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Conceptual ecobiological screening of municipal plastic waste pressure on riverine ecosystems

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Abstract. Municipal plastic waste represents not only a management and technological challenge but also a potential source of ecobiological pressure on riverine and riparian ecosystems. Inadequate separate collection, uncontrolled accumulation and fragmentation of plastic materials may facilitate the release of macroplastics and microplastics into freshwater ecosystems, where they can interact with macroinvertebrates, fish, microbial communities, bottom sediments, soils and riparian habitats. The aim of this study was to identify and characterise the potential pathways through which municipal plastic waste may enter riverine ecosystems, synthesise the possible mechanisms of its interaction with biota, and develop a preliminary conceptual framework for identifying priorities for ecobiological monitoring. A theoretical and analytical approach was applied, combining a targeted narrative review of recent scientific literature, a "pressure – pathway – receptor – response" framework, and an illustrative application of the developed by the authors plastic waste collection efficiency index to two hypothetical scenarios of municipal waste collection. The synthesis of the scientific literature showed that municipal plastic waste may interact with biota through physical habitat contamination, particle ingestion, transport of associated pollutants, formation of the plastisphere, and alterations in microbial processes in water, bottom sediments and soils. The illustrative application of the index to the two hypothetical scenarios yielded values of 0.67 and 0.64 and demonstrated how different combinations of service coverage and infrastructure accessibility affected the overall assessment. These scenario-based values do not characterise specific municipalities and do not quantify actual plastic leakage, concentrations in the aquatic environment, biological toxicity or biodiversity degradation. The study proposes a conceptual ecobiological framework for prioritising separate collection, local microplastic monitoring, assessment of bottom sediments, bioindication, and subsequent field verification in river basins affected by pressure from municipal plastic waste

Keywords: macroinvertebrates; plastisphere; bottom sediments; bioindication; floodplains

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INTRODUCTION

The environmental consequences of municipal solid waste have traditionally been discussed through the language of infrastructure, costs, recycling rates, waste generation trends, and institutional capacity (Kaza *et al*., 2018). Such a perspective is necessary, but it is incomplete when plastic waste escapes municipal collection systems and enters riverine landscapes. In that case, waste management failure becomes a biological pressure: plastic items occupy habitats, fragment into smaller particles, become colonised by microorganisms, transport additives and sorbed pollutants, and create exposure pathways for aquatic and riparian organisms. Therefore, the assessment of environmentally safe waste management should not be limited to the amount of material recovered or diverted from landfills; it should also include the capacity of a system to prevent adverse effects on living components of ecosystems. Municipal plastic waste is especially relevant for river basins because plastics are light, persistent, mobile, and frequently generated in spatially dispersed household and commercial activities. When collection coverage is incomplete or when container accessibility is poor, plastics can accumulate in streets, ravines, drainage channels, riverbanks, floodplains, and informal dumps. High-flow events then mobilise a fraction of this material into watercourses. T.H.M. van Emmerik *et al*. (2023) showed that flood episodes could sharply intensify river plastic transport and deposition, demonstrating that rivers acted not as passive conduits but as dynamic reservoirs and remobilisation corridors for plastic debris. The Carpathian and Upper Tisza context is particularly important because mountain and foothill rivers combine high ecological value with strong hydrological variability and infrastructural constraints. A. Balla *et al*. (2024) used the Tisza River as a case study to examine the spatial distribution of microplastics in fluvial sediments and confirmed that plastic contamination was measurable in transboundary river systems and required basin-scale interpretation.

The biological relevance of this problem is increasingly supported by studies on freshwater and terrestrial receptors. A.K. Mora-Teddy *et al*. (2024) found that macroinvertebrates could ingest microplastics and modify their drift and benthic behaviour under particle exposure. Fish may experience physical, physiological, biochemical, immunological, and reproductive effects under microplastic exposure, although the magnitude of effects depends on polymer type, particle size, concentration, exposure duration, and associated chemicals (Banaee *et al*., 2025). V.K. Aralappanavar *et al*. (2024) showed that microplastics in soils and riparian zones could influence microbial diversity, nutrient cycling, and carbon-related processes. At the ecosystem scale, V. Nava *et al*. (2024) found that biofouled plastics could alter community structure and functional traits, indicating that the plastisphere played a role in ecological processes rather than functioning as an inert surface. For this reason, the circular economy should be interpreted not merely as an economic model of resource recovery, but as a preventive ecological safety approach. When separate collection, reuse, recycling, extended producer responsibility, and local logistics work effectively, they reduce the probability that plastic waste will enter rivers and interact with biota. Conversely, when circular strategies are evaluated only through resource efficiency indicators, the biological endpoint may remain invisible. This gap is especially problematic for journals and disciplines focused on ecology, biodiversity, and biological systems.

The aim of this study was to identify and characterise the main pathways through which municipal plastic waste may enter riverine ecosystems, synthesise information on biologically relevant receptors and their potential interactions with plastic pollution, and develop a preliminary framework for prioritising ecobiological monitoring. The specific objectives were: (1) to systematise the main potential pathways connecting municipal plastic waste with freshwater and riparian environments; (2) to identify receptor groups and biological endpoints relevant to macroplastic and microplastic exposure; and (3) to demonstrate the calculation and interpretation of the authors-developed Plastic Collection Efficiency Index (PCEI) using two hypothetical municipal collection scenarios and to define monitoring priorities for subsequent field verification of plastic occurrence and possible biological responses.

MATERIALS AND METHODS

The study used a theoretical-analytical design combining a targeted narrative review with an illustrative index-modelling component. It was not designed as a laboratory toxicity experiment or a direct field assessment of biological effects. Instead, the study developed a conceptual ecobiological framework linking municipal plastic-flow control with potential exposure pathways, biologically relevant receptors, and priorities for subsequent field monitoring in riverine and riparian ecosystems. The targeted narrative review drew on publicly accessible peer-reviewed articles, official methodological documents, regulatory acts, and institutional reports identified through targeted online searches and backward reference checking. The search focused primarily on studies published between 2023 and 2025; earlier sources were retained when they provided foundational concepts, established methods, or relevant legal and policy context. Because the review was narrative rather than systematic, no exhaustive database-specific search protocol or quantitative record of identified, screened, and excluded publications was maintained. The principal search terms and their combinations included "river plastic pollution", "riverine macroplastics", "freshwater microplastics", "microplastic transport", "plastisphere", "microplastic macroinvertebrates", "microplastic fish", "soil microorganisms microplastics", "plastic waste circularity", and "plastic waste leakage". Sources were included when they: (1) addressed freshwater, riverine, riparian, sediment, or floodplain environments; (2) examined transport pathways, biological receptors, ecosystem processes, or municipal plastic-waste control; (3) contained a sufficiently described methodology or represented an official methodological or policy document; and (4) were relevant to the pressure – pathway – receptor – response framework. Sources focused exclusively on marine environments without a transferable methodological or conceptual contribution, duplicate publications, non-scientific opinion materials, and publications without sufficient methodological information were excluded. Titles and abstracts were screened first, followed by full-text assessment of potentially relevant sources. The selected evidence was grouped into four thematic categories: environmental pressures, migration pathways, biological receptors, and potential biological or ecosystem responses. The analytical structure followed a pressure – pathway – receptor – response logic adapted to municipal plastic waste in riverine environments. The framework was developed by integrating evidence on riverine transport and remobilisation of plastics, environmental factors controlling microplastic movement, biological quality elements used in freshwater assessment, and documented interactions of plastic particles with freshwater organisms and microbial communities, including studies by E.K. Owowenu *et al*. (2023), European Environment Agency (2024), and A.K. Mora-Teddy *et al*. (2024).

In this framework, pressure is represented by municipal plastic waste generation, incomplete source separation, insufficient collection accessibility, informal dumping, and residual losses from controlled waste systems. Pathways include transport from urban surfaces and drainage channels, riverbank and floodplain remobilisation, fragmentation of macroplastics, sedimentation of microplastics, ingestion, trophic transfer, and colonisation of plastic surfaces by microbial biofilms. Receptors include benthic macroinvertebrates, fish, microbial communities in water and sediments, soil microorganisms in riparian zones, and aquatic or riparian habitats affected by physical obstruction or substrate modification. Responses include organism-level exposure, changes in behaviour or physiological condition, modification of microbial processes, and alteration of habitat structure. These responses are treated as potential endpoints identified from the literature and were not measured directly in any specific Upper Tisza municipality within the present study. To demonstrate the calculation and interpretation of the PCEI without presenting the results as an empirical assessment of named municipalities, two hypothetical municipal collection scenarios were constructed. Scenario A represents a relatively compact territorial community with broad collection coverage but spatially fragmented infrastructure specifically intended for separate plastic-waste collection. Scenario B represents a more territorially dispersed community with lower overall collection coverage but relatively better infrastructure availability in the administrative centre and principal settlements. The component scores were assigned solely for methodological demonstration. They were not derived from municipal records, operator statistics, household surveys, field measurements, or observations from any specific municipality. No calendar-year reference period was assigned to the scenarios. Their purpose is to show how contrasting combinations of collection coverage and infrastructure availability can produce numerically similar composite PCEI values and why such values require direct empirical verification before application to real communities. The illustrative modelling component applied the authors-developed PCEI to two hypothetical municipal collection scenarios. The index was designed to demonstrate an integrated assessment of selected operational characteristics that may influence the capacity of a local collection system to retain plastic waste within organised collection flows. In the present study, the calculated values are methodological examples rather than empirical estimates of actual municipal performance. The index does not measure the quantity of plastic entering watercourses or the biological effects of plastic pollution. The PCEI was calculated using the following weighted additive formula:

$$PCEI = 0.25C + 0.20F + 0.20A + 0.20Y + 0.15I, \quad (1)$$

where C is plastic collection coverage; F is collection service frequency; A is transport accessibility; Y is the per-capita yield of separately collected plastic waste; and I is the availability of collection infrastructure, including containers, stationary collection points, and mobile collection arrangements. Each component was converted to a standardised score of 1.0, 0.7, 0.4, or 0.1, where 1.0 represented the most favourable condition for organised plastic collection and 0.1 represented the weakest condition.

The weighting coefficients were determined using an authors-defined rank-normalisation procedure. Collection coverage received the highest initial rank of 5 because the absence of territorial service coverage directly excludes residents and settlements from organised collection. Service frequency, transport accessibility, and per-capita collected yield each received a rank of 4 because they jointly characterise the operational continuity, logistical feasibility, and practical output of the collection system. Infrastructure availability received a rank of 3 because the presence of containers or collection points alone does not ensure effective collection without regular servicing and transport capacity. The initial ranks of 5, 4, 4, 4, and 3 were divided by their total of 20, producing normalised weights of 0.25, 0.20, 0.20, 0.20, and 0.15, respectively. The weights sum to 1.00. The operational criteria used to assign standardised scores to the five PCEI components are presented in Table 1. The same scoring matrix was applied to both illustrative scenarios.

Table 1. Operational scoring criteria for the PCEI components

Indicator	Score 1.0	Score 0.7	Score 0.4	Score 0.1
Collection coverage (C)	At least 80% of the resident population or settlements covered by organised plastic-waste collection	From 50% to less than 80% covered	From 20% to less than 50% covered	Less than 20% covered or no regular organised service
Service frequency (F)	Weekly or more frequent collection	Two to four collections per month	Monthly or seasonal collection	Irregular or on-demand collection
Transport accessibility (A)	Main serviced settlements accessible by all-season roads and located no more than 15 km from the collection route or transfer point	Moderate accessibility; typical distance of more than 15 km but no more than 30 km	Difficult accessibility; typical distance of more than 30 km but no more than 50 km, or seasonal road limitations	Very difficult accessibility; typical distance of more than 50 km or unstable road access
Per-capita collected plastic yield (Y)	At least 10.0 kg per person per year	From 6.0 to less than 10.0 kg per person per year	From 3.0 to less than 6.0 kg per person per year	Less than 3.0 kg per person per year

Table 1. Continued

Indicator	Score 1.0	Score 0.7	Score 0.4	Score 0.1
Infrastructure availability (I)	Permanent containers or collection points available in most settlements	Infrastructure available in the administrative centre and main settlements	Limited or spatially fragmented collection infrastructure	No permanent plastic-waste collection infrastructure

Note: the thresholds and numerical scores are authors-defined preliminary operational categories developed solely for illustrative PCEI modelling; they are neither statutory service standards nor validated environmental-risk thresholds. No categorical thresholds of low, moderate, or high environmental leakage pressure were applied in this study. Empirical calibration is required before these categories are used for actual municipal assessment
Source: developed by the authors

The four-level scoring scale was selected to distinguish favourable, relatively favourable, constrained, and critically limited collection conditions without implying unsupported numerical precision. The scores of 1.0, 0.7, 0.4, and 0.1 form an equally spaced ordinal scale with increments of 0.30. The upper and lower anchors represent the most and least favourable operational categories, respectively; the lower value of 0.1 denotes critically limited rather than completely absent collection capacity. The percentage, frequency, distance, yield, and infrastructure boundaries presented in Table 1 were defined as provisional operational cut-offs for differentiating contrasting collection scenarios. They were not derived from statutory requirements, measured biological responses, or empirical calibration. These component-level cut-offs should not be interpreted as thresholds of low, moderate, or high environmental leakage pressure. Consequently, they require validation and, where necessary, recalibration before the PCEI is applied to actual municipalities. The component scores were assigned ex ante as hypothetical combinations of collection-system characteristics using the common operational matrix presented in Table 1. Their purpose was not to reproduce actual municipal conditions but to demonstrate the behaviour of the weighted index when collection coverage and infrastructure availability differ between otherwise comparable scenarios. Scenario A was assigned the scores C = 1.0, F = 0.7, A = 0.7, Y = 0.4, and I = 0.4. This combination represents broad hypothetical collection coverage accompanied by spatially fragmented dedicated infrastructure. Scenario B was assigned the scores C = 0.7, F = 0.7, A = 0.7, Y = 0.4, and I = 0.7. This combination represents lower hypothetical coverage but more favourable infrastructure availability in central and principal settlements. Identical scores for service frequency, transport accessibility, and per-capita collected yield were used to isolate the influence of the contrasting C and I components. The component scores and weighted calculations are presented in Table 2.

Table 2. Illustrative component scores and calculation of the PCEI

Illustrative scenario	C	F	A	Y	I	Weighted calculation	PCEI
Scenario A: broader coverage and fragmented infrastructure	1.0	0.7	0.7	0.4	0.4	(0.25 × 1.0) + (0.20 × 0.7) + (0.20 × 0.7) + + (0.20 × 0.4) + (0.15 × 0.4)	0.67
Scenario B: lower coverage and more favourable central infrastructure	0.7	0.7	0.7	0.4	0.7	(0.25 × 0.7) + (0.20 × 0.7) + (0.20 × 0.7) + + (0.20 × 0.4) + (0.15 × 0.7)	0.64

Note: C – collection coverage; F – collection service frequency; A – transport accessibility; Y – per-capita collected plastic yield; I – infrastructure availability. All component scores are hypothetical and were assigned solely to demonstrate the calculation and interpretation of the index. They do not describe any actual municipality and should not be used as municipal performance estimates without verification using documented operational data
Source: developed by the authors

The difference of 0.03 between the illustrative scenarios results solely from the balance between the higher weight assigned to collection coverage and the lower weight assigned to infrastructure availability. Scenario A has a higher C score, whereas Scenario B has a higher I score. Under equal weighting of all five components, both scenarios would produce the same value of

0.64. This sensitivity check demonstrates that the observed difference is a consequence of the selected weighting structure rather than evidence of different environmental leakage, biological risk, or actual municipal performance. No categorical thresholds for low, moderate, or high environmental leakage pressure were applied in the present study. The PCEI was interpreted as a continuous screening indicator of the relative capacity of a municipal collection system to retain plastic waste within organised collection flows. Values closer to 1 indicate more favourable collection conditions according to the five components included in the index, whereas values closer to 0 indicate greater operational limitations. However, a higher or lower PCEI value does not directly quantify the amount of plastic released into the environment, the concentration of plastics in water or sediments, or the magnitude of biological effects. Consequently, the index values were interpreted descriptively and comparatively, without assigning them to environmental-risk classes. Direct field measurements are required to determine whether differences in PCEI correspond to differences in actual plastic leakage or biological exposure.

The biological assessment component was developed as a receptor-and-endpoint matrix through thematic synthesis of the reviewed literature. Benthic macroinvertebrates were included because they are established biological quality elements in freshwater ecological-status assessment and may interact with microplastics through sediment contact, ingestion, and behavioural responses (European Environment Agency, 2024; Mora-Teddy *et al.*, 2024). Fish were included because they integrate direct ingestion, trophic exposure, and organism-level responses reported in microplastic toxicology studies (Banaee *et al.*, 2025). Microbial communities in water and sediments were included because plastic surfaces can support distinct biofilms and influence microbial community structure and ecosystem processes (Nava *et al.*, 2024). Riparian soil microorganisms were included because floodplain and riverbank soils may act as sinks and secondary sources of microplastics, while microbial processes regulate nutrient and carbon cycling (Aralappanavar *et al.*, 2024). Riparian and aquatic habitats were included because macroplastics may modify substrate availability, sediment dynamics, and the physical structure of riverine microhabitats (Russell *et al.*, 2023). The resulting matrix identifies candidate receptors and endpoints for subsequent monitoring; it does not represent biological effects directly measured in any specific municipality. The methodology was based on a conceptual ecobiological synthesis with illustrative index modelling, without laboratory, field, or statistical testing.

RESULTS AND DISCUSSION

Municipal plastic waste as a potential ecobiological pressure

Municipal plastic waste may become a source of ecobiological pressure when it escapes controlled collection and treatment and subsequently enters riverine or riparian environments. This transition is determined not only by waste generation but also by the occurrence of environmental leakage and the exposure of biological receptors. Once released into the environment, plastic materials may persist in habitats, move between environmental compartments, and undergo physical, chemical, and biological transformations. Macroplastic items can entangle organisms, obstruct or cover benthic substrates, accumulate in riparian vegetation, and modify the physical structure of local microhabitats. Fragmentation, abrasion, ultraviolet degradation, and mechanical stress may subsequently generate smaller particles capable of entering the microplastic size range. These mechanisms represent potential exposure pathways identified from previous studies and were not measured directly in any municipality within the present study. The transition from macroplastic items to smaller particles is potentially ecologically relevant because particle size influences mobility, retention, bioavailability, and the probability of interaction with organisms. Large items are generally more visible and may be removed through clean-up operations, whereas smaller particles can be retained in sediments, transported during high-flow events, or ingested by organisms. Experimental research by C.E. Russell *et al.* (2023) has also shown that plastics present in riverbeds can modify natural sediment-transport processes, demonstrating a possible interaction between plastic pollution and riverbed dynamics. These findings provide a conceptual basis for including sediment condition and benthic habitats among the proposed monitoring priorities.

In mountainous and foothill river systems, hydrological variability may increase the mobility and redistribution of improperly managed plastic waste. Periods of low discharge can favour local accumulation on banks, bars, and floodplains, whereas storm events and floods may remobilise deposited material. Evidence that extreme floods amplify riverine plastic transport and deposition supports the inclusion of hydrological conditions in plastic-waste monitoring frameworks (van Emmerik *et al.*, 2023). For municipalities located near rivers, particularly in narrow valleys and transboundary basins, incomplete control of plastic flows may therefore create a potential basin-scale environmental concern. However, the presence and magnitude of such leakage in any specific municipality can only be established through direct field verification. Because the present article is a theoretical-analytical screening study, the receptor matrix presented in Table 3 should be interpreted as a literature-based conceptual synthesis rather than as a statistically tested dataset. Its function is to organise biologically relevant receptors, potential exposure pathways, and candidate endpoints that can guide subsequent field monitoring. The matrix does not document biological effects measured in any specific municipality.

Table 3. Biological receptors and candidate endpoints for monitoring municipal plastic waste pressure

Receptor group	Main exposure pathway	Relevant endpoints	Interpretation for monitoring
Benthic macroinvertebrates	Contact with contaminated sediments; ingestion of particles; habitat obstruction by macroplastics	Taxonomic richness, EPT share, drift response, ingestion frequency, functional feeding groups	Priority group for river bioindication because it links sediment pressure with ecological status
Fish	Ingestion of particles and prey; contact with suspended microplastics and sorbed pollutants	Gut content, condition factor, growth, oxidative stress biomarkers, reproductive indicators	Useful for trophic and organism-level effects, but requires ethical and standardised sampling
Microbial communities in water and sediments	Colonisation of plastic surfaces; changes in organic matter degradation and biofilm structure	Microbial diversity, respiration, extracellular enzyme activity, plastisphere composition	Sensitive to functional ecosystem changes, especially where plastic surfaces become microbial habitats
Riparian soil microorganisms	Deposition of litter and microplastics on floodplains; incorporation into soils	Microbial biomass, nutrient cycling, carbon transformation, community composition	Important for floodplain and riverbank ecosystems that act as secondary sinks of plastics
Riparian and aquatic habitats	Accumulation of macroplastics, sediment modification, shading or physical coverage	Habitat heterogeneity, bank vegetation condition, substrate availability	Links waste leakage with biodiversity-supporting habitat quality

Note: the listed receptors and endpoints represent literature-derived monitoring candidates; their responses were not measured directly in any specific Upper Tisza municipality within the present study and require field validation. EPT – ephemeroptera, plecoptera, trichoptera

Source: developed by the authors based on the freshwater biological-quality assessment framework and studies by C.E. Russell *et al*. (2023), V.K. Aralappanavar *et al*. (2024), A.K. Mora-Teddy *et al*. (2024), V. Nava *et al*. (2024), European Environment Agency (2024), M. Banaee *et al*. (2025)

The pathway from municipal plastic waste to biota can be divided into five linked stages, consistent with the general plastic waste management framework described by N.L. Bhandari *et al*. (2021) and with recent reviews of macroplastic and microplastic transport in riverine systems by L. Gallitelli & M. Scalici (2022) and E.K. Owowenu *et al*. (2023). First, plastic is generated as packaging, household waste, consumer goods, disposable items, and mixed residual waste. Second, if separate collection is incomplete or inconvenient, plastic enters mixed waste containers, informal storage points, street litter, or illegal dumping sites. Third, wind, runoff, drainage systems, and direct human disposal move this material towards rivers and floodplains. Fourth, hydrological processes transport, retain, bury, or remobilise plastic particles. Fifth, biological receptors interact with plastics through physical contact, ingestion, biofilm colonisation, or habitat modification. This pathway-based interpretation is essential because it clarifies why circular economy measures can have biological significance. Deposit-return schemes, accessible collection points, source separation, local sorting, and extended producer responsibility reduce the quantity of plastic available for leakage. Their ecological value is therefore not limited to resource recovery; they operate as upstream controls for biological exposure. This is especially relevant for mountain and border communities where waste can be exported downstream by rivers even when the source is local. Freshwater microplastic governance studies emphasise that monitoring, source reduction, recycling, substitution, and policy coordination should be considered together (Shi *et al*., 2024). In an ecobiological framework, these instruments can be ranked by their capacity to interrupt exposure pathways. Prevention and reuse reduce the initial pressure; separate collection and recycling reduce leakage probability; clean-up activities remove already leaked macroplastics but do not fully address microplastic residues; and biological monitoring detects whether residual pressure is associated with ecosystem response. The biological interactions discussed below are derived from the reviewed literature and represent mechanisms that may be relevant to future monitoring. They should not be interpreted as effects demonstrated in any municipality of the Upper Tisza Basin within the present study.

Potential effects on macroinvertebrates, fish and microbial communities

Macroinvertebrates are among the most relevant organisms for assessing riverine effects of plastic pollution because many taxa live in close contact with sediments and organic detritus. Microplastics may be ingested accidentally during feeding, especially by deposit feeders, filter feeders, and shredders. Experimental and field-oriented research by A.K. Mora-Teddy *et al*. (2024) suggests that microplastics may influence drift behaviour and ingestion patterns in lotic invertebrates, although these effects may be weaker or more context-dependent than those associated with fine sediment. This nuance is important: plastics should not be presented as a universal cause of biodiversity loss in every setting, but as an emerging stressor that may interact with sedimentation, hydromorphology, nutrients, temperature, and chemical pollution. Fish integrate several pathways of exposure. They may ingest particles directly, consume contaminated prey, or experience indirect effects through changes in benthic food resources and habitat structure. M. Banaee *et al*. (2025), in their review of microplastic toxicology in fish, described potential physical damage, inflammatory responses, oxidative stress, immune effects, genetic damage, and reduced growth or reproductive performance under certain exposure conditions.

For river basin management, this means that fish monitoring should not be limited to visual observation of abundance; it may require gut content analysis, condition metrics, and biochemical endpoints where resources and ethical approval permit. Microbial communities represent a less visible but ecologically crucial receptor group. Plastic surfaces in water and sediments become colonised by biofilms, forming the plastisphere. These biofilms can differ from surrounding microbial communities and may influence organic matter processing, nutrient cycling, and microbial dispersal. Large-river research by V. Nava *et al*. (2024) indicates that plastic pollution can affect ecosystem processes, including community structure and functional traits, suggesting that plastics may alter biological functioning beyond their physical presence. Riparian soils and floodplain deposits also require attention. Municipal plastic waste deposited during floods or informal dumping can fragment and enter soils. V.K. Aralappanavar *et al*. (2024) reported that microplastics in soil can alter microbial diversity and functions associated with nutrient and carbon cycling. For river valleys, this creates a link between waste leakage, floodplain ecology, soil processes, and downstream aquatic exposure. Therefore, a complete ecobiological assessment should combine water, sediment, biota, and riparian soil compartments. The illustrative PCEI application produced a value of 0.67 for Scenario A and 0.64 for Scenario B. These values are mathematical outputs of predefined hypothetical component combinations. They do not characterise any named municipality and should not be interpreted as evidence of actual collection performance, environmental leakage, biological exposure, or ecosystem effects. The numerical proximity of the two outputs demonstrates that different operational profiles may produce similar composite values (Table 4).

Table 4. Illustrative interpretation of PCEI scenario outputs and required empirical verification

Illustrative scenario	PCEI value	Methodological interpretation	Environmental meaning	Required empirical verification
Scenario A	0.67	Hypothetical composite value generated from predefined component scores	No direct environmental or biological meaning without verified municipal and field data	Collection coverage, service frequency, collected plastic yield, infrastructure inventory, riverbank litter, and sediment microplastics
Scenario B	0.64	Hypothetical composite value generated from predefined component scores	No direct environmental or biological meaning without verified municipal and field data	Collection coverage, service frequency, collected plastic yield, infrastructure inventory, riverbank litter, and sediment microplastics

Note: the PCEI values are illustrative mathematical outputs and not estimates of actual municipal collection efficiency, plastic leakage, or biological impact. The common verification requirements reflect the methodological purpose of the scenarios and the absence of site-specific operational and environmental data
Source: developed by the authors

Scenario A combines broader hypothetical collection coverage with fragmented infrastructure, whereas Scenario B combines lower coverage with more favourable infrastructure availability in central settlements. Because the two scenarios differ only in the C and I components, they support the same general requirement: composite index values should be disaggregated and verified using actual service records, collected-mass data, infrastructure inventories, and direct environmental measurements before management or monitoring decisions are made. Table 4 presents an illustrative interpretation of the two scenario outputs. Its purpose is not to establish site-specific monitoring priorities but to demonstrate the type of empirical verification required before PCEI can be applied to real municipalities. Because the scenarios are hypothetical and no biological, environmental, or operational municipal measurements were performed, no statistical comparison or environmental-risk classification was applied. Table 4 should therefore be interpreted as a methodological guide for future data collection rather than as an assessment of conditions in the Upper Tisza municipalities.

The potential relevance of municipal plastic waste to biodiversity depends on the occurrence and intensity of environmental leakage, exposure duration, particle characteristics, hydrological connectivity, and the ecological sensitivity of receiving habitats. Plastic waste may represent one of several interacting stressors in urban and modified river channels. In mountain streams, tributaries, floodplain wetlands, and riparian zones, its ecological relevance may vary according to habitat condition, flow regime, substrate structure, and the presence of other pressures. Therefore, the same quantity of plastic waste may have different ecological implications in different receiving environments. The present study does not quantify these relationships but identifies factors that should be considered during subsequent field verification. Benthic macroinvertebrates may be considered a priority receptor group for subsequent bioindication because they are widely used in freshwater ecological-status assessment and respond to changes in substrate, oxygen conditions, organic matter, sediment quality, and hydromorphology. Microplastic sampling may be combined with conventional macroinvertebrate assessment by collecting sediment and biological samples at the same sites. However, any observed association should be interpreted cautiously. Changes in macroinvertebrate communities near waste-accumulation sites may also be related to wastewater discharge, nutrient enrichment, channel modification, fine-sediment deposition, temperature, or hydrological stress. Consequently, a field study should include reference sites and measurements of major co-occurring pressures before plastic waste is considered a plausible explanatory factor.

Fish may provide supplementary information on organism-level and trophic exposure, but their inclusion in the initial monitoring programme should be carefully justified. Where fish assessment is feasible, non-lethal approaches, opportunistic examination of legally obtained specimens, or integration with existing fisheries-monitoring programmes may reduce ethical and logistical constraints. Gut-content screening can be combined with species identification, body length, body mass, and condition metrics. Biochemical or reproductive biomarkers should be included only where adequate laboratory capacity, quality assurance, sample size, and ethical or legal permissions are available. Such indicators are proposed for future validation and were not assessed in the present study. Microbial indicators may complement organism- and habitat-based monitoring by characterising biological processes associated with plastic surfaces, sediments, and riparian soils. Plastisphere composition, microbial respiration, extracellular enzyme activity, and community structure are potential indicators of whether plastic particles function as biologically active substrates. In riparian soils, microbial measurements may help assess changes in nutrient and carbon cycling in areas where plastics accumulate or fragment. However, microbial responses are influenced by numerous environmental factors and cannot be attributed to plastic pressure without suitable reference samples, contamination controls, and measurements of relevant physicochemical variables. Overall, the proposed bioindication priorities represent a tiered set of candidate measurements rather than a confirmed causal assessment scheme. Macroinvertebrates and habitat condition may form the initial monitoring tier, while fish and advanced microbial endpoints may be added where preliminary environmental measurements confirm the presence of plastic contamination and sufficient analytical capacity is available.

Circular economy measures as potential upstream controls

The ecobiological interpretation proposed in this study does not replace conventional circular economy analysis but extends it by considering the potential environmental consequences of uncontrolled plastic flows. Circular economy policy is commonly structured around prevention, reuse, separate collection, recycling, resource efficiency, and reduction of residual waste streams (Geissdoerfer *et al.*, 2017; European Commission, 2020). Within the proposed framework, these measures are treated as potential upstream controls because they may reduce the quantity of plastic available for environmental leakage. However, the present study did not measure changes in riverine plastic abundance or biological responses following the implementation of such measures. Their ecological effectiveness therefore requires verification through comparative monitoring before and after intervention or between appropriately selected reference and intervention sites. Extended producer responsibility may support improved control of plastic flows when it finances collection, sorting, public communication, and take-back systems (OECD, 2016; Tumu *et al.*, 2023).

Deposit-return systems may similarly reduce the probability that beverage containers remain outside organised collection, although their local environmental effect depends on system coverage, return rates, accessibility, and enforcement. Pay-as-you-throw and other charging schemes may encourage waste prevention and source separation, but their design should account for possible unintended consequences, including illegal dumping or unequal access to services, as noted by G. Di Foggia & M. Beccarello (2023). In the conceptual framework developed here, these instruments are regarded as potential source-control measures rather than interventions whose biological effectiveness has already been demonstrated in the Upper Tisza Basin. In Ukraine, the waste hierarchy established by the Law of Ukraine No. 2320-IX (2022) and the Order of the Cabinet of Ministers of Ukraine No. 1353-r (2024) provide a policy basis for strengthening prevention, separate collection, recovery, and monitoring. For river-basin communities, implementation may be complemented by indicators that characterise the degree of plastic-flow control, the presence of waste outside organised systems, and the condition of receiving environments. This is particularly relevant in the Upper Tisza Basin, where hydrological connectivity creates the possibility that locally released plastic waste may be transported beyond municipal and national boundaries. The present study does not quantify such transboundary transport but identifies it as a priority for subsequent field investigation and coordinated monitoring. A practical implication of the proposed framework is that municipal waste planning may be complemented by environmental verification indicators. These may include the location of waste-accumulation points relative to watercourses, standardised riverbank-litter density, the condition and servicing frequency of collection infrastructure, microplastic abundance in sediments, habitat characteristics, and selected biological indicators. Such measurements would make it possible to test whether limitations identified through PCEI correspond to observable plastic contamination or biological exposure. Until these relationships are empirically verified, municipal collection indicators and ecobiological indicators should be interpreted as connected but methodologically distinct evidence streams.

A staged monitoring framework is recommended for municipalities where direct biological data are not yet available. Stage 1 should map pressure sources: container coverage, informal dumping points, drainage outlets, riverbank litter, floodplain deposits, and high-risk zones near markets, bridges, schools, transport nodes, and recreational areas. Stage 2 should quantify environmental compartments: macroplastic item density on riverbanks, microplastic abundance in sediments, and, where feasible, particles in surface water. Stage 3 should add biological receptors: macroinvertebrate community composition, selected fish indicators, microbial activity in sediments and soils, and riparian habitat condition. Quality assurance is essential because microplastic sampling is vulnerable to contamination and methodological inconsistency. Laboratory procedures should use procedural blanks, contamination control, particle-size definitions, and polymer verification where possible. Established methodological guidance, including laboratory of the National Oceanic and Atmospheric Administration recommendations, emerging standardised methods for microplastic analysis, and sample-specific protocols for freshwater, sediment, and fish matrices, can help improve comparability (Masura *et al.*, 2015; Vural *et al.*, 2025). For initial local studies, even a limited but well-documented protocol is preferable to broad claims based on unverified observations. The minimum dataset for a future empirical article should include: sampling coordinates; date and hydrological conditions; number of sediment or water samples; macroplastic density per unit area of riverbank; microplastic abundance per kilogram of dry sediment or per cubic metre of water; macroinvertebrate metrics; and at least one habitat-quality descriptor. If fish are included, the dataset should specify species, sample size, body length, weight, gut-content procedure, and ethical or legal basis for sampling. These data would allow statistical comparison among sites with contrasting observed plastic occurrence, collection-system conditions, and environmental characteristics and would provide the empirical basis required to examine possible relationships between municipal plastic-flow control and biological indicators.

Ecological mechanisms linking plastic leakage and biodiversity change

Plastic waste may influence biodiversity through several mechanisms that operate at different spatial and biological scales. At the habitat scale, macroplastics can cover stones, gravel, coarse particulate organic matter, and marginal vegetation. Such physical coverage may reduce habitat availability for benthic invertebrates and alter the distribution of refugia used by juvenile fish. In small mountain streams, where habitat mosaics are spatially limited, even local accumulation can modify the microhabitat structure that supports sensitive taxa. At the organism level, ingestion is the most direct pathway. Microplastic particles may be consumed because they resemble food particles, are attached to biofilms, or are trapped in organic matter. The ecological significance of ingestion depends on particle size, shape, polymer, concentration, and residence time in the digestive tract. Fibres, fragments, films, and foams can differ in their physical behaviour. Therefore, future field studies should report particle morphology and polymer type rather than only total particle counts. At the community level, plastics can act as artificial substrates. The plastisphere may support microbial assemblages that differ from natural biofilms on stones, wood, or sediment. These assemblages can influence nutrient cycling, organic matter processing, and microbial dispersal. The concern is not only the presence of bacteria on plastics, but the possibility that persistent anthropogenic substrates alter the spatial structure of microbial habitats in rivers and floodplains. At the ecosystem level, plastic pollution may interact with existing stressors. Nutrient enrichment can increase biofilm growth on plastics; hydromorphological alteration can enhance retention zones; floods can remobilise buried litter; and chemical contaminants can sorb to polymer surfaces. As a result, biodiversity responses to plastic waste are unlikely to be linear. The same observed plastic load may have different biological relevance in a sensitive tributary and a heavily modified channel because ecological vulnerability and co-occurring pressures differ among habitats.

The PCEI describes selected operational characteristics of municipal plastic-waste collection, including service coverage, collection frequency, transport accessibility, separately collected yield, and infrastructure availability. It does not evaluate the full circularity of plastic materials and does not directly measure environmental leakage, ecological status, or biological effects. Its role in the present framework is limited to identifying potential weaknesses in organised plastic-flow control that may justify targeted environmental verification. Accordingly, PCEI should be interpreted together with direct environmental and biological measurements rather than as a substitute for them.

A staged verification chain is proposed. First, municipal collection indicators, including PCEI and its individual components, characterise the capacity of the organised system to collect and retain plastic waste. Second, direct environmental indicators document whether plastic is present outside the controlled system, for example through standardised riverbank-litter counts, macroplastic density, or microplastic abundance in water and sediments. Third, exposure and biological indicators may include particles detected in organisms, macroinvertebrate community metrics, fish condition or gut-content data, microbial functional measurements, and habitat-condition descriptors. Fourth, the interpretation stage compares these evidence levels while accounting for wastewater discharge, nutrients, hydromorphological modification, sedimentation, land use, and hydrological variability. Only this combined approach can test whether limitations in municipal collection are associated with observable environmental contamination or biological responses.

This staged approach helps avoid two methodological errors. The first is to assume that favourable municipal collection indicators automatically demonstrate low environmental contamination or improved biodiversity status. Collection efficiency may reduce the probability of uncontrolled waste accumulation, but its environmental effect must be tested directly. The second error is to attribute biological degradation observed near waste-accumulation sites exclusively to plastic pollution. Riverine ecosystems are exposed to multiple interacting pressures, and causal interpretation requires reference sites, measurements of co-occurring stressors, adequate replication, and appropriate statistical analysis. In the proposed framework, PCEI is therefore an initial screening tool for directing field investigation, not evidence of ecological condition or causality. The proposed framework therefore separates three analytically distinct levels: municipal collection performance, environmental occurrence of plastic, and biological exposure or response. Relationships between these levels remain hypotheses until they are tested using spatially and temporally matched field data. Maintaining this distinction is essential for preventing collection-system characteristics from being interpreted as direct evidence of environmental or biological condition.

Implications for mountainous and transboundary river basins

Mountainous and transboundary river basins require a specific interpretation because plastic released into watercourses may produce both local and downstream consequences. In narrow valleys, settlements, roads, drainage systems, and river channels are often spatially connected, reducing the distance between municipal plastic-waste sources and aquatic environments. During heavy rainfall, snowmelt, and flood events, plastic accumulated on banks, slopes, floodplains, or informal disposal sites may be mobilised and transported downstream. The probability and distance of transport depend on waste characteristics, topography, hydrological connectivity, discharge conditions, and retention within channel and floodplain environments (Owowenu *et al.*, 2023; van Emmerik *et al.*, 2023). The Upper Tisza is a transboundary river system in which plastic waste transported from upstream areas may cross administrative and national borders and accumulate in downstream river reaches, sediments, floodplains, and riparian zones. A. Balla *et al.* (2024) documented plastic contamination in the Tisza River and mismanaged plastic waste along Carpathian watercourses, respectively, supporting the relevance of basin-scale and internationally coordinated monitoring.

The present study did not quantify the contribution of any specific municipality to transboundary plastic transport. Nevertheless, the hydrological connectivity of settlements within the Upper Tisza River network makes the prevention of local plastic leakage relevant to downstream and cross-border environmental safety. For small municipalities with limited laboratory resources, the first practical step should be a low-cost monitoring package: mapping of visible plastic accumulation points, standardised photographic documentation, item counting by riverbank segment, and basic habitat description. The second step should add sediment microplastic screening in cooperation with a university laboratory. The third step should include macroinvertebrate sampling using nationally or internationally compatible bioindication methods. This staged approach is more realistic than immediate implementation of a full laboratory programme in every community. Transboundary cooperation is necessary for distinguishing locally generated plastic pollution from material transported from upstream parts of the basin. Comparable protocols applied across upstream and downstream sites can support the identification of accumulation zones, temporal changes, and possible source areas. Monitoring should account for hydrological conditions, particularly flood events, because plastic deposited at one location may subsequently be remobilised and transported across municipal or national boundaries. Accordingly, prevention of plastic leakage in upstream communities should be regarded as a component of downstream and transboundary environmental protection, while source attribution requires coordinated spatial sampling and hydrological interpretation.

For field validation of the proposed framework, a comparative design should include three to five river or stream sites representing contrasting municipal collection conditions and directly observed plastic occurrence. The site network should include at least one reference site with no visible waste accumulation and limited nearby municipal pressure, one or more sites near settlements or collection infrastructure, and at least one site near a documented accumulation zone, drainage outlet, or informal dumping location. Site classification should be based on preliminary field reconnaissance and standardised observations rather than on PCEI values alone. Sampling should be conducted during the same hydrological season and, where possible, repeated under comparable low-flow and post-flood conditions to reduce seasonal and hydrological bias. For each site, the minimum environmental dataset should include coordinates, date, river width, approximate flow conditions, substrate type, bank condition, nearby waste sources, and macroplastic item density along a standardised bank transect. Sediment samples should be collected from comparable depositional zones and analysed for microplastic abundance using contamination-control procedures. Results should be reported as particles per kilogram of dry sediment, with size classes and particle morphology where possible. The biological dataset should include benthic macroinvertebrate taxa identified at the lowest feasible taxonomic level. At a minimum, the study should report total richness, abundance, EPT taxa or an equivalent sensitivity indicator, and the relative share of tolerant groups. If resources allow, selected specimens can be examined for ingested particles, but this should be done using a transparent digestion and visual or spectroscopic identification protocol. Fish data are useful but not essential for the first field paper; if included, they should follow ethical and legal requirements. For riparian soils, a small number of composite samples near accumulation zones and reference zones could provide valuable information on the terrestrial component of leakage. Microbial biomass, respiration, or enzyme activity would strengthen the biological argument, but even a documented soil microplastic screening would improve the empirical basis. Such a dataset would transform the proposed risk-screening synthesis into a direct ecobiological field assessment. Until such field sampling is completed, the framework should be interpreted as a preliminary prioritisation tool. Adding a pilot dataset on plastic occurrence and biological receptors would allow future research to examine relationships between municipal collection conditions, measured environmental plastic occurrence, biodiversity indicators, and ecosystem functioning.

CONCLUSIONS

This study developed a conceptual ecobiological screening framework that links municipal plastic-waste collection conditions with potential environmental pathways, biologically relevant receptors, and priorities for subsequent field monitoring in riverine and riparian ecosystems. The literature synthesis indicates that improperly managed plastic waste may be transported into watercourses, retained in sediments and floodplains, fragmented into smaller particles, and interact with organisms and microbial communities. These mechanisms were identified from previous studies and were not measured directly in any specific Upper Tisza municipality within the present study. The authors-developed PCEI integrates collection coverage, service frequency, transport accessibility, per-capita collected plastic yield, and infrastructure availability. Its illustrative application produced values of 0.67 for Scenario A and 0.64 for Scenario B. These mathematical outputs show that different hypothetical scenarios can produce similar composite scores and should not be interpreted as empirical evidence of environmental conditions. The small difference reflects the selected weighting structure, while both scenarios require empirical verification through collection data, litter surveys, sediment microplastic analysis, habitat assessment, and benthic macroinvertebrate monitoring. Fish, microbial, and riparian-soil indicators may be added where direct evidence of plastic occurrence and sufficient analytical capacity are available. Circular economy and waste-management instruments, including prevention, separate collection, accessible infrastructure, extended producer responsibility, deposit-return systems, and local sorting, may function as upstream controls by reducing the amount of plastic available for environmental release. However, their environmental and biological effectiveness in the Upper Tisza Basin requires empirical verification. This study has several limitations. The PCEI values are hypothetical and do not represent empirical municipal estimates, while the authors-defined weights and scoring categories remain unvalidated. The index does not measure actual plastic leakage, environmental concentrations, biological exposure, toxicity, or biodiversity degradation, and no direct field sampling was conducted. The receptor-and-endpoint matrix also requires validation under Upper Tisza conditions, particularly given the influence of multiple co-occurring riverine stressors. Future research should therefore integrate municipal collection data with direct plastic measurements, biological monitoring, hydrological conditions, reference sites, and appropriate spatial, temporal, and statistical analyses. The framework should be viewed as a tool for prioritising field investigation rather than evidence of causal relationships.

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None.

REFERENCES

[1] Aralappanavar, V.K., *et al*. (2024). Effects of microplastics on soil microorganisms and microbial functions in nutrients and carbon cycling – a review. *Science of the Total Environment*, 924, article number 171435. doi: 10.1016/j.scitotenv.2024.171435.

[2] Balla, A., Teofilovic, V., & Kiss, T. (2024). Microplastic contamination of fine-grained sediments and its environmental driving factors along a lowland river: Three-year monitoring of the Tisza River and Central Europe. *Hydrology*, 11(1), article number 11. doi: 10.3390/hydrology11010011.

[3] Banaee, M., Multisanti, C.R., Impellitteri, F., Piccione, G., & Faggio, C. (2025). Environmental toxicology of microplastic particles on fish: A review. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, 287, article number 110042. doi: 10.1016/j.cbpc.2024.110042.

[4] Bhandari, N.L., Bhattarai, S., Bhandari, G., Subedi, S., & Dhakal, K.N. (2021). A review on current practices of plastics waste management and future prospects. *Journal of Institute of Science and Technology*, 26(1), 107-118. doi: 10.3126/jist.v26i1.37837.

[5] Di Foggia, G., & Beccarello, M. (2023). Designing circular economy-compliant municipal solid waste management charging schemes. *Utilities Policy*, 81, article number 101506. doi: 10.1016/j.jup.2023.101506.

[6] European Commission. (2020). *A new Circular Economy Action Plan: For a cleaner and more competitive Europe. (COM/2020/98 final)*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0098.
[7] European Environment Agency. (2024). *Water Framework Directive – quality elements*. Retrieved from https://surl.li/lhkwmq.
[8] Gallitelli, L., & Scalici, M. (2022). Riverine macroplastic gradient along watercourses: A global overview. *Frontiers in Environmental Science*, 10, article number 937944. doi: 10.3389/fenvs.2022.937944.
[9] Geissdoerfer, M., Savaget, P., Bocken, N.M.P., & Hultink, E.J. (2017). The circular economy – a new sustainability paradigm? *Journal of Cleaner Production*, 143, 757-768. doi: 10.1016/j.jclepro.2016.12.048.
[10] Kaza, S., Yao, L.C., Bhada-Tata, P., van Woerden, F., & Levine, D. (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050*. Washington, DC: World Bank. doi: 10.1596/978-1-4648-1329-0.
[11] Law of Ukraine No. 2320-IX "On Waste Management". (2022, June). Retrieved from https://zakon.rada.gov.ua/laws/show/2320-20#Text.
[12] Masura, J., Baker, J.E., Foster, G.D., & Arthur, C. (2015). Laboratory methods for the analysis of microplastics in the marine environment: Recommendations for quantifying synthetic particles in waters and sediments. In *NOAA Technical Memorandum NOS-OR&R-48*. Silver Spring, MD: National Oceanic and Atmospheric Administration.
[13] Mora-Teddy, A.K., Closs, G.P., & Matthaei, C.D. (2024). Microplastics and riverine macroinvertebrate communities in a multiple-stressor context: A mesocosm approach. *Science of the Total Environment*, 951, article number 175456. doi: 10.1016/j.scitotenv.2024.175456.
[14] Nava, V., *et al*. (2024). Plastic pollution affects ecosystem processes including community structure and functional traits in large rivers. *Water Research*, 259, article number 121849. doi: 10.1016/j.watres.2024.121849.
[15] OECD. (2016). *Extended producer responsibility: Updated guidance for efficient waste management*. Paris: OECD Publishing. doi: 10.1787/9789264256385-en.
[16] Order of the Cabinet of Ministers of Ukraine No. 1353-r "On Approval of the National Waste Management Plan until 2033 and Recognition of Certain Acts as Invalid". (2024, December). Retrieved from https://zakon.rada.gov.ua/laws/show/1353-2024-%D1%80#Text.
[17] Owowenu, E.K., Nnadozie, C.F., Akamagwuna, F., Noundou, X.S., Uku, J.E., & Odume, O.N. (2023). A critical review of environmental factors influencing the transport dynamics of microplastics in riverine systems: Implications for ecological studies. *Aquatic Ecology*, 57, 557-570. doi: 10.1007/s10452-023-10029-7.
[18] Russell, C.E., Fernández, R., Parsons, D.R., & Gabbott, S.E. (2023). Plastic pollution in riverbeds fundamentally affects natural sand transport processes. *Communications Earth & Environment*, 4, article number 255. doi: 10.1038/s43247-023-00820-7.
[19] Shi, Y., Chen, W., Yang, S., Fan, Y., & Lu, L. (2024). Freshwater microplastics governance and sustainable development: Pollution status, interactions, policies, and prospective studies. *Desalination and Water Treatment*, 320, article number 100704. doi: 10.1016/j.dwt.2024.100704.
[20] Tumu, K., Vorst, K., & Curtzwiler, G. (2023). Global plastic waste recycling and extended producer responsibility laws. *Journal of Environmental Management*, 348, article number 119242. doi: 10.1016/j.jenvman.2023.119242.
[21] van Emmerik, T.H.M., Frings, R.M., Schreyers, L.J., Hauk, R., de Lange, S.I., & Mellink, Y.A.M. (2023). River plastic transport and deposition amplified by extreme flood. *Nature Water*, 1, 514-522. doi: 10.1038/s44221-023-00092-7.
[22] Vural, T., Çetinkaya, S., Yeğen, V., Şapçıoğlu, S., & Gündoğdu, S. (2025). Protocol for extraction and analysis of microplastics in freshwater, sediment, and fish samples. *STAR Protocols*, 6(3), article number 104057. doi: 10.1016/j.xpro.2025.104057.

Концептуальний екобіологічний скринінг тиску муніципальних пластикових відходів на річкові екосистеми

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Анотація. Муніципальні пластикові відходи не лише становлять управлінську або технологічну проблему, а й є потенційним джерелом екобіологічного тиску на річкові та прибережні екосистеми. Недостатнє роздільне збирання, неконтрольоване накопичення та фрагментація пластикових матеріалів здатні сприяти надходженню макро- та мікропластику до прісноводних екосистем, де вони можуть взаємодіяти з макробезхребетними, рибами, мікробними угрупованнями, донними відкладами, ґрунтами та прибережними оселищами. Метою роботи було систематизувати потенційні шляхи надходження муніципальних пластикових відходів до річкових екосистем, узагальнити можливі механізми їх взаємодії з біотою та розробити попередню концептуальну рамку для визначення пріоритетів екобіологічного моніторингу. Застосовано теоретико-аналітичний підхід, який поєднував цільовий наративний огляд сучасних наукових джерел, рамку «тиск – шлях міграції – рецептор – відповідь» та ілюстративне застосування розробленого авторами індексу ефективності збирання пластикових відходів для двох умовних сценаріїв організації муніципального збирання. Узагальнення наукових джерел показало, що муніципальні пластикові відходи можуть взаємодіяти з біотою через фізичне засмічення оселищ, ковтання частинок, перенесення пов’язаних із ними забруднювачів, формування пластисфери та зміну мікробних процесів у воді, донних відкладах і ґрунтах. Ілюстративне застосування індексу до двох умовних сценаріїв дало значення 0,67 і 0,64 та продемонструвало, як різні поєднання охоплення послугою й доступності інфраструктури впливають на інтегральну оцінку. Ці сценарні значення не характеризують конкретні громади та не вимірюють фактичні витоки пластику, його концентрації у водному середовищі, біологічну токсичність або деградацію біорізноманіття. У роботі запропоновано концептуальну екобіологічну рамку для визначення пріоритетів роздільного збирання, локального моніторингу мікропластику, оцінювання донних відкладів, біоіндикації та подальшої польової верифікації в річкових басейнах, що зазнають тиску муніципальних пластикових відходів

Ключові слова: макробезхребетні; пластисфера; донні відклади; біоіндикація; заплави