0.702	1.000	NS
Dalakit MPA vs. Kookoos	-5.204	1.29e-05	p < 0.0001
Dalakit MPA vs. Latason MPA	-2.926	0.227	NS
Dalakit MPA vs. Lutoban North MPA	-3.736	0.0123	p < 0.05
Dalakit MPA vs. Lutoban Pier	-3.782	0.0103	p < 0.05
Dalakit MPA vs. Lutoban South MPA	-4.423	0.000644	p < 0.001
Dalakit MPA vs. Maluay Malatapay MPA	-2.118	1.000	NS
Dalakit MPA vs. Salag MPA	0.548	1.000	NS
Guinsuan MPA vs. Kookoos	-7.363	1.19e-11	p < 0.0001
Guinsuan MPA vs. Latason MPA	-3.204	0.0895	NS
Guinsuan MPA vs. Lutoban North MPA	-4.727	0.00015	p < 0.001
Guinsuan MPA vs. Lutoban Pier	-4.997	3.85e-05	p < 0.0001
Guinsuan MPA vs. Lutoban South MPA	-6.340	1.51e-08	p < 0.0001
Guinsuan MPA vs. Maluay Malatapay MPA	-2.292	1.000	NS
Guinsuan MPA vs. Salag MPA	1.898	1.000	NS
Kookoos vs. Latason MPA	2.396	1.000	NS
Kookoos vs. Lutoban North MPA	2.105	1.000	NS
Kookoos vs. Lutoban Pier	2.423	1.000	NS
Kookoos vs. Lutoban South MPA	1.699	1.000	NS
Kookoos vs. Maluay Malatapay MPA	5.350	5.80e-06	p < 0.0001
Kookoos vs. Salag MPA	8.940	2.56e-17	p < 0.0001
Latason MPA vs. Lutoban North MPA	-0.661	1.000	NS

Latason MPA vs. Lutoban Pier	-0.603	1.000	NS
Latason MPA vs. Lutoban South MPA	-1.313	1.000	NS
Latason MPA vs. Maluay Malatapay MPA	1.522	1.000	NS
Latason MPA vs. Salag MPA	4.631	0.00024	p < 0.001
Lutoban North MPA vs. Lutoban Pier	0.112	1.000	NS
Lutoban North MPA vs. Lutoban South MPA	-0.741	1.000	NS
Lutoban North MPA vs. Maluay Malatapay MPA	2.746	0.398	NS
Lutoban North MPA vs. Salag MPA	6.340	1.51e-08	p < 0.0001
Lutoban Pier vs. Lutoban South MPA	-0.955	1.000	NS
Lutoban Pier vs. Maluay Malatapay MPA	2.872	0.269	NS
Lutoban Pier vs. Salag MPA	6.694	1.44e-09	p < 0.0001
Lutoban South MPA vs. Maluay Malatapay MPA	4.123	0.00247	p < 0.01
Lutoban South MPA vs. Salag MPA	8.057	5.15e-14	p < 0.0001
Maluay Malatapay MPA vs. Salag MPA	4.148	0.00221	p < 0.01

Appendix F: Multivariate debris composition models

A GLM was first fitted for land-based consumer plastics (Consumer_Plastics ~ Infra_Score + Distance_To_River + Wind Speed + Current + Depth, quasipoisson family). This model failed to produce meaningful coefficients: all estimates converged to approximately zero (p = 1.000 for every predictor). This is not a data error but a reflection of the underlying distribution land-based plastics are concentrated in extreme bursts near specific river mouths and markets, with a large number of absolute zeros elsewhere in the dataset. This extreme variance causes a continuous regression model to collapse. For this reason, the Spearman rank correlations reported in Section 4.5 are used instead to characterise land-based debris drivers, and this model is reported here only to justify that methodological choice.

Table F1: Generalized Linear Model (GLM) coefficients , fishing Gear (Model 2)
Model Structure: glm(Fishing_Gear ~ Fishing_Pressure_Index + Distance_To_Nearest_River_km + MaxWindSpeed_kmh + Current_Combined + Depth, family = quasipoisson, data = MV2). NS = Not Significant.

Predictor Variable	***Estimate (Log-Count)***	***Standard Error***	***p-value***	***Significance Level***
(Intercept)	0.0118	0.2179	0.9570	NS
Fishing Pressure Index	0.0605	0.0493	0.2194	NS
Distance to Nearest River Mouth (km)	-0.0683	0.0121	1.87e-08	*** (Highly Significant)
Maximum Wind Speed (km/h)	-0.0007	0.0048	0.8835	NS
Current: No Current (vs. active)	0.1515	0.0620	0.0146	* (Significant)
Depth: Medium (vs. Shallow)	0.4901	0.0844	7.02e-09	*** (Highly Significant)
Depth: Deep (vs. Shallow)	0.9475	0.0795	< 2e-16	*** (Highly Significant)

Table F2: Non-Metric Multidimensional Scaling (NMDS) Model Diagnostics

Model Variable	***Estimate (Log-Count)***
Ordination Method	Non-Metric Multidimensional Scaling (NMDS)
Distance Metric Matrix	Bray-Curtis Dissimilarity
Dimensions (k)	2
Final Calculated Stress Value	0.1729
Multivariate PERMANOVA Significance	F = 24.109, p = 0.005 (Based on 199 permutations; see Supplementary File 3 for full R-code output).

Appendix G: Coastal infrastructure and fishing pressure scores by site

Table G1: Allocated Scores for Level of Coastal Infrastructure, Legal Fishing, and Illegal Fishing per Monitored Site.

Site	Coastal Infrastructure Score	Legal Fishing Score	Illegal Fishing Score	Fishing Pressure Index
Andulay MPA	3	4	1	2.5
Antulang	2	4	—	2
Basak Can-Unsang MPA	3	4	4	4
Dalakit MPA	4	2	2	2
Guinsuan MPA	4	4	4	4
Kookoos	4	5	—	2.5
Latason MPA	4	3	4	3.5
Lutoban North MPA	3	3	3	3
Lutoban Pier	3	4	—	2
Lutoban South MPA	2	3	4	3.5
Maluay Malatapay MPA	5	5	3	4
Mojon MPA	4	1	2	1.5
Salag MPA	3	4	3	3.5
Santa Catalina Cawitan	3	4	2	3
Santa Catalina Manalongon	4	4	2	3

Note: Scores range from 1 (lowest) to 5 (highest) and were assigned through an expert-knowledge session with the research supervisor and MCP staff (see Section 3.3). The Fishing Pressure Index is the average of the Legal and Illegal Fishing scores.

Appendix H: AI usage statement

AI tools (Claude and Gemini) were used during this report between 30 March 2026 and 15 June 2026 for the following purposes:

1. Debugging of R code (Gemini). AI assistance was used to help identify and resolve errors in R scripts used for data cleaning and analysis. This included resolving an issue where PERMANOVA and NMDS functions failed to run due to zero-sum rows in the community matrix, requiring the addition of a dummy variable, as well as smaller, simpler error messages during script development.

2. Verification of statistical output against source data (Claude). Draft tables in the Results and Appendix sections were cross-checked against the raw R output files (statistical_test_results.txt, phase3–6 output files) to identify errors. some mistakes were identified and corrected using the original R output as the source.

3. Restructuring of raw output into a table for the appendix (Claude). The complete pairwise Dunn's test matrix (Appendix E, Table E2) was reformatted from raw R console output into a structured table.