**Table S1.** Overview of the statistical analyses, the rationale for each choice, and the outcome each was designed to detect. Obj. = study objective as listed in the Introduction.

| Obj. | Analysis (§) | Rationale for the choice | Designed to detect / expected outcome under the hypothesis |
|---|---|---|---|
| i–iv | Descriptive statistics, CV | MP counts are strongly right-skewed, so the mean alone is uninformative; the CV places among-beach spread on the same scale as the designed contrast | Whether among-beach heterogeneity is comparable to, or larger than, the gulf–open-coast difference the design was built to test |
| i, ii | Negative binomial GLMM, log link, Beach random effect nested in Area | Response is an overdispersed count (variance ≫ mean) from a nested design; Poisson is inadmissible and OLS/ANOVA on raw or log counts would violate variance assumptions and ignore the replicate-within-beach structure | Primary confirmatory test of the retention hypothesis: a positive Area effect (gulf > open coast). A Zone effect would indicate systematic cross-shore sorting; an Area × Zone interaction would indicate that cross-shore sorting differs between the two hydrodynamic settings |
| i, ii | Poisson vs. NB comparison by AIC | Establishes that the extra dispersion parameter is warranted rather than assumed | Large AIC advantage for NB confirms overdispersion (obtained: 1,089.3 vs. 8,327.8) |
| ii | Random-slope refit, (1 + Zone \| Beach), selected by LRT | The intercept-only model assumes one common zone contrast; if the contrast varies among beaches, that assumption is wrong and the fixed-effect standard errors are anticonservative | Whether cross-shore zonation is a general property of the coastline or a beach-specific phenomenon; the BLUPs then identify which beaches depart from the average |
| i, ii | Type III Wald $\chi^2$ with sum-to-zero contrasts | With an interaction in the model, Type III tests of the main effects are only interpretable under sum-to-zero coding | Effect of each factor averaged over the levels of the other |
| i, ii | Estimated marginal means, Tukey-adjusted (emmeans) | The log link makes model coefficients non-intuitive; EMMs return interpretable predictions in items $m^{-2}$ and contrasts as incidence-rate ratios | The magnitude of any area or zone difference, and whether its confidence interval excludes 1 |
| — | DHARMa simulation-based residual diagnostics | Standard residual plots are uninformative for GLMMs; simulated quantile residuals allow formal tests of dispersion and zero inflation | Verification that the NB error structure is adequate and that no zero-inflated component is required (obtained: dispersion p = 0.09 and 0.27; zero-inflation p = 1) |
| i, ii | Mann–Whitney U (Area), paired Wilcoxon (Zone), Kruskal–Wallis (Beach), all on beach-level summaries | Distribution-free robustness check on n = 5 vs. 5 independent beaches; the pairing of zones within beach matches the design; tests whether the GLMM conclusions depend on the parametric specification | Agreement with the GLMM would indicate the conclusions are not model artefacts. Kruskal–Wallis specifically quantifies among-beach heterogeneity |
| iii | Bray–Curtis dissimilarity | Standard for compositional abundance data; ignores joint absences, which is appropriate given the many zero counts for rare morphotypes | Basis for all composition-level inference |
| iii | PERMANOVA, marginal terms, 9,999 permutations, permutations restricted | Zone is a within-beach factor and Area a between-beach factor; permuting at the matching level is what | Whether morphotype composition, independently of total abundance, differs between coastal settings or zones. |

| | | | |
|---|---|---|---|
| | within beach for Zone and Area × Zone; Area tested on beach-level centroids | makes each test valid and avoids pseudoreplication | Under the source hypothesis, an area difference driven by pellets was expected |
| iii | PERMDISP | PERMANOVA can return significance from unequal within-group dispersion rather than from a genuine centroid shift; PERMDISP separates the two | Non-significance validates a location-based interpretation of PERMANOVA (obtained: p = 0.939 and 0.586) |
| iii | nMDS (Bray–Curtis, k = 2) | Non-metric ordination preserves only the rank order of dissimilarities and makes no linearity assumption, unlike PCA on raw counts. Used for visualisation, not inference | Visual separation of samples along a pellet-associated axis; stress reported as an adequacy criterion |
| iii | SIMPER, 999 permutations | Converts a multivariate result into a morphotype-specific, source-diagnostic statement by attributing dissimilarity to individual categories | Which morphotypes drive any between-area difference. Under the industrial-input hypothesis, pellets were expected to be the dominant contributor |
| iii | Morphotype-specific GLMMs, tiered by occurrence (≥15 non-zero → NB GLMM; 5–14 → binomial presence/absence; <5 → descriptive) | Count models on near-empty categories are unstable and prone to separation; the tiered rule was applied uniformly and set before inspecting the results | Whether the aggregate pattern is driven by one morphotype. Pellets and fragments were expected to behave differently, reflecting primary vs. secondary origin |
| iii | Shannon diversity (H′), Gaussian LMM with Beach random intercept (Supplementary Results S2) | H′ is continuous and approximately symmetric, so a linear mixed model is appropriate; the random intercept mirrors the count models | Whether one morphotype dominates locally. Whether local dominance by one morphotype reduces morphotype diversity; a strong point-source input was expected to produce lower H′ in the affected zone. |
| iv | Spearman rank correlation with latitude, computed within area | Rank-based, so insensitive to the extreme values that characterise these data; computed within area because latitude is fully confounded with Area across the ten sites | Whether variation follows a broad-scale spatial gradient or is site-specific. Explicitly exploratory: n = 5 beaches per area gives very low power |
| iv | Graduated-symbol and composition-pie maps | Descriptive visualisation; no inference | Joint spatial display of magnitude and source signature |

**Table S2.** Descriptive statistics of total microplastic concentration (items $m^{-2}$) by Beach and Zone.

| Area | Beach | Zone | n | Mean | SD | Median | Min | Max |
|---|---|---|---|---|---|---|---|---|
| Pagasitikos Gulf (semi -enclosed) | Agria | Supralittoral | 5 | 87.8 | 60.98 | 91 | 26 | 158 |
| Pagasitikos Gulf (semi -enclosed) | Agria | Active Swash | 5 | 63.4 | 36.75 | 54 | 36 | 126 |
| Pagasitikos Gulf (semi -enclosed) | Alikes | Supralittoral | 5 | 122 | 71.29 | 117 | 31 | 230 |
| Pagasitikos Gulf (semi -enclosed) | Alikes | Active Swash | 5 | 192.8 | 268.25 | 99 | 10 | 666 |
| Pagasitikos Gulf (semi -enclosed) | Anavros | Supralittoral | 5 | 226.4 | 240.81 | 69 | 51 | 575 |
| Pagasitikos Gulf (semi -enclosed) | Anavros | Active Swash | 5 | 24.6 | 5.73 | 25 | 17 | 33 |
| Pagasitikos Gulf (semi -enclosed) | Kala Nera | Supralittoral | 5 | 90.4 | 49.49 | 115 | 26 | 135 |
| Pagasitikos Gulf (semi -enclosed) | Kala Nera | Active Swash | 5 | 592.8 | 406.73 | 455 | 245 | 1297 |
| Pagasitikos Gulf (semi -enclosed) | N. Anchialos | Supralittoral | 5 | 36.8 | 10.31 | 39 | 20 | 45 |
| Pagasitikos Gulf (semi -enclosed) | N. Anchialos | Active Swash | 5 | 39.4 | 3.78 | 40 | 33 | 43 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| NW Aegean (open) | Agiokampos | Supralittoral | 5 | 164 | 193.54 | 88 | 54 | 507 |
| NW Aegean (open) | Agiokampos | Active Swash | 5 | 118.4 | 43.12 | 106 | 70 | 183 |
| NW Aegean (open) | N. Mesagala | Supralittoral | 5 | 29.6 | 25 | 20 | 2 | 58 |
| NW Aegean (open) | N. Mesagala | Active Swash | 5 | 41.2 | 14.04 | 36 | 29 | 63 |
| NW Aegean (open) | Papakosta | Supralittoral | 5 | 95 | 16.14 | 92 | 73 | 117 |
| NW Aegean (open) | Papakosta | Active Swash | 5 | 43 | 20.29 | 41 | 19 | 64 |
| NW Aegean (open) | Platamonas | Supralittoral | 5 | 46.8 | 27.5 | 35 | 22 | 87 |
| NW Aegean (open) | Platamonas | Active Swash | 5 | 62 | 22.44 | 70 | 37 | 90 |
| NW Aegean (open) | Velika | Supralittoral | 5 | 14.8 | 8.87 | 10 | 8 | 29 |
| NW Aegean (open) | Velika | Active Swash | 5 | 10 | 8.63 | 8 | 1 | 20 |

Items $m^{-2}$: particles recovered from a standardized ~800 g composite of the upper 2–3 cm collected within a 1 $m^2$ quadrat (Section 2.2).

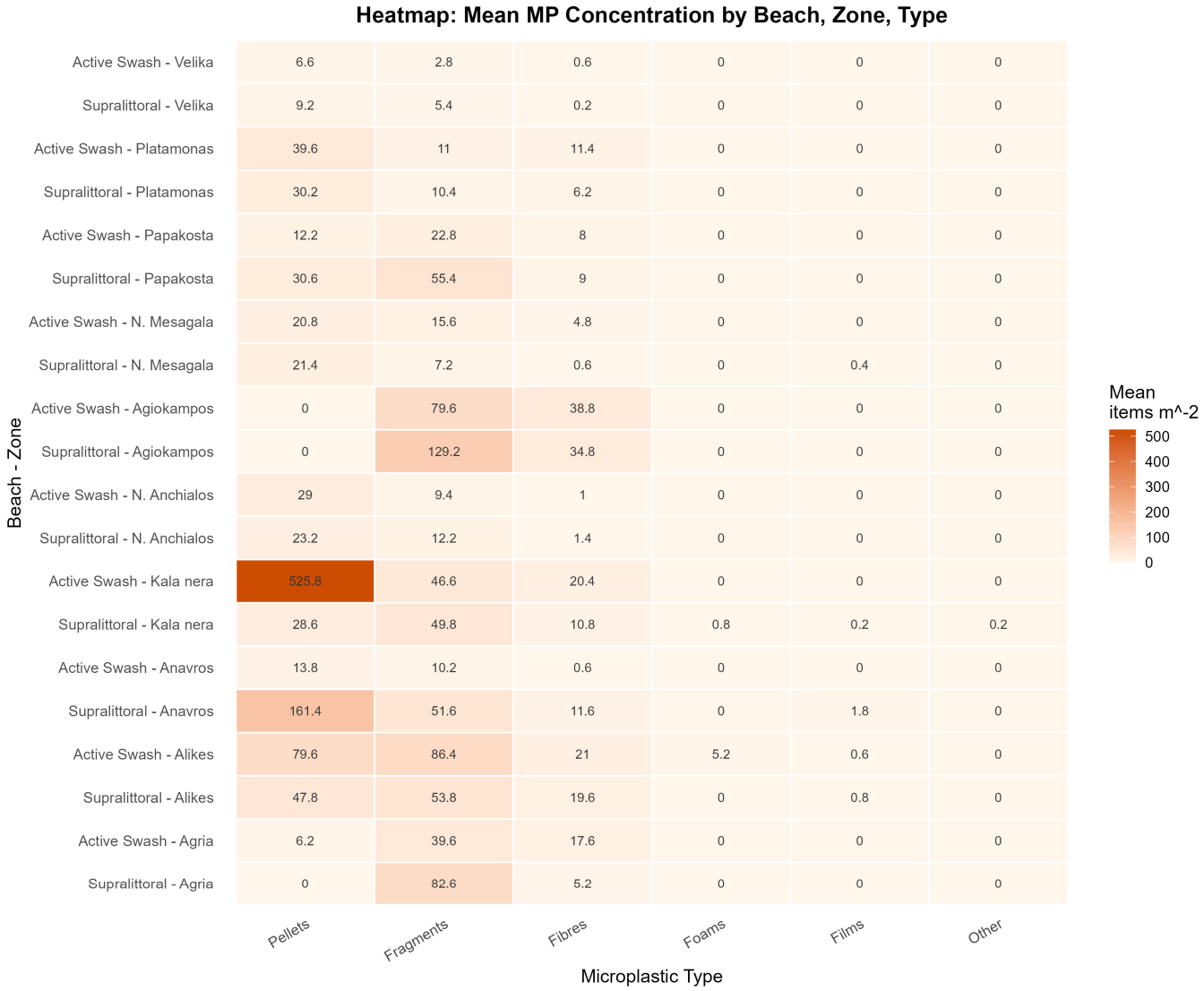



**Figure S1.** Heatmap of mean microplastic concentration (items $m^{-2}$) by morphotype, beach, and zone. Darker colors indicate higher concentrations. Values are printed within each cell.

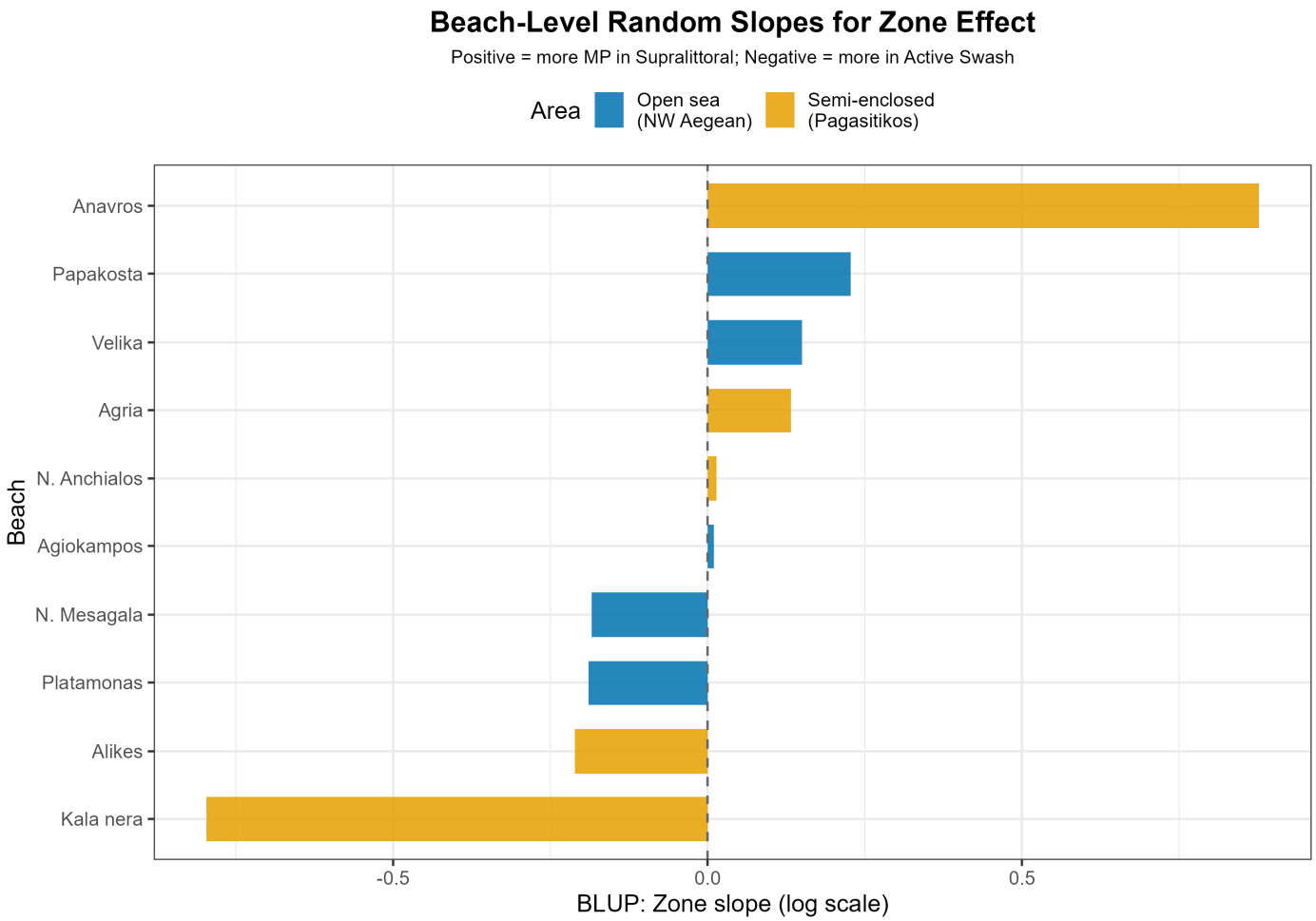



**Figure S2.** Beach-level random slopes (BLUPs) for the Zone effect from the negative binomial GLMM with random slopes. Positive values indicate higher microplastic concentration in the supralittoral zone; negative values indicate higher concentration in the active swash zone. Bars are colored by coastal area.

*Supplementary Results S1. Non-Parametric Comparisons*

These distribution-free tests were performed to verify that the mixed-model conclusions do not depend on the assumed negative binomial error structure. Beach-level non-parametric tests corroborated the GLMM findings. The Mann-Whitney U test on beach-level means (n = 5 per area) did not detect a significant difference between the Pagasitikos Gulf and the NW Aegean (W = 20, p = 0.151). The paired Wilcoxon signed-rank test for Zone (pairing supralittoral and swash means within each beach) was also non-significant (V = 29, p = 0.922). However, the Kruskal-Wallis test among beaches was highly significant ($\chi^2$ = 47.55, df = 9, p < 0.001), confirming that among-beach heterogeneity dominated the variance structure. Post-hoc pairwise comparisons (Holm-adjusted) identified Velika as significantly different from most other beaches, and Kala Nera and Agiokampos as borderline or significantly different from lower-concentration sites such as N. Mesagala and N. Anchialos.

*Supplementary Results S2. Morphotype Diversity*

Morphotype diversity was examined as a supplementary summary of heterogeneity in microplastic composition. Shannon diversity (H′) ranged from 0 to 1.50 across individual samples, with an overall mean of 0.695 ± 0.290. The linear mixed model detected a significant Area × Zone interaction (F = 4.20, df = 1/88, p = 0.043), whereas neither the Area (F ≈ 0, p = 0.999) nor Zone (F = 0.89, p = 0.349) main effects were significant. In the

Pagasitikos Gulf, H′ was higher in the supralittoral (EMM = 0.721) than in the active swash zone (EMM = 0.668), whereas the opposite pattern occurred on the NW Aegean coast (active swash: EMM = 0.766; supralittoral: EMM = 0.624). This cross-over pattern is consistent with spatial variation in morphotype dominance, particularly the strong pellet enrichment observed in the Pagasitikos active swash.

*Supplementary Discussion S1. Morphotype Diversity*

The significant Area × Zone interaction for Shannon diversity ($p = 0.043$) reveals an informative cross-over pattern. In the Pagasitikos Gulf, morphotype diversity was higher in the supralittoral ($H' = 0.721$) than the active swash zone ($H' = 0.668$), because the swash zone at sites like Kala Nera is dominated by pellets, reducing evenness. In the NW Aegean, the reverse pattern held: the active swash zone had higher diversity ($H' = 0.766$) than the supralittoral ($H' = 0.624$), likely because the supralittoral at some Aegean sites was fragment-dominated whereas the swash zone received a more balanced mix from wave sorting.

This cross-over interaction illustrates that zone-level processes differ qualitatively between the two coastal settings. In the semi-enclosed gulf, the swash zone acts as a selective trap for one dominant morphotype (pellets), depressing diversity, whereas in the open coast environment, stronger wave energy and longshore transport produce a more even redistribution of morphotypes across zones. Morphotype diversity has no ecological meaning comparable to biological diversity indices; it reflects pollution heterogeneity rather than ecosystem function. It nonetheless usefully summarizes the shift from a point-source-dominated (pellet-rich) to a diffuse (fragment-and-fiber) regime.