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Bridging the microplastic awareness gap: community awareness, risk perception, and policy support for mitigating plastic pollution in Eastern Black Sea catchments

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Effective mitigation of plastic pollution in catchment–coastal systems depends on community understanding of pollution pathways, risk perception, and policy support. This study assessed plastic-waste awareness, microplastic awareness, risk perception, policy support, and future engagement intention among school, university, and community-course centre respondents within an Eastern Black Sea source-to-sea project context linked to the Arılı and Çağlayan river catchments (n = 151). A venue-stratified questionnaire was analysed using ordinal-appropriate non-parametric and regression-based methods. The results showed a clear knowledge–concern asymmetry: plastic-waste awareness was moderate (mean = 3.25), whereas microplastic awareness was lower (mean = 2.52), despite high risk perception (mean = 4.38) and strong policy support (mean = 4.16). Microplastic awareness was the strongest cross-sectional correlate of higher plastic-waste awareness (odds ratio [OR] = 2.41), while plastic-waste awareness was positively associated with future engagement intention (OR = 2.29). A venue/life-stage-associated mismatch was also evident: school respondents reported higher microplastic awareness but lower risk perception and policy support than other respondent groups. Policy support was consistently high, particularly for regular river and coastal clean-ups, educational awareness initiatives, and deposit-refund systems, aligning with locally perceived pollution sources such as bottles, plastic bags, and household waste. Despite strong policy support, reported plastic-product use remained moderate, indicating an awareness–action gap. Overall, the findings identify favourable attitudinal conditions for intervention, but also limited microplastic awareness and incomplete behavioural translation. Because the study was cross-sectional, these patterns indicate associations rather than causal pathways. Strengthening microplastic-focused communication, aligning interventions with locally perceived sources, and

integrating education with participatory and infrastructure-based measures are therefore critical for catchment-based plastic-pollution management in the Eastern Black Sea region.

KEYWORDS

Black Sea, catchment-based management, deposit-refund systems, microplastic awareness, ordinal logistic regression, plastic-waste awareness

1 Introduction

Plastic pollution constitutes a persistent systemic pressure across terrestrial, freshwater, coastal, and marine ecosystems and remains a major environmental-governance challenge (UNEP, 2021; IUCN, 2024; GPAP, 2026). Global plastic production has reached approximately 460 million tonnes annually, while recycling remains near 9%, and plastics constitute an estimated 85% of marine litter (UNEP, 2021; IUCN, 2024; GPAP, 2026). Mismanaged plastic waste can leak into aquatic environments, fragment into smaller particles, and persist over long temporal scales. Current estimates indicate that 11–14 million tonnes of plastic enter the oceans annually, adding to 75–199 million tonnes already present in marine environments, with plastic waste projected to triple by 2060 (UNEP, 2021; IUCN, 2024; GPAP, 2026). These trends underscore the need for coordinated life-cycle governance, including source reduction, improved waste management, circular-economy transitions, and international instruments such as the emerging Global Plastics Treaty.

Plastic inputs to aquatic and marine systems are strongly linked to land-based activities and waste-governance failures (Jambeck et al., 2015; Terzi and Seyhan, 2017; Meijer et al., 2021). Inadequate waste management, stormwater runoff, littering, and riverine transport dominate many marine-litter pathways, although fishing, shipping, and aquaculture also contribute to plastic inputs (McIlgorm et al., 2011; UNEP, 2020; IUCN, 2024). Rivers connect inland consumption, household waste generation, stormwater drainage, disposal practices, and downstream coastal accumulation (Lebreton et al., 2017; McGlade et al., 2021). Plastic pollution in catchment-linked coastal regions should therefore be framed as a source-to-sea governance challenge requiring coordinated management across terrestrial, freshwater, coastal, and marine systems, rather than solely as shoreline contamination (Mathews and Stretz, 2019; UNEP, 2020; IUCN, 2024).

Microplastics intensify this source-to-sea challenge. These particles, commonly defined as plastics smaller than 5 mm, originate from primary sources or secondary fragmentation of larger debris (Pop et al., 2023; Akdemir et al., 2025; Khorsandi et al., 2025; Terzi et al., 2026). Compared with macroplastic litter, microplastics are less visible, more difficult to monitor and remove, and less readily understood by non-specialist audiences (Tekman et al., 2022; Aliani et al., 2026). Public-perception research consistently shows that general concern about plastic pollution is often high, whereas detailed understanding of microplastic sources, pathways, exposure routes, and mitigation options remains limited (Baechler et al., 2024; Caminiti et al., 2025; Tekin et al., 2026). This distinction matters because policy support and behavioural participation depend not only on broad environmental concern but also on whether communities understand how everyday plastic use, disposal practices, and waste leakage contribute to downstream contamination (Henderson and Green, 2020; Baechler et al., 2024; Caminiti et al., 2025).

Türkiye provides a relevant setting for examining plastic-waste awareness, microplastic awareness, risk perception, and policy support because of its substantial plastics sector, domestic value chain, and exposure across the Mediterranean, Aegean, Marmara, and Black Sea basins (Gündoğdu and Walker, 2021; Karasik, 2022; UNDP, 2023). The country has also faced persistent plastic-waste management challenges, including low recycling rates, landfill dependence, uncollected waste, open dumping, and pressures associated with the global plastic-waste trade after China's 2018 import restrictions (Katz, 2019; Gündoğdu and Walker, 2021; Karasik, 2022; UNDP, 2023). Within Türkiye, the Black Sea is particularly important for source-to-sea plastic-pollution research because northern catchments drain into a semi-enclosed basin where land-based inputs, riverine transport, coastal settlement, and hydrodynamic retention may intensify pollution pressures (Lazăr et al., 2021; Seyhan et al., 2025; Terzi et al., 2025). Previous studies along the southeastern Black Sea coast show that plastic and expanded polystyrene/Styrofoam dominate marine litter by both count and weight, highlighting regional vulnerability to persistent accumulation (Terzi and Seyhan, 2017; Karasik, 2022). Despite increasing environmental monitoring, community-level understanding of plastic-waste pathways, microplastic risks, policy support, and public engagement remains underexplored.

Türkiye has introduced several policy instruments to reduce plastic consumption and improve waste governance, including the Zero Waste Project, packaging-waste regulation, recycling contribution fees, plastic-bag charging, deposit-return planning, and emerging single-use-plastic measures under the Roadmap for Single-Use Plastics, Marine Litter and Microplastics (TRT World, 2019; Karasik, 2022; European Environment Agency, 2025; CSB, 2026). These initiatives support broader transitions towards waste prevention, circular-economy alignment, extended producer responsibility, improved collection and recycling, reduced single-use consumption, and reduced leakage into aquatic environments (Senturk and Dumludag, 2021; European Environment Agency, 2025; Anadolu Ajansı, 2026; CSB, 2026). Their effectiveness, however, depends on implementation conditions, including infrastructure, institutional coordination, public trust, behavioural compliance, and access to practical alternatives (Truelove et al., 2022; Milbreta et al., 2025). Public concern and policy support do not necessarily translate into sustained behavioural change, particularly where convenience barriers, habits, weak infrastructure, or limited

technical understanding persist (Gündoğdu et al., 2018; Hartley et al., 2018a, Hartley et al., 2018b; Konstantoglou et al., 2023; Caminiti et al., 2025).

Accordingly, locally grounded assessment of public awareness, risk perception, policy support, and future engagement intention is central to effective plastic-pollution governance (Henderson and Green, 2020; Baechler et al., 2024; Caminiti et al., 2025). Survey-based approaches can identify knowledge gaps, salient risk perceptions, and socially acceptable interventions; however, many studies in this field remain constrained by inconsistent terminology, weak validation, and limited methodological rigour (Burns and Kho, 2015; Caminiti et al., 2025). Robust local baselines should therefore distinguish plastic-waste awareness from microplastic awareness, use reliable indices for risk perception and policy support, and evaluate how perception-based variables relate to future engagement intention.

The present study addresses this need by assessing plastic-waste awareness, microplastic awareness, risk perception, policy support, perceived sources and pathways, self-reported behaviour, and future engagement intention among school, university, and community-course centre respondents within an Eastern Black Sea source-to-sea project context linked to the Arılı and Çağlayan river catchments. The analysis was guided by a pragmatic source-to-sea environmental-behaviour framing, in which risk perception represented threat appraisal, policy support represented perceived acceptability of structural mitigation measures, and future engagement intention represented intention-oriented environmental behaviour. Four expectations were evaluated: (1) microplastic awareness would be positively associated with plastic-waste awareness; (2) risk perception would be positively associated with policy support; (3) plastic-waste awareness would be positively associated with future engagement intention; and (4) venue/life-stage groups would differ in awareness, risk perception, and policy support, although age–venue interdependence required cautious interpretation.

Using a venue-stratified design and ordinal-appropriate descriptive, non-parametric, and regression-based methods, the study provides a structured local baseline for catchment-based plastic-pollution governance. It examines awareness levels, perceived risks, policy support, venue/life-stage-associated differences, cross-sectional correlates of awareness and engagement, and perceived plastic sources and pathways. The findings are expected to contribute to plastic-pollution perception research and to inform locally relevant interventions, including education, source reduction, infrastructure improvement, deposit-refund systems, and participatory monitoring in Eastern Black Sea catchments.

2 Materials and methods

2.1 Study area and project context

This cross-sectional questionnaire survey was conducted within an Eastern Black Sea source-to-sea project context linked to the Arılı and Çağlayan river catchments. These catchments drain into the southeastern Black Sea and represent locally important freshwater–coastal systems associated with settlement, recreation, daily mobility, and ecosystem services. The study targeted catchment-linked educational and community venues in which school-age, young-adult, and adult/community respondents could observe, experience, or interpret riverine and coastal plastic pollution.

The survey assessed plastic-waste awareness, microplastic awareness, perceived ecological and human-health risks, policy support, perceived plastic-pollution sources and pathways, self-reported pro-environmental behaviours, and future engagement intention in local environmental education, awareness, or clean-up activities.

2.2 Study design, participants, and sampling framework

A structured questionnaire was administered using a venue-stratified sampling design to capture perceptions across distinct demographic, educational, and life-stage contexts. The sample comprised 151 respondents recruited from three Eastern Black Sea survey venues linked to the project's educational and community-engagement framework: primary school students from Fındıklı İlkokulu (n = 33), university students primarily from Artvin Çoruh University (n = 56), and participants recruited through the community-course centre, locally known as Fındıklı Halk Eğitimi Merkezi (n = 62). These groups are hereafter referred to as school, university, and community-course centre respondents.

The venues provided structured access to school-age, young-adult, and adult/community participants within the Arılı–Çağlayan source-to-sea project context. Participation was voluntary and anonymous. Respondents with consent and usable core questionnaire data were retained; no additional exclusion criteria were applied beyond absence of required consent or unusable core responses. Venue-specific response rates could not be calculated because recruitment denominators were not recorded consistently across venues.

The venue-based structure enabled comparisons among younger school participants, university students, and community-course centre respondents. The overall sample had a mean age of 39.3 years, a standard deviation of 22.7 years, and a median age of 36 years. Age composition differed strongly across venues: median age was 10 years among school respondents, 22 years among university respondents, and 63.5 years among community-course centre respondents. Supplementary Table 1 provides detailed sample characteristics and data-audit information.

Because recruitment was venue-based rather than population-random, the sample represents a structured education-sector and community sample, not a statistically representative sample of a single district or province. The design therefore supports comparison across selected demographic and educational contexts and identification of locally relevant patterns in plastic-waste awareness, microplastic awareness, risk perception, and policy support.

2.3 Survey instrument and thematic domains

The questionnaire was developed for the CARESEA project context to capture locally relevant plastic-waste awareness,

microplastic awareness, risk perception, policy support, perceived sources/pathways, self-reported pro-environmental behaviours, and future engagement intention in the Arılı–Çağlayan catchment setting. The project team reviewed items for content relevance, clarity, and contextual appropriateness. Before field administration, the questionnaire was clarity-pretested with 15 individuals from different age groups to evaluate comprehensibility, wording, and response-scale interpretation; these individuals were excluded from the analytical sample. Minor wording adjustments were made where necessary. Turkish wording was used during field administration, and English terminology was harmonised during data cleaning and manuscript preparation; no formal back-translation procedure was conducted.

The cleaned questionnaire dataset included 38 original survey variables covering socio-demographic characteristics, residential context, river and catchment exposure, awareness, risk perception, policy support, perceived sources and pathways, pro-environmental behaviours, and future engagement intention. Survey items were organised into five Likert-type response-scale families:

- Policy support/agreement items: 1 = strongly disagree; 5 = strongly agree.
- Risk-perception items: 1 = no likelihood; 5 = definitely.
- Ecological importance/evaluation items: 1 = not important; 5 = very important.
- Awareness/knowledge items: 1 = no knowledge; 5 = very good knowledge.
- Observation/frequency items: 1 = never; 5 = always.

Throughout the study, plastic-waste awareness refers to self-reported knowledge of general/visible plastic waste, whereas microplastic awareness refers to self-reported knowledge of microplastic pollution. Microplastic literacy is used only as an interpretive discussion term denoting practical understanding of microplastic sources, pathways, risks, and mitigation options.

These Likert-scale structures informed descriptive analysis, inferential testing, and venue-specific visualisation. Figure panels were organised around five thematic response families: policy support, risk perception, ecological importance/local pollution evaluation, awareness, and observation/frequency patterns.

2.4 Data cleaning, recoding, and analytic dataset construction

Data cleaning and statistical analyses were conducted in R (version 4.5.3; RStudio 2026.05.1-225), using *tidyverse*-based workflows and packages for psychometrics, non-parametric testing, effect-size estimation, ordinal and bias-reduced regression modelling, and multivariate analysis (*psych*, *rstatix*, *effectsize*, *ordinal*, *brglm2*, *broom*, *car*, and *FactoMineR*). Variable names were standardised using reproducible column labels.

Likert-type responses were recoded to numerical scores from 1 to 5, with higher values indicating stronger agreement, higher perceived risk, greater ecological importance, higher self-reported knowledge, or more frequent observation/use. Text and multi-response variables were harmonised across English and Turkish entries where necessary. After recoding, the analytic dataset comprised 67 variables derived from 38 cleaned survey variables; Supplementary Table 1 summarises the dataset structure and respondent distribution. Missingness was assessed across analytic variables, available cases were used for each outcome, and imputation was not applied because missingness was limited for core structured Likert-scale variables and concentrated mainly in open-ended items and future engagement intention.

2.5 Composite indices

Two composite indices were constructed *a priori*: a risk perception index and a policy support index. The risk perception index comprised three items assessing perceived human-health and aquatic-ecosystem risks. The policy support index comprised seven items measuring support for plastic-pollution mitigation policies.

For each respondent, the composite score was calculated as the arithmetic mean of the non-missing item scores:

$$X_i = \frac{1}{k}\sum_{j=1}^{k} X_{ij}$$

where X_i is the composite score for respondent i, k is the number of items in the scale, and X_{ij} is the numeric score for item j. Higher composite scores indicated stronger risk perception or stronger policy support.

2.6 Reliability and construct assessment

Internal consistency was assessed using Cronbach's alpha and McDonald's omega total, separately for the seven-item policy support scale and the three-item risk perception scale. Because the items used ordinal Likert-type response scales, ordinal/polychoric alpha was calculated as a sensitivity analysis. One-factor exploratory factor analysis evaluated whether each item set supported a unidimensional construct interpretation. Confirmatory factor analysis and multi-group measurement-invariance testing were not conducted because the study was exploratory and subgroup sizes were modest, particularly for the school group. Reliability coefficients, ordinal reliability sensitivity results, and factor loadings are reported in the Supplementary Material.

Cronbach's alpha was calculated as:

$$\alpha = \frac{k}{k-1}\left(1\frac{\sum_{j=1}^{k}\sigma_j^2}{\sigma_T^2}\right)$$

where k is the number of scale items, σ_j^2 is the variance of item j, and σ_T^2 is the variance of the total scale score.

2.7 Descriptive and inferential statistical analysis

Descriptive statistics were calculated as sample size, mean, standard deviation, median, standard error, and 95% confidence interval (CI), where appropriate. Because the survey relied primarily on ordinal Likert-type responses, inferential analyses used non-parametric methods.

One-sample Wilcoxon signed-rank tests compared Likert item medians against the neutral midpoint of 3. Kruskal–Wallis tests evaluated differences across survey venue groups, age groups, and residential context. When Kruskal–Wallis tests indicated significant differences, Dunn *post hoc* tests with Holm adjustment were applied. Kruskal–Wallis effect sizes were expressed as epsilon-squared.

Associations among plastic-waste awareness, microplastic awareness, observation frequency, ecological importance, local plastic-pollution evaluation, risk perception, and policy support were assessed using Spearman rank-order correlations. Correlation *p*-values were Holm adjusted where appropriate.

Ordinal logistic regression identified cross-sectional correlates of ordered plastic-waste awareness. Predictors included microplastic awareness, the risk perception index, the policy support index, age group, residential context, survey venue, and gender. Odds ratios (ORs) were calculated from model coefficients. The proportional-odds assumption was assessed using nominal tests. Reduced model specifications alternately excluded age group or survey venue to evaluate model sensitivity. Predictor collinearity was assessed using generalised variance inflation factors (GVIFs).

Future engagement intention was modelled as a binary outcome using bias-reduced logistic regression based on Firth-type penalised likelihood. This approach was selected because the outcome was imbalanced, with substantially more "yes" than "no" responses among respondents with available future engagement data. Reduced models evaluated sensitivity to model complexity. Statistical significance was interpreted at $p < 0.05$, and exact *p*-values and confidence intervals were reported where available.

2.8 Multi-response analysis

Several questionnaire items allowed multiple responses, including perceived riverside macroplastic categories, surface-floating plastic categories, primary sources of plastic pollution, entry pathways into local habitats, environmental dispersion mechanisms, sectoral plastic-use perceptions, and self-reported pro-environmental behaviours.

Multi-response variables were separated into individual response mentions, summarised as frequencies, and expressed as percentages of total mentions. These analyses identified the most frequently perceived plastic categories, sources, pathways, dispersion processes, sectoral contributors, and behavioural responses.

3 Results

3.1 Sample structure and data completeness

Supplementary Table 1 summarises the analytic sample and venue distribution. Data completeness was high for core structured questionnaire items, with complete Likert-scale data for the principal awareness, risk-perception, policy-support, observation, and evaluation variables. Missingness was concentrated mainly in open-ended questions and future engagement intention.

Future engagement intention data were unavailable for 33 respondents, representing 21.9% of the total sample. Among respondents with available engagement data ($n = 118$), 94 respondents (79.7%) reported willingness to participate in future environmental education, awareness, or clean-up activities, whereas 24 respondents (20.3%) reported no such intention. This missingness pattern and positive-response imbalance were considered when interpreting future-engagement models.

3.2 Reliability and structure of the composite scales

Both composite indices showed strong internal consistency. The seven-item policy support scale yielded Cronbach's alpha = 0.868 and McDonald's omega total = 0.877, whereas the three-item risk perception scale yielded Cronbach's alpha = 0.848 and McDonald's omega total = 0.855. Ordinal/polychoric reliability sensitivity analysis produced similarly strong estimates for policy support (ordinal alpha = 0.907) and risk perception (ordinal alpha = 0.913), supporting aggregation of Likert-type items into exploratory composite indices (Supplementary Table 2).

Exploratory factor analysis further supported one-factor solutions for both scales. Policy support factor loadings ranged from 0.571 to 0.804, with the strongest loading for educational awareness initiatives. Risk perception factor loadings ranged from 0.739 to 0.926, with the strongest loading for harmful effects of plastic waste on aquatic ecosystems (Supplementary Table 3). These results indicate internally coherent scales suitable for exploratory composite-based analyses, although confirmatory construct validation and measurement-invariance testing require larger subgroup*p*-balanced samples.

3.3 Overall awareness, risk perception, and policy support

Table 1 presents descriptive statistics for the key numeric variables. Plastic-waste awareness was moderate (mean = 3.25, SD = 0.916, median = 3), whereas microplastic awareness was lower (mean = 2.52, SD = 1.03, median = 2), indicating limited self-reported knowledge of microplastic pollution.

Despite this awareness gap, respondents reported high risk perception and strong policy support. The risk perception index had a mean of 4.38 (SD = 0.724, median = 4.67), and the policy support index had a mean of 4.16 (SD = 0.725, median = 4.29). Policy support, risk perception, ecological importance, and local plastic-pollution evaluation showed strongly right-skewed distributions, whereas awareness responses were more centrally distributed for plastic-waste awareness and shifted towards lower categories for microplastic awareness (Figures 1-4).

3.4 Policy support for mitigating plastic pollution

Policy support was consistently high across all seven mitigation items and significantly above the neutral midpoint of 3 (Table 2). The strongest support was observed for regular cleaning of rivers and coastal areas (mean = 4.38, 95% CI = 4.24–4.52), educational

TABLE 1 **Descriptive statistics for age, plastic-waste awareness, microplastic awareness, and the composite risk perception and policy support indices among respondents from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context.**

Variable	*n*	Mean	SD	Median
Age	151.00	39.30	22.70	36.00
Plastic-waste awareness	151.00	3.25	0.92	3.00
Microplastic awareness	151.00	2.52	1.03	2.00
Risk perception index	151.00	4.38	0.72	4.67
Policy support index	151.00	4.16	0.73	4.29

Values are pooled across school, university, and community-course centre survey venues and reported as sample size (*n*), mean, standard deviation (SD), and median.

awareness initiatives (mean = 4.36, 95% CI = 4.22–4.50), and deposit-refund systems for beverage packaging (mean = 4.27). Support was also high for installation of filter grates in stormwater drainage systems, elimination of microplastics in cosmetic products, restriction or banning of single-use plastic products, and improvement of waste-collection containers and infrastructure. One-sample Wilcoxon signed-rank tests confirmed that all seven items differed significantly from the neutral midpoint. Figure 1 shows that agreement-side responses predominated across all venues, indicating that high policy support was not confined to a single respondent group. School respondents showed lower mean support than university and community-course centre respondents for several items, particularly waste-collection infrastructure,

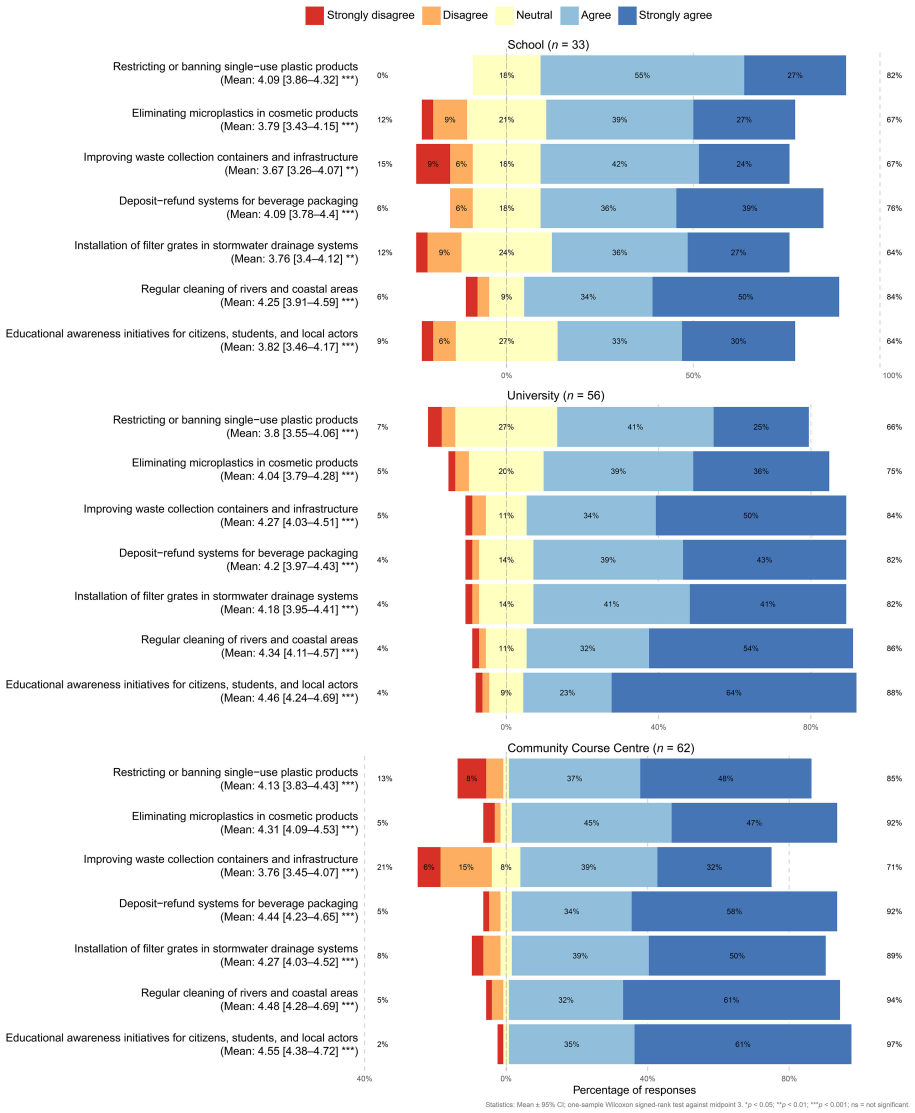


FIGURE 1
Venue-specific support for plastic-pollution mitigation policies among respondents from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context. Diverging stacked Likert bar charts show response distributions for seven policy-support items among school, university, and community-course centre respondents. Responses were recorded on a five-point agreement scale ranging from 1 = strongly disagree to 5 = strongly agree. Bars represent within-venue response distributions. Item labels report venue-specific mean scores with 95% confidence intervals (CIs). Significance markers indicate one-sample Wilcoxon signed-rank tests against the neutral midpoint of 3: $p < 0.05$; $p < 0.01$; $p < 0.001$; ns, not significant.

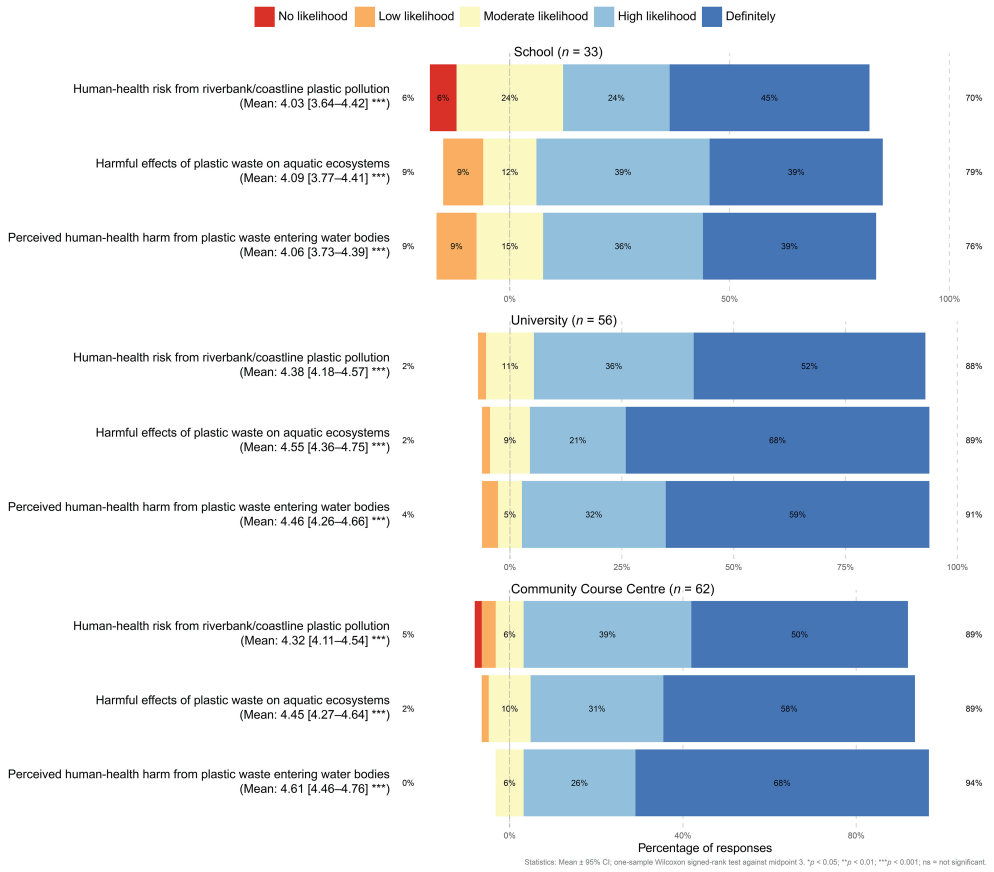


FIGURE 2
Venue-specific risk perception of plastic pollution among respondents from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context. Diverging stacked Likert bar charts show response distributions for three risk-perception items among school, university, and community-course centre respondents. Responses were recorded on a five-point risk-perception scale ranging from 1 = no likelihood to 5 = definitely. Bars represent within-venue response distributions. Item labels report venue-specific mean scores with 95% confidence intervals (CIs). Significance markers indicate one-sample Wilcoxon signed-rank tests against the neutral midpoint of 3: $p < 0.05$; $p < 0.01$; $p < 0.001$; ns, not significant.

stormwater filter grates, microplastic elimination in cosmetic products, and educational awareness initiatives. Nevertheless, all school-level policy-support means remained above the neutral midpoint, with the highest support for regular cleaning of rivers and coastal areas (mean = 4.25).

University respondents showed high agreement across most policies, whereas community-course centre respondents showed the strongest overall endorsement, particularly for educational awareness initiatives (mean = 4.55), regular cleaning of rivers and coastal areas (mean = 4.48), and deposit-refund systems for beverage packaging (mean = 4.44). Overall, the response pattern supports a comprehensive mitigation portfolio combining educational, regulatory, infrastructural, economic, and clean-up-oriented measures.

3.5 Risk perception, ecological importance, and evaluation of local plastic pollution

Respondents reported high perceived ecological and human-health risks associated with plastic pollution (Table 3). The highest-scoring item was perceived human-health harm from plastic waste entering water bodies (mean = 4.44, 95% CI = 4.31–4.56), followed by harmful effects of plastic waste on aquatic ecosystems (mean = 4.41, 95% CI = 4.28–4.54) and human-health risk from riverbank/coastline plastic pollution (mean = 4.28, 95% CI = 4.14–4.42). All three items were significantly above the neutral midpoint. Figure 2 shows strong clustering in the "high likelihood" and "definitely" categories across venues. School respondents reported slightly lower risk perception than university and community-course centre respondents, although their distributions remained skewed towards high perceived risk.

Perceived ecological importance was also high. Respondents rated the importance of river and marine ecological conditions in daily life with a mean score of 4.43 (95% CI = 4.32–4.54), and evaluated plastic pollution in the Çağlayan and Arılı streams as a serious local problem (mean = 4.30, 95% CI = 4.18–4.42; Supplementary Table 4). These perceptions were consistently high across venues, with limited between-group variation (Figure 3). Collectively, these results indicate that respondents framed plastic pollution as a locally salient freshwater–coastal, ecosystem, and human-health issue rather than as a distant environmental problem.

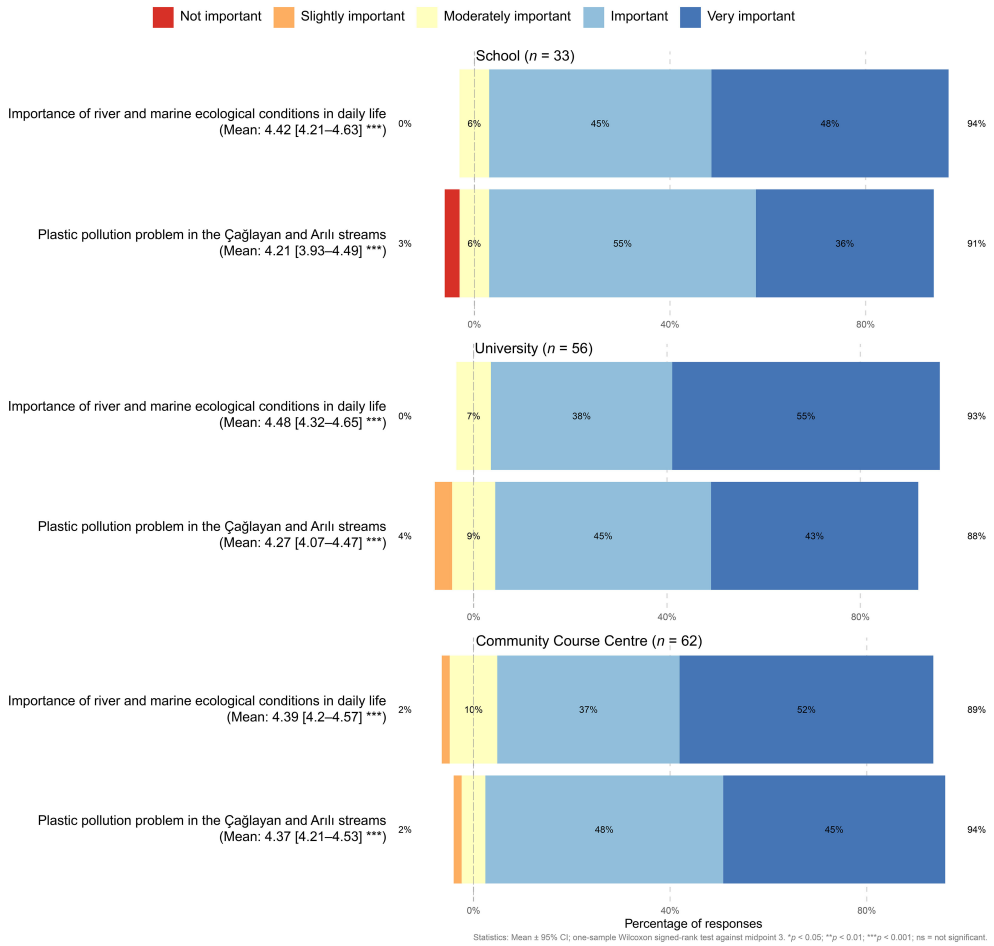


FIGURE 3
Venue-specific perceptions of ecological importance and local plastic-pollution severity within the Arılı–Çağlayan source-to-sea project context. Diverging stacked Likert bar charts show response distributions for perceived importance of river and marine ecological conditions in daily life and evaluation of plastic pollution in the Çağlayan and Arılı streams as a local problem among school, university, and community-course centre respondents. Responses were recorded on a five-point importance/evaluation scale ranging from 1 = not important to 5 = very important. Bars represent within-venue response distributions. Item labels report venue-specific mean scores with 95% confidence intervals (CIs). Significance markers indicate one-sample Wilcoxon signed-rank tests against the neutral midpoint of 3: $p < 0.05$; $p < 0.01$; $p < 0.001$; ns, not significant.

3.6 Awareness and frequency of observation

Awareness-related items revealed a pronounced knowledge asymmetry (Supplementary Table 5). Plastic-waste awareness was slightly above the neutral midpoint (mean = 3.25, median = 3), whereas microplastic awareness was significantly below the midpoint (mean = 2.52, median = 2). Figure 4 shows moderate plastic-waste awareness across venues and lower microplastic awareness, particularly among university and community-course centre respondents. School respondents reported comparatively higher microplastic awareness (mean = 3.00) than university (mean = 2.44) and community-course centre respondents (mean = 2.34).

Observation-frequency items clustered near the neutral midpoint (Supplementary Table 6). Respondents reported moderate frequencies of noticing plastic waste in rivers (mean = 3.02), encountering plastic waste on beaches (mean = 2.86), and noticing plastic waste while swimming in rivers or the sea (mean = 3.11); none differed significantly from the midpoint. Figure 5 shows dispersed distributions for these observation variables, indicating heterogeneous direct experiences with plastic pollution. By contrast, personal plastic-product use was significantly above the midpoint (mean = 3.23, 95% CI = 3.07–3.38), with the highest mean among community-course centre respondents (mean = 3.47). This combination of moderate observed pollution, high perceived risk, and frequent plastic-product use identifies everyday consumption as a potential intervention target.

3.7 Descriptive differences by venue

The three survey venues represented distinct demographic profiles (Supplementary Table 7). Median plastic-waste awareness was identical across venues (median = 3), whereas microplastic awareness was higher among school respondents (median = 3) than among university and community-course centre respondents (both median = 2). Conversely, risk perception and policy support were lower among school respondents. The mean risk perception index was 4.06 among school respondents and 4.46 among both university and community-course centre respondents. The mean policy support index increased from 3.92 among school respondents to

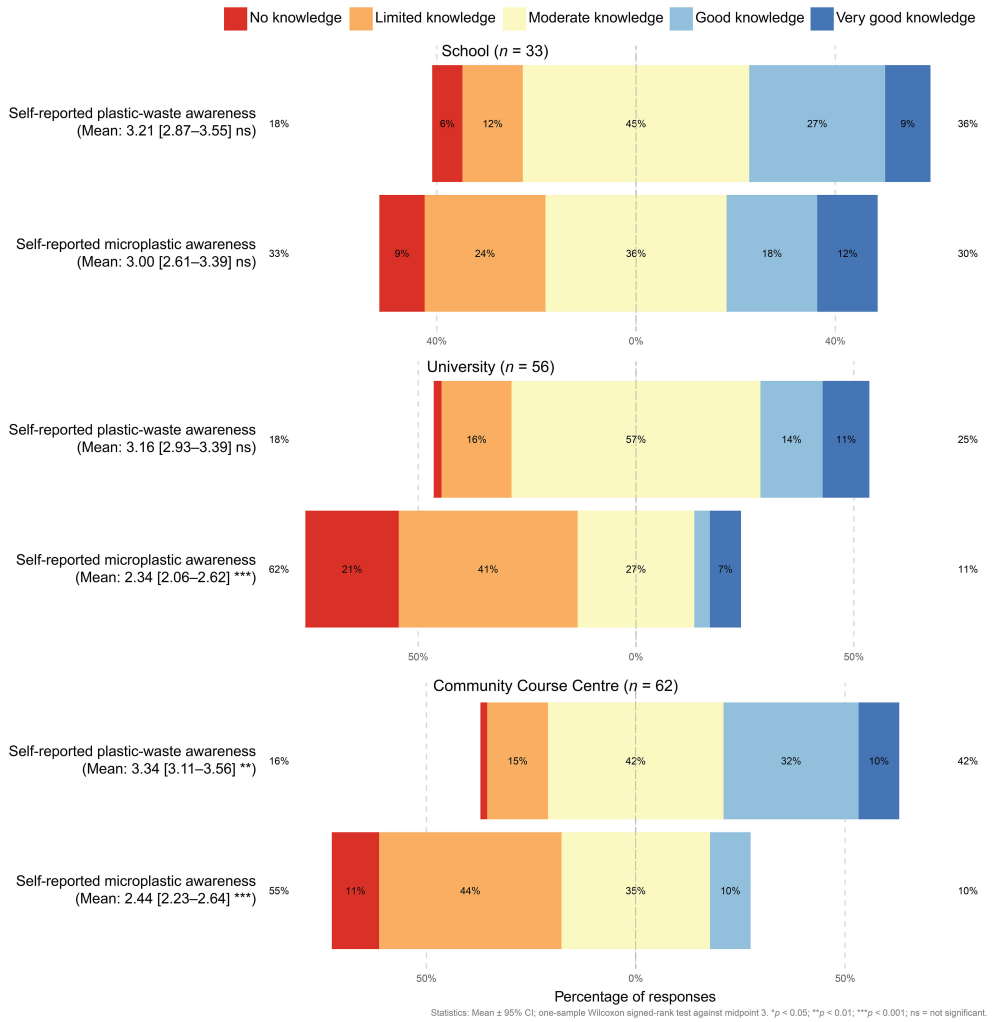


FIGURE 4
Venue-specific self-reported plastic-waste and microplastic awareness among respondents from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context. Diverging stacked Likert bar charts show response distributions for two awareness items among school, university, and community-course centre respondents. Responses were recorded on a five-point self-reported knowledge scale ranging from 1 = no knowledge to 5 = very good knowledge. Bars represent within-venue response distributions. Item labels report venue-specific mean scores with 95% confidence intervals (CIs). Significance markers indicate one-sample Wilcoxon signed-rank tests against the neutral midpoint of 3: $p < 0.05$; $p < 0.01$; $p < 0.001$; ns, not significant.

TABLE 2 **Pooled descriptive statistics for seven plastic-pollution mitigation policy-support items among respondents from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context.**

Policy item	*n*	Mean	Median	SD	95% CI	*P*-value
Improving waste collection containers and infrastructure	151	3.93	4.00	1.14	3.74–4.11	< 0.001
Restricting or banning single-use plastic products	151	4.00	4.00	1.03	3.84–4.16	< 0.001
Eliminating microplastics in cosmetic products	151	4.09	4.00	0.96	3.94–4.24	< 0.001
Installation of filter grates in stormwater drainage systems	151	4.13	4.00	0.98	3.97–4.28	< 0.001
Deposit-refund systems for beverage packaging	151	4.27	4.00	0.88	4.13–4.41	< 0.001
Educational awareness initiatives	151	4.36	5.00	0.89	4.22–4.50	< 0.001
Regular cleaning of rivers and coastal areas	150	4.38	5.00	0.88	4.24–4.52	< 0.001

Figure 1 presents venue-specific Likert response distributions for the same policy-support items.
Values are reported as sample size (*n*), mean, median, standard deviation (SD), 95% confidence interval (CI), and *p*-value from one-sample Wilcoxon signed-rank tests against the neutral midpoint of 3.

TABLE 3 **Pooled descriptive statistics for perceived human-health and ecological risks associated with plastic pollution in riverine and coastal environments within the Eastern Black Sea source-to-sea project context.**

Risk-perception item	*n*	Mean	Median	SD	95% CI	*P*-value
Human-health risk from riverbank/coastline plastic pollution	151	4.28	4.00	0.90	4.14–4.42	< 0.001
Harmful effects of plastic waste on aquatic ecosystems	151	4.41	5.00	0.80	4.28–4.54	< 0.001
Perceived human-health harm from plastic waste entering water bodies	151	4.44	5.00	0.78	4.31–4.56	< 0.001

Values are reported as sample size (*n*), mean, median, standard deviation (SD), 95% confidence interval (CI), and *p*-value from one-sample Wilcoxon signed-rank tests against the neutral midpoint of 3. Figure 2 presents venue-specific Likert response distributions for the same risk-perception items.

4.18 among university respondents and 4.28 among community-course centre respondents.

Future engagement intention also varied descriptively. Among respondents with available data, 62.5% of university respondents and 95.2% of community-course centre respondents reported willingness to participate in future environmental activities. School respondents were excluded from cross-venue engagement comparisons because response coverage for this item was insufficient.

3.8 Comparisons by venue, age, and residential context

Kruskal–Wallis tests indicated no significant differences in plastic-waste awareness by survey venue ($H = 1.73$, $p = 0.421$) or residential context ($H = 0.354$, $p = 0.838$; Table 4). In contrast, policy support differed by venue ($H = 11.0$, $p = 0.004$, $\varepsilon^2 = 0.0605$), as did risk perception ($H = 7.08$, $p = 0.029$, $\varepsilon^2 = 0.0343$).

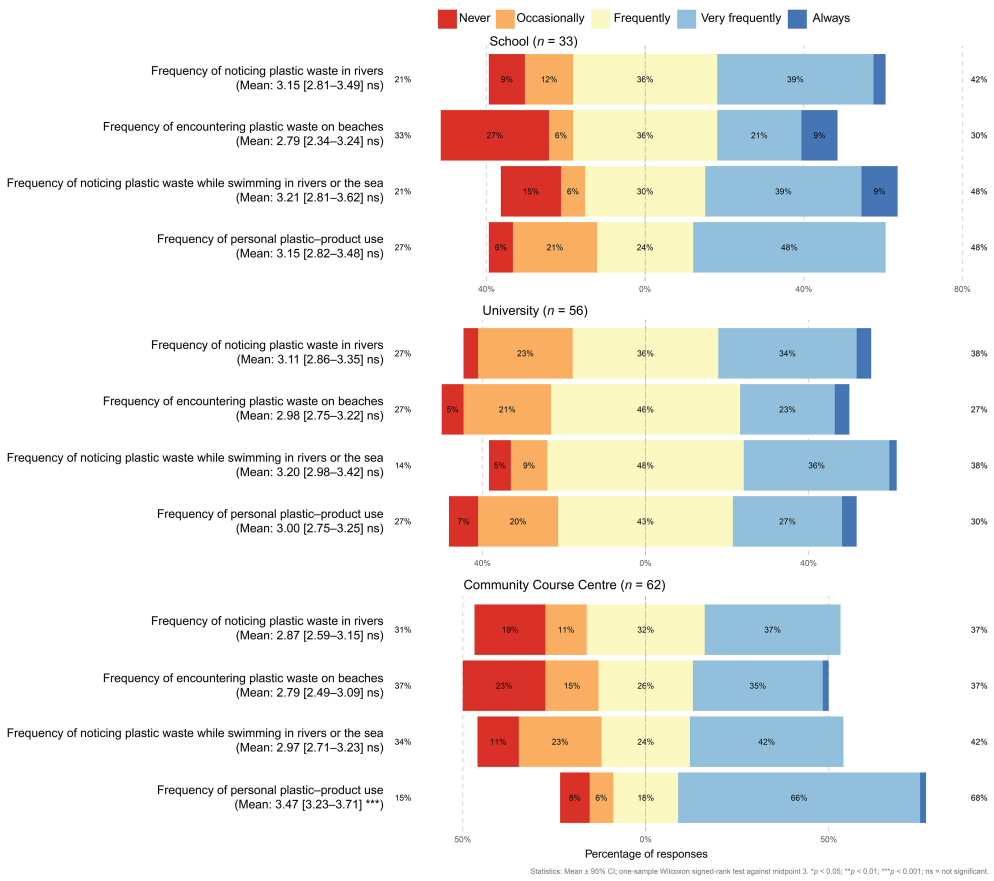


FIGURE 5
Venue-specific observation frequency of plastic waste and personal plastic-product use among respondents from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context. Diverging stacked Likert bar charts show response distributions for noticing plastic waste in rivers, encountering plastic waste on beaches, noticing plastic waste while swimming in rivers or the sea, and personal plastic-product use among school, university, and community-course centre respondents. Responses were recorded on a five-point frequency scale ranging from 1 = never to 5 = always. Bars represent within-venue response distributions. Item labels report venue-specific mean scores with 95% confidence intervals (CIs). Significance markers indicate one-sample Wilcoxon signed-rank tests against the neutral midpoint of 3: $p < 0.05$; $p < 0.01$; $p < 0.001$; ns, not significant.

Dunn *post hoc* tests showed that school respondents had significantly lower policy support and risk perception than university and community-course centre respondents, whereas the latter two groups did not differ significantly. Age-group comparisons showed stronger effects for policy support ($H = 20.1$, $p < 0.001$, $\varepsilon^2 = 0.116$) and risk perception ($H = 18.8$, $p < 0.001$, $\varepsilon^2 = 0.107$). Age group and survey venue were strongly associated ($\chi^2 = 218$, df = 6, $p < 0.001$; Fisher simulated $p < 0.001$; Cramér's V = 0.842): 81.8% of school respondents were under 18 years old, 73.2% of university respondents were aged 18–35 years, and 79.0% of community-course centre respondents were aged 56 years or older. Venue-related differences were therefore interpreted as venue/life-stage-associated patterns rather than independent venue effects.

3.9 Item-level venue differences

Item-level Kruskal–Wallis tests identified variables contributing to venue/life-stage-associated differences. Significant differences occurred for microplastic awareness, personal plastic-product use, multiple policy-support items, human-health risk from riverbank/coastline plastic pollution, and harmful effects of plastic waste on aquatic ecosystems. Significant policy-support items included educational awareness initiatives, elimination of microplastics in cosmetic products, restriction or banning of single-use plastic products, installation of filter grates in stormwater drainage systems, and improvement of waste-collection containers and infrastructure.

For microplastic awareness, school respondents reported higher scores (mean = 3.00, median = 3) than university respondents (mean = 2.44, median = 2) and community-course centre respondents (mean = 2.34, median = 2). This venue/life-stage-associated difference was significant ($H = 9.11$, df = 2, $p = 0.011$). Dunn–Holm tests indicated higher microplastic awareness among school respondents than university respondents (adjusted $p = 0.009$) and community-course centre respondents (adjusted $p = 0.048$), whereas university and community-course centre respondents did not differ significantly (adjusted $p = 0.359$).

Overall, school respondents reported higher microplastic awareness but lower policy support and risk perception across several items. University and community-course centre respondents generally did not differ significantly. This pattern indicates a venue/life-stage-associated mismatch between self-reported microplastic awareness and risk/policy salience; it does not demonstrate causal translation from knowledge to responsibility.

3.10 Correlation analysis

Spearman's correlation analysis showed a strong positive association between risk perception and policy support ($\rho = 0.551$; Table 5). Plastic-waste awareness was positively correlated with microplastic awareness ($\rho = 0.396$) and policy support ($\rho = 0.292$). Local plastic-pollution evaluation was positively associated with risk perception ($\rho = 0.454$) and policy support ($\rho = 0.396$), while ecological importance was positively associated with risk perception ($\rho = 0.340$) and policy support ($\rho = 0.287$). Observation variables were also mutually correlated: riverine litter observation was associated with beach litter observation ($\rho = 0.487$), and beach litter observation was associated with plastic observation during aquatic activities ($\rho = 0.510$). These correlations indicate internally consistent perception patterns across related environmental observation domains.

3.11 Cross-sectional correlates of plastic-waste awareness

Ordinal logistic regression identified microplastic awareness as the strongest cross-sectional correlate of higher plastic-waste awareness (Table 6). Each one-unit increase in microplastic awareness was associated with higher odds of being in a higher plastic-waste awareness category (OR = 2.41, 95% CI = 1.65–3.50, $p = 0.001$). This association remained stable in reduced models that alternately excluded survey venue or age group (OR = 2.38–2.46, both $p < 0.001$).

Policy support showed a positive but borderline association with plastic-waste awareness (OR = 1.60, 95% CI = 0.983–2.59, $p = 0.059$). Risk perception, age group, residential context, survey venue, and gender were not significant predictors in the adjusted model. Nominal tests did not indicate major proportional-odds violations for estimable predictors, including microplastic awareness ($p = 0.482$), risk perception ($p = 0.277$), age group ($p = 0.366$), survey venue ($p = 0.464$), and gender ($p = 0.151$). Collinearity diagnostics did not indicate severe numerical multicollinearity, with adjusted GVIF values ranging from 1.04 to 2.02. These estimates indicate a close cross-sectional association between

TABLE 4 Kruskal–Wallis test results for differences in plastic-waste awareness, policy support, and risk perception across survey venue, age group, and residential context among respondents from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context.

Analysis	*n*	H statistic	df	*P*-value	Epsilon-squared
Plastic-waste awareness by survey venue	151	1.73	2.00	0.421	< 0.001
Policy support by survey venue	151	11.00	2.00	0.004	0.061
Risk perception by survey venue	151	7.08	2.00	0.029	0.034
Policy support by age group	151	20.10	3.00	< 0.001	0.116
Risk perception by age group	151	18.80	3.00	< 0.001	0.107
Plastic-waste awareness by residential context	150	0.35	2.00	0.838	< 0.001

Effect sizes are reported as epsilon-squared (ε^2).

TABLE 5 Spearman rank-order correlations among plastic-waste awareness, microplastic awareness, risk perception, policy support, ecological importance, local plastic-pollution evaluation, and plastic-waste observation variables in the venue-stratified Arılı–Çağlayan source-to-sea project sample.

Variable pair	Spearman ρ
Plastic-waste awareness – Microplastic awareness	0.396
Plastic-waste awareness – Policy support index	0.292
Risk perception index – Policy support index	0.551
Ecological importance – Risk perception index	0.340
Ecological importance – Policy support index	0.287
Local pollution evaluation – Risk perception index	0.454
Local pollution evaluation – Policy support index	0.396
Riverine litter observation – Beach litter observation	0.487
Beach litter observation – Aquatic activity litter observation	0.510

microplastic awareness and plastic-waste awareness, without implying causal direction.

3.12 Cross-sectional correlates of future engagement intention

Bias-reduced logistic regression showed that plastic-waste awareness was positively associated with future engagement intention among respondents with available engagement data (Table 7). Each one-unit increase in plastic-waste awareness was associated with higher odds of intending to participate in future environmental activities (OR = 2.29, 95% CI = 1.12–4.66, p = 0.023). This association remained positive across reduced model specifications (OR = 2.26–2.56).

Respondents aged 36–55 years had higher odds of future engagement intention than respondents aged 18–35 years, the reference group (OR = 9.13, 95% CI = 1.36–61.30, p = 0.023), whereas male gender was associated with lower odds of engagement intention (OR = 0.26, 95% CI = 0.08–0.92, p = 0.037). Other predictors were not significant. Collinearity diagnostics did not indicate severe numerical multicollinearity, with adjusted GVIF values ranging from 1.04 to 1.88. Wide confidence intervals, particularly for age-related estimates, reflect the small number of negative engagement responses; these results should therefore be interpreted as exploratory available-case associations rather than stable population-level estimates.

TABLE 6 Ordinal logistic regression model identifying cross-sectional correlates of higher plastic-waste awareness among respondents from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context.

Predictor	Estimate	OR	95% CI	*P*-value
Microplastic awareness	0.88	2.41	1.65–3.50	0.001
Risk perception index	-0.15	0.87	0.517–1.45	0.581
Policy support index	0.47	1.60	0.983–2.59	0.059
Age 18–35	0.88	2.40	0.424–13.6	0.321
Age 36–55	1.91	6.73	0.927–48.9	0.060
Age 56+	1.80	6.07	0.735–50.1	0.094
River/riverbed proximity	0.26	1.30	0.550–3.07	0.550
University venue	-0.68	0.51	0.106–2.43	0.397
Community course centre	-0.92	0.40	0.0609–2.63	0.341
Male gender	-0.11	0.90	0.464–1.75	0.757

Estimates, odds ratios (ORs), 95% confidence intervals (CIs), and p-values are reported. Reference categories were age <18 years, coast/near-coast residential context, school survey venue, and female gender.

TABLE 7 Bias-reduced logistic regression model identifying cross-sectional correlates of future engagement intention among respondents with available engagement data from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context.

Predictor	OR	95% CI	*P*-value
Plastic-waste awareness	2.29	1.12–4.66	0.023
Microplastic awareness	1.11	0.57–2.16	0.750
Risk perception index	1.37	0.50–3.71	0.541
Policy support index	0.52	0.16–1.65	0.264
Age 36–55	9.13	1.36–61.30	0.023
Age 56+	4.86	0.32–73.90	0.255
River/riverbed proximity	1.28	0.28–5.84	0.751
Community course centre	3.54	0.27–47.00	0.338
Male gender	0.26	0.08–0.92	0.037

The outcome indicates willingness to participate in future environmental education, awareness, or clean-up activities related to local river and coastal environments. Odds ratios (ORs), 95% confidence intervals (CIs), and p-values are reported. Reference categories were age 18–35 years, university survey venue, coast/near-coast residential context, and female gender. School respondents were excluded because the future engagement item was not available for this group.

3.13 Perceived plastic categories, sources, pathways, and actions

Multi-response analysis showed that bottles and plastic bags were the most frequently observed macroplastic categories near rivers and on water surfaces (Table 8). Among riverside macroplastics, bottles accounted for 121 mentions (41.9%) and plastic bags for 113 mentions (39.1%). Among surface-floating plastics, plastic bags accounted for 118 mentions (45.0%) and bottles for 107 mentions (40.8%).

Urban household waste was the most frequently perceived source of plastic pollution (130 mentions; 33.6%). The most commonly identified entry pathway was waste directly discarded by people (126 mentions; 32.4%), and the dominant dispersion mechanism was transport via water (127 mentions; 52.3%). Packaging and packaging materials were identified as the leading sectoral source of plastic use (142 mentions; 27.9%). The most frequently reported pro-environmental behaviours were reducing plastic consumption (97 mentions; 29.0%) and recycling or waste management (82 mentions; 24.6%).

Together, these findings link visible pollution types, perceived sources and pathways, and self-reported behavioural responses, reinforcing the relevance of waste-collection infrastructure, clean-up programmes, educational awareness initiatives, and deposit-refund systems.

TABLE 8 Pooled multi-response summary of perceived plastic categories, pollution sources, plastic-entry pathways, environmental dispersion mechanisms, sectoral plastic-use perceptions, and self-reported pro-environmental behaviours among respondents from Eastern Black Sea educational and community venues linked to the Arılı–Çağlayan source-to-sea project context.

Question	Top response	*n*	Percentage of mentions
Riverside macroplastic categories	Bottles	121	41.90
	Plastic bags	113	39.10
Surface-floating plastic categories	Plastic bags	118	45.00
	Bottles	107	40.80
Primary sources of plastic pollution	Urban household waste	130	33.60
Pathways of plastic entry	Directly discarded by people	126	32.40
Environmental dispersion mechanisms	Via water	127	52.30
Sectoral plastic use perception	Packaging and packaging materials	142	27.90
Self-reported pro-environmental behaviour	Reduce plastic consumption	97	29.00
	Recycling and waste management	82	24.60

Percentages represent the proportion of total response mentions within each multi-response question.

4 Discussion

Effective plastic-pollution management in river-connected coastal systems requires integration of technical infrastructure with public awareness, risk perception, policy support, and future engagement intention (Pahl and Wyles, 2017; Hartley et al., 2018a, Hartley et al., 2018b; Baechler et al., 2024). The Arılı and Çağlayan catchments provide a structured social baseline for this governance challenge. Respondents showed high environmental concern and strong policy support, but uneven technical understanding, particularly for micro-scale pollutants. This combination indicates favourable attitudinal conditions for intervention, alongside cognitive and behavioural gaps that may constrain translation of support into sustained action (Gündoğdu et al., 2018; Baechler et al., 2024; Caminiti et al., 2025).

4.1 Knowledge–concern asymmetry and microplastic literacy

The asymmetry between plastic-waste awareness and microplastic awareness represents a central finding. Respondents reported moderate plastic-waste awareness but substantially lower microplastic awareness (Figure 4), consistent with evidence that plastic pollution is widely recognised while public understanding of microplastic formation, transport, exposure pathways, and mitigation remains limited (Henderson and Green, 2020; Garcia-Vazquez and Garcia-Ael, 2021; Baechler et al., 2024).

Microplastic awareness was the strongest cross-sectional correlate of higher plastic-waste awareness. This association suggests that microplastic literacy, defined here as practical understanding of microplastic sources, pathways, risks, and mitigation options, may constitute an important component of broader plastic-pollution understanding. Because the study is cross-sectional, this relationship identifies association rather than causal direction. Nevertheless, the findings indicate that communication strategies should not treat microplastics as a secondary or specialist topic. Microplastics can function as an explanatory bridge linking visible litter, fragmentation processes, riverine transport, and potential ecological or human exposure (Garcia-Vazquez and Garcia-Ael, 2021; Baechler et al., 2024; Caminiti et al., 2025).

The results also indicate that current concern may derive primarily from the salience of visible macroplastic debris rather than detailed understanding of microplastic toxicity, exposure, or environmental fate. This interpretation aligns with studies showing that communities often recognise plastics as a dominant pollutant but have limited access to formal information on microplastic pathways, policy instruments, and structural mitigation options (Baechler et al., 2024; Caminiti et al., 2025; Yenici, 2026). High risk perception should therefore be interpreted as a favourable attitudinal condition for engagement, not as evidence of advanced technical literacy.

4.2 Risk perception: local ecological and human-health salience

Respondents perceived plastic pollution as a serious risk to human health and aquatic ecosystems, with the highest scores assigned to human-health harm from plastic waste entering water bodies and ecological harm in aquatic systems. This pattern indicates a locally grounded risk frame centred on water quality, seafood safety, ecosystem condition, and everyday exposure, rather than distant or abstract environmental degradation (Davison et al., 2021; Baechler et al., 2024; Kılıç and Evgin, 2025).

The strong human-health framing differs from studies in which public concern centres primarily on marine wildlife, entanglement, and ecosystem injury (Hartley et al., 2018a, Hartley et al., 2018b; Lotze et al., 2018; Baechler et al., 2024), but aligns with evidence linking microplastic concern to perceived health risks, media narratives, and physical-health consciousness (Pop et al., 2023; Khorsandi et al., 2025; Kılıç and Evgin, 2025). The positive association between risk perception and policy support further indicates that perceived threat is an important correlate of intervention acceptance. Regional communication should therefore connect local plastic sources, riverine transport, exposure routes, and feasible mitigation measures, rather than relying solely on broad environmental messaging (Hartley et al., 2015; Pahl and

Wyles, 2017; Garcia-Vazquez and Garcia-Ael, 2021; Baechler et al., 2024).

4.3 Support for structural interventions

Policy support was high across all seven mitigation measures, indicating broad receptiveness to a multicomponent management portfolio (Figure 1). The strongest support was observed for regular cleaning of rivers and coastal areas, educational awareness initiatives, and deposit-refund systems for beverage packaging (Table 2). This preference structure suggests support for both visible remedial actions and longer-term structural interventions targeting pollution at source (Hartley et al., 2018b; Konstantoglou et al., 2023).

Support for deposit-refund systems is particularly relevant because beverage bottles were among the most frequently perceived plastic items in local rivers (Table 8). This correspondence indicates alignment between policy preferences and locally experienced pollution patterns. Previous research shows that deposit-refund effectiveness depends not only on environmental motivation but also on enabling conditions, including user convenience, accessible return points, reliable infrastructure, and clear communication (Zhou et al., 2020; Khedr et al., 2023; Konstantoglou et al., 2023). Thus, the principal constraint in the studied catchments may lie less in public acceptance than in implementation quality. Converting policy support into sustained behavioural change will require visible municipal coordination, adequate waste-collection and stormwater-filtration infrastructure, reliable maintenance, and continued public engagement. This interpretation is relevant to Türkiye's current policy context, including plastic-bag charges, deposit-refund systems, reductions in single-use plastics, and circular-economy strategies under the Zero Waste framework (Karasik, 2022; Anadolu Ajansı, 2026; CSB, 2026).

4.4 Awareness–action gap and future engagement intention

Plastic-waste awareness was positively associated with future engagement intention, indicating that awareness may support mobilisation in this exploratory cross-sectional sample. However, high concern, strong policy support, and frequent personal plastic-product use co-occurred, indicating a persistent awareness–action gap. Similar patterns have been reported where individuals recognise the environmental impacts of plastic pollution yet continue plastic-bag use or limited waste separation (Gündoğdu et al., 2018; Hartley et al., 2018a, Hartley et al., 2018b; Caminiti et al., 2025).

The study did not directly measure affordability, convenience, recycling access, municipal-service reliability, social norms, or availability of reusable alternatives. These factors therefore cannot be evaluated empirically here, but they represent plausible contextual constraints through which intention may fail to translate into sustained behaviour. Future intervention-oriented research should measure these constraints explicitly.

These findings challenge a purely informational-deficit model. Educational interventions should move beyond awareness-raising and incorporate action-oriented components such as citizen-science monitoring, school-based initiatives, clean-up activities, source-separation demonstrations, and feedback on locally collected waste. Such approaches can strengthen perceived responsibility, reduce behavioural barriers, and provide repeated opportunities for engagement (Hidalgo-Ruz and Thiel, 2013; Hartley et al., 2015, Hartley et al., 2018b).

4.5 Venue/life-stage mismatches and audience differentiation

The venue/life-stage analysis revealed a mismatch between knowledge and perception. School respondents reported higher microplastic awareness than university and community-course centre respondents, yet showed lower risk perception and policy support. Because age and venue were strongly intertwined, this pattern should be interpreted as a venue/life-stage-associated mismatch, not as evidence that younger respondents failed to translate knowledge into responsibility.

Education studies indicate that knowledge gains more effectively influence attitudes and behaviour when learning is experiential, participatory, and linked to concrete action (Hidalgo-Ruz and Thiel, 2013; Hartley et al., 2015, Hartley et al., 2018a). Conversely, university and community-course centre respondents showed stronger risk perception and policy support despite lower microplastic awareness. This pattern may reflect combined age, educational-context, local-experience, and place-attachment effects, but the present venue-stratified design cannot separate these mechanisms. Previous studies show that age, environmental experience, social norms, and perceived proximity to pollution can shape risk perception, although demographic patterns remain context-dependent (Pop et al., 2023; Baechler et al., 2024; Bergami et al., 2025).

These findings support differentiated communication. School programmes should move beyond factual awareness towards participatory and action-oriented learning. Adult and community programmes should build on existing concern while strengthening technical understanding of pollution sources, transport pathways, and prevention options (Hartley et al., 2018a, Hartley et al., 2018b; Ozkan Vardar and Çalı, 2024; Yenici, 2026).

4.6 Perceived sources, pathways, and catchment-based management

The multi-response findings link public perception with catchment-based management priorities. Respondents identified bottles and plastic bags as dominant visible plastic categories, urban household waste as the leading perceived source, direct disposal by people as the main entry pathway, water transport as the dominant dispersion mechanism, and packaging materials as the leading sectoral contributor (Table 8). This pattern indicates that respondents connect local plastic pollution with everyday consumption, household waste generation, and river-mediated transport.

Similar studies identify single-use packaging, household waste, and public disposal behaviour as major perceived contributors to aquatic and marine plastic pollution (Gündoğdu et al., 2018; Hartley et al., 2018b; Baechler et al., 2024). The present findings support a catchment-based management approach integrating

upstream waste prevention, source separation, packaging reduction, deposit-refund systems, stormwater filtration, and riverbank waste management with downstream coastal clean-ups. In the Arılı and Çağlayan catchments, clean-ups remain important because they received strong public support; however, they should form part of a broader source-to-sea strategy rather than isolated remedial actions. This approach aligns with current policy directions in Türkiye, including Zero Waste implementation, plastic-bag charging, deposit-return planning, and the Roadmap for Single-Use Plastics, Marine Litter, and Microplastics (Karasik, 2022; European Environment Agency, 2025; Anadolu Ajansı, 2026; CSB, 2026).

4.7 Methodological contribution and design limitations

This study contributes methodologically to plastic-pollution perception research. Recent reviews indicate that many surveys in this field lack validated instruments, psychometric testing, clear sampling frames, or consistent reporting (Burns and Kho, 2015; Caminiti et al., 2025). The present study strengthened analytical transparency through internally consistent composite indices, reliability testing, ordinal/polychoric reliability sensitivity analysis, exploratory factor analysis, ordinal-appropriate inferential methods, and bias-reduced logistic regression for imbalanced engagement data. These features provide a structured regional baseline for future research.

Several limitations require caution. The venue-stratified, cross-sectional sample does not support population-level representativeness or causal inference. The questionnaire did not include full item batteries for subjective norms, perceived behavioural control, response efficacy, self-efficacy, or personal norms; therefore, the analysis represents a theory-informed exploratory baseline rather than a formal test of the Theory of Planned Behaviour, Protection Motivation Theory, or Value–Belief–Norm theory. Age group and survey venue were strongly intertwined, limiting separation of age, life-stage, educational-context, and recruitment-setting effects. Future engagement data were missing for 21.9% of respondents and were concentrated among younger/school respondents; engagement models therefore represent available-case exploratory associations rather than full-sample estimates.

Although bias-reduced logistic regression, proportional-odds diagnostics, VIF/GVIF checks, and reduced-model sensitivity analyses improved statistical transparency, the small number of negative engagement responses requires cautious interpretation of odds ratios with wide confidence intervals. Self-reported measures may also introduce social desirability bias, particularly for policy support and future engagement intention. Future research should use larger representative samples, longitudinal designs, intervention evaluations, formal measurement-invariance testing, and integration of observed behaviour or litter-monitoring data to assess whether support for measures such as deposit-refund systems translates into sustained behavioural change (Hartley et al., 2018b; Baechler et al., 2024; Caminiti et al., 2025).

5 Conclusions

The Arılı and Çağlayan catchments show favourable baseline conditions for plastic-pollution mitigation, characterised by high risk perception and strong policy support. However, limited microplastic awareness indicates a clear knowledge–concern asymmetry. The positive cross-sectional association between microplastic awareness and plastic-waste awareness suggests that microplastic literacy should be strengthened within future communication and education efforts, while the association between plastic-waste awareness and future engagement intention indicates that awareness may support mobilisation. Nevertheless, frequent personal plastic-product use confirms that knowledge alone is insufficient for sustained behavioural change.

Venue/life-stage-associated differences further indicate the need for audience-specific strategies. School programmes should move beyond factual awareness towards participatory and action-oriented learning, whereas adult and community programmes should build on existing concern by improving understanding of pollution sources, transport pathways, and prevention options. Education should therefore be integrated with practical interventions, including deposit-refund systems, improved waste-collection infrastructure, stormwater filter grates, regular river and coastal clean-ups, and participatory monitoring. Overall, plastic-pollution management in the study area should adopt integrated catchment-based strategies that connect personal consumption and disposal practices with river health, coastal water quality, and ecosystem protection. Such an approach may help convert existing public concern into informed and sustained environmental stewardship in the Eastern Black Sea region, although longitudinal or intervention-based evidence is required to evaluate behavioural change.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

The study was conducted in accordance with the relevant ethical principles for research involving human participants. Ethical approval was granted by the Rectorate of Karadeniz Technical University on January 31, 2026, under document/reference number E-82554930-050.01.04-772830, as part of the project “Cooperation and Awareness for Pollution-free and Environmentally Sustainable Black Sea.” The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent

for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

KS: Conceptualization, Data curation, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing. ÖD: Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. YT: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. KÖ: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. NA: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. IA: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2026.1884662/full#supplementary-material

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