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The Current Situation and Future of Marine Microplastics: A Comprehensive Review

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Abstract: Microplastic pollution has emerged as a major environmental issue in recent decades. Thompson (2004) introduced the concept of "microplastics" (< 5 mm), a term now widely recognized to describe ubiquitous pollutants formed through the weathering and degradation of larger plastic items. Millions of tons of plastic enter the oceans annually, posing threats to marine ecosystems and human health. Microplastic concentrations in some regions are projected to double by 2030, yet research continues to face methodological and conceptual challenges that hinder the development of effective solutions.

Keywords: Microplastic; Marine pollution; Ocean ecosystem; Microplastic capture

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1. Introduction

As early as the 1970s, Carpenter et al.'s research discovered the widespread presence of microplastics on the sea surface of the Sargasso Sea [1]. This did not draw the researchers' attention to Marine microplastics. However, it was not until 2001 when Moore et al. discovered a substantial quantity of microplastics in the North Pacific and estimated a plastic abundance as high as 330,000 pieces/km^2 that people began to recognize the severity of microplastic pollution [2]. In 2004, Professor Thompson from the University of Plymouth in the UK first introduced the concept of "microplastics" in his research to describe small-sized (< 5 mm) plastic debris [3]. Won et al. further investigated microplastics in the ocean, providing important insights into their distribution and potential environmental impacts [4].

Since the onset of commercial production around 1950, the reliance on plastic products has been escalating. Although most plastic products are utilized and discarded on land [5], due to physical weathering, chemical degradation, and biological degradation of larger plastic items, along with the production and application of small plastic particles, microplastics are generated and a significant portion of them enters the ocean, posing threats to the marine ecological environment and humanity itself [6]. It is estimated that millions of tons of plastic flow into the ocean each year [7]. Simultaneously, it is anticipated that by 2030, the quantity of microplastics in some oceanic areas will double. At the same time, current research on microplastics has also encountered some problems.

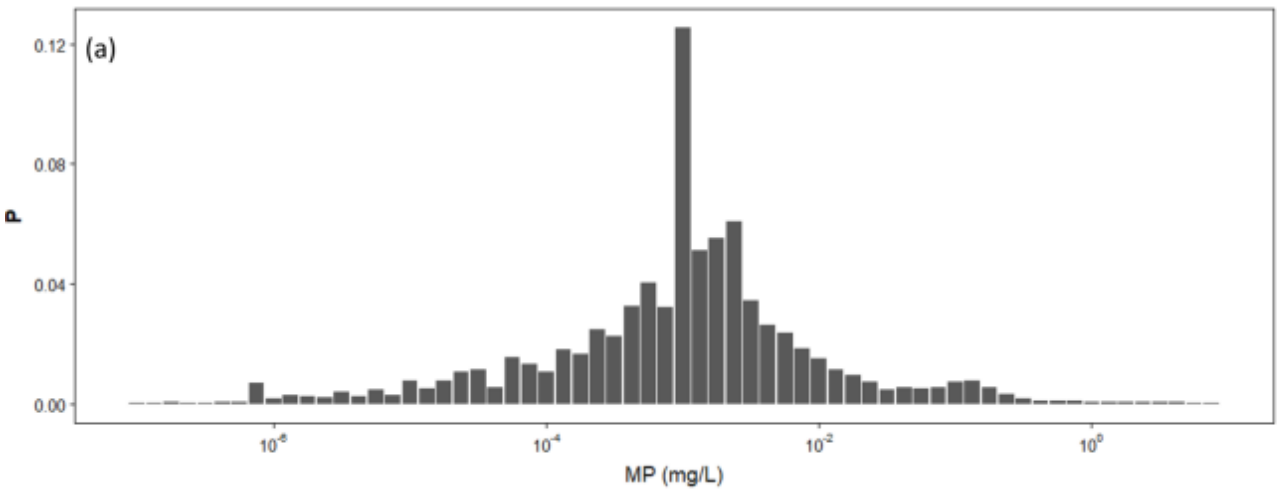

Figure 1. Probability (P) distribution of microplastic density (MP, mg/L in log scale) in seawater from all data reviewed. The 0 mg/L values were excluded. (From Ricardo Beiras & Alexandre M. Schönemann [7]).

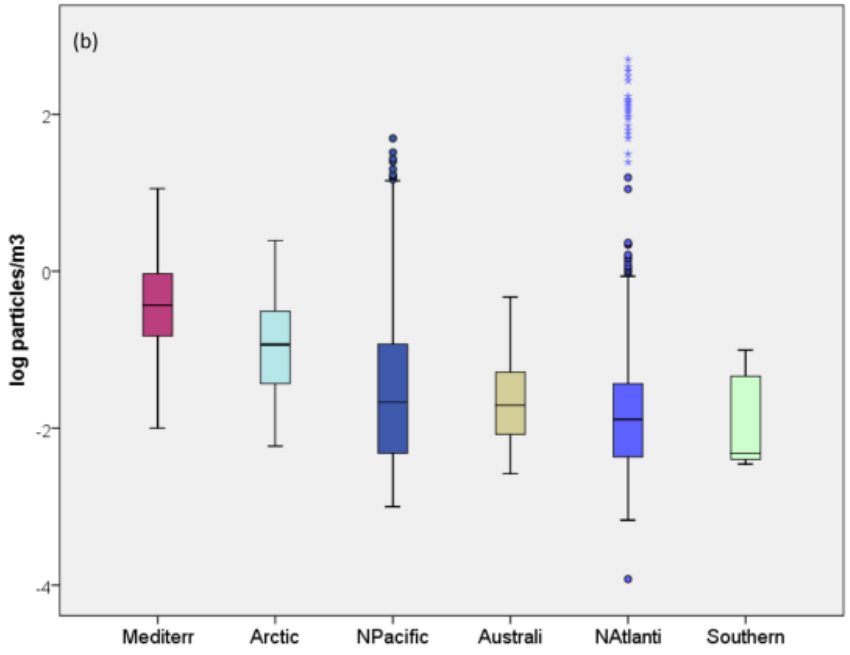

Figure 2. MP density (log particles/m^3) in the different oceans sampled ordered from left to right by decreasing median. Horizontal line: median; box boundaries: 25th and 75th percentiles; bars: range of observed values; dots and asterisks: potential outliers. (From Ricardo Beiras & Alexandre M. Schönemann [7]).

2. Project objectives

Owing to the influence of factors such as wind and ocean currents in the marine environment, microplastics can be transported over long distances, leading to their wide dissemination in the marine environment and causing issues in sample collection. Concurrently, current research on microplastics still encounters numerous challenges, and the following problems exist:

(1) This large-scale distribution causes considerable difficulties in sample collection, as plastic fragments are often unevenly concentrated in surface waters, sediments, and biological tissues.

(2) Due to the limitations of microplastic identification techniques, the currently available data can only represent a

minor portion of the marine environment.

(3) The continuous alterations in the morphology and composition of plastic debris under the influence of UV radiation, external forces, and biological interactions further complicate detection.

(4) As marine microplastics is a relatively nascent field, global spatial data is incomplete, resulting in the near non-existence of baseline values for comparison.

(5) Relevant research data is deficient, particularly concerning the collection methods of small particle sizes.

The review aims to conduct a comprehensive analysis of the problems encountered in the study of marine microplastics.

3. Significance of the object

Collect relevant data and articles for comprehensive analysis, which can help us understand the problems encountered in the current research field and explore solutions. Conducting such integrative reviews also enables researchers to identify methodological gaps, compare different analytical approaches, and evaluate the reliability of existing data across regions. This process deepens our knowledge of microplastic pollution and provides a scientific basis for developing standardized monitoring protocols and supporting policy decisions aimed at mitigating environmental impacts.

4. State of art

The main methods for collecting seawater samples of microplastics include trawl sampling, pump sampling, and water collection sampling [8]. The trawl sampling often employs plankton trawls with apertures of approximately 330 μm, but the pore sizes of the trawl nets used in current studies range from 200 μm to 500 μm. The filter membranes and silk screens utilized in the pump sampling and water collection container sampling also have pore diameters ranging from 0.20 μm to 600 μm. Compared to the other two methods, trawl sampling offers the advantages of large sample volume and high efficiency, but the stability of the sampling results is rather poor. Additionally, due to the large mesh size, the content of smaller-sized microplastics with greater biological significance is more prone to being overlooked. The pump sampling method has the advantages of large water intake and convenient silk screen replacement, but it involves excessive energy consumption and cannot be employed in certain exceptional circumstances. The water collection container sampling method is straightforward in operation; however, due to the small water intake, the representativeness of the sample results is inadequate and is often used to study the vertical distribution of microplastics in seawater.

Fourier Transform Infrared Spectroscopy is one of the prevailing superior techniques for identifying microplastics. Large particles with a particle size ≥ 300 μm can be detected using the conventional FTIR “attenuated total reflection” (ATR) mode, and the analysis can be completed within one minute with high precision. For smaller particles within the range of 20-300 μm, micro-Fourier Transform Infrared Spectroscopy (μ-FTIR) can be employed for analysis [9]. μ-FTIR combines Fourier Transform Infrared Spectroscopy with traditional optical microscopy. Typically, the samples are visually inspected initially, and then the regions of interest on the samples are selected for chemical analysis or identification. It is a highly straightforward “idiot-proof” approach. Meanwhile, Kosuke et al. [10] constructed a palm-sized long-wave infrared hyperspectral camera, which reduces the analysis time and study costs. At the same time, it improved its operability. The long-wave infrared (LWIR) band can effectively distinguish dark-colored plastics. This system uses a common and inexpensive microbolometer for the long-wave infrared band. Plastic polymers have characteristic Raman spectra, and the polymer components can be identified by comparison with the reference spectral library, which is highly reliable. In the past two years, microscopic Raman spectroscopy has been successfully applied for the identification of microplastics in different environmental samples and is the preferred method for identifying small microplastics (< 20 μm). However, its use has not been widely popularized because of the long measurement time and the spectral distortion easily caused by fluorescence. Spectral analyses such as pyrolysis gas chromatography mass spectrometry, and energy dispersive

X-ray spectroscopy are also commonly used for the collection, processing, and interpretation of data from microplastic samples. The number of MPs tends to increase with the decrease in size, leading to possible misidentification during visual recognition. Pyrolysis combined with gas chromatography/mass spectrometry (Py-Gc/MS) is used to obtain information on polymer components and has some applications in the identification of MPs. Ludovic et al. made supplements to μ-Raman spectroscopy because Py-GC/MS will identify all pigments containing plastic particles as plastics, and some fibers and all particles from sediment and sea surface will be identified as plastics.

5. Justification for tackling specific scientific problems by the proposed project

5.1. Data comparability and methodological standardization

The non-uniform distribution of microplastics in the marine environment and the diversity of research objectives make it difficult to apply a standardized sampling method in marine investigations. Corresponding standardized sampling methods should be established based on different investigation targets, and the comparability of data obtained under different sampling methods should be enhanced. At the same time, establishing standard separation and detection analysis methods is also an important task in the research of marine micro-nano plastics. The advantages and disadvantages of different methods should be balanced, and standard separation and detection analysis methods for plastic particles of different particle sizes should be developed and established. Parameters for quantifying and characterizing the abundance and characteristics of micro-nano plastics should be unified to improve the accuracy and comprehensiveness of marine plastic pollution monitoring and reporting. Different standard methods can be established for routine monitoring and scientific research, but attention must be paid to the possible differences brought about by different methods.

5.2. Ecological risk assessment

Build ecological toxicology research methods and quantitative characterization systems of micro-nano plastics with environmental concentrations and characteristics. Given that microplastics in the marine environment are in a dynamic state, laboratories can start from studying the process from marine plastic waste to small-sized microplastics and nano plastics of all levels, achieve the estimation of the stock of marine micro-nano plastics based on plastic waste emissions, and thereby improve the ecological risk effect model of micro-nano plastics of different particle sizes.

5.3. International cooperation

The cross-border pollution characteristics of marine microplastics have gradually transformed it from a local environmental issue into a complex international environmental issue that requires the attention of all countries globally. Currently, the international community is actively promoting the formulation of globally binding action plans for the control of marine plastic waste and microplastic pollution. Each country should take the initiative to strengthen collaboration with neighboring countries in the governance of marine microplastic pollution, study and formulate regional action plans for the monitoring and control of marine microplastic pollution, and jointly strive to achieve the goal of sustainable development.

5.4. Policy research

During the side event of the United Nations Ocean Conference held in June 2022, representatives generally agreed that actions should be taken on the issue of marine debris and microplastics. The resolution of the issue of marine microplastics ultimately relies on the implementation of relevant policies and regulations by countries around the world. Currently, the international community has not yet carried out legislation related to marine microplastics. Each country should clarify the focus of marine microplastic governance based on fully summarizing the current situation of marine microplastic pollution, study relevant policies and establish related mechanisms. As a major maritime and industrialized country.

6. Research methodology

6.1. Sample collection

(1) Trawl sampling

(2) pump sampling

(3) water container sampling

6.2. Sample pretreatment

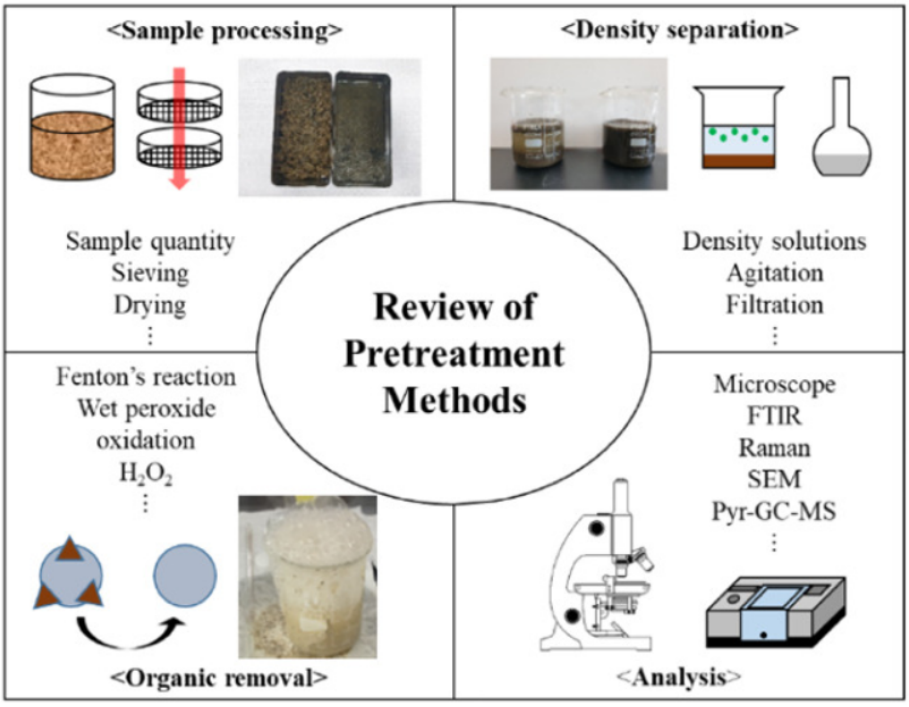

Figure 3. Review of pretreatment methods (From Lee et al. [11]).

6.3. Sample analysis

6.3.1. Microplastics in water samples

This method can be used to analyze plastic debris as suspended solids in water samples collected through surface nets, including hard plastics, soft plastics (such as foam), films, ropes, fibers, and sheets [12].

Solids obtained from a 0.335 mm surface sampling net (such as a net used for surface water towing) are filtered through 5.6 mm and/or 0.3 mm sieves as a method to separate out solids of appropriate size (**Figure 3–6**). The mass of solids in the sample is obtained by drying the sieved material. The Fe (II)-based catalyst in the solids is used to digest unstable organic matter during the wet peroxide oxidation (WPO) process, and plastic fragments are not affected in any way. The WPO mixture undergoes density separation in a sodium chloride solution to isolate plastic debris via flotation. Using a density separator, the floating solids are separated from the heavier undigested mineral components. The floating plastic debris is collected on a custom 0.3 mm filter, air-dried, and then removed and weighed to determine the microplastics concentration.

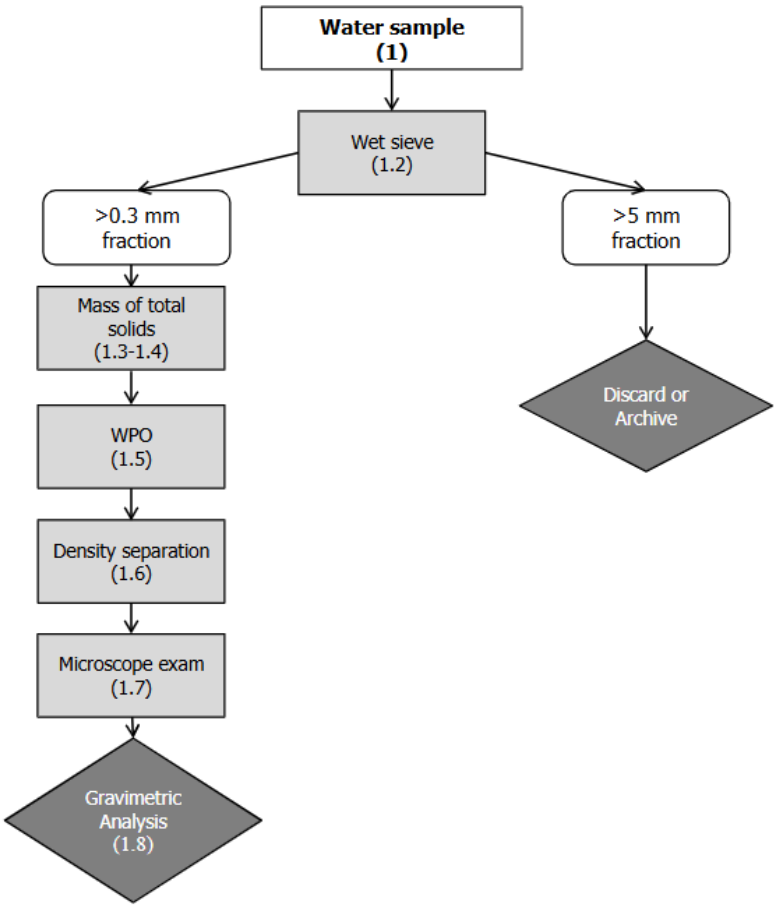

Figure 4. Flow diagram for the analysis of microplastics in water samples. (From NOAA and University of Washington [13]).

5.3.2. Microplastics in beach samples

The specific operation involves collecting plastic fragments from beach sand using a shovel or shovel, and sieving the dried beach samples to 5 millimeters to remove visible large fragments, including hard plastics, soft plastics (such as foam), films, ropes, fibers, and sheets.

This method determines common microplastics, such as polyethylene, polypropylene, PVC, and polystyrene, with densities ranging from 0.91 g/mL to 1.4 g/mL and particle sizes between 0.3 mm and 5 mm. It operationally defines microplastics as solid materials within this size range that are resistant to wet peroxide oxidation, float in a dense salt solution (e.g., 5 M NaCl or 5.4 M lithium metatungstate), and are visually confirmed under 40x magnification.

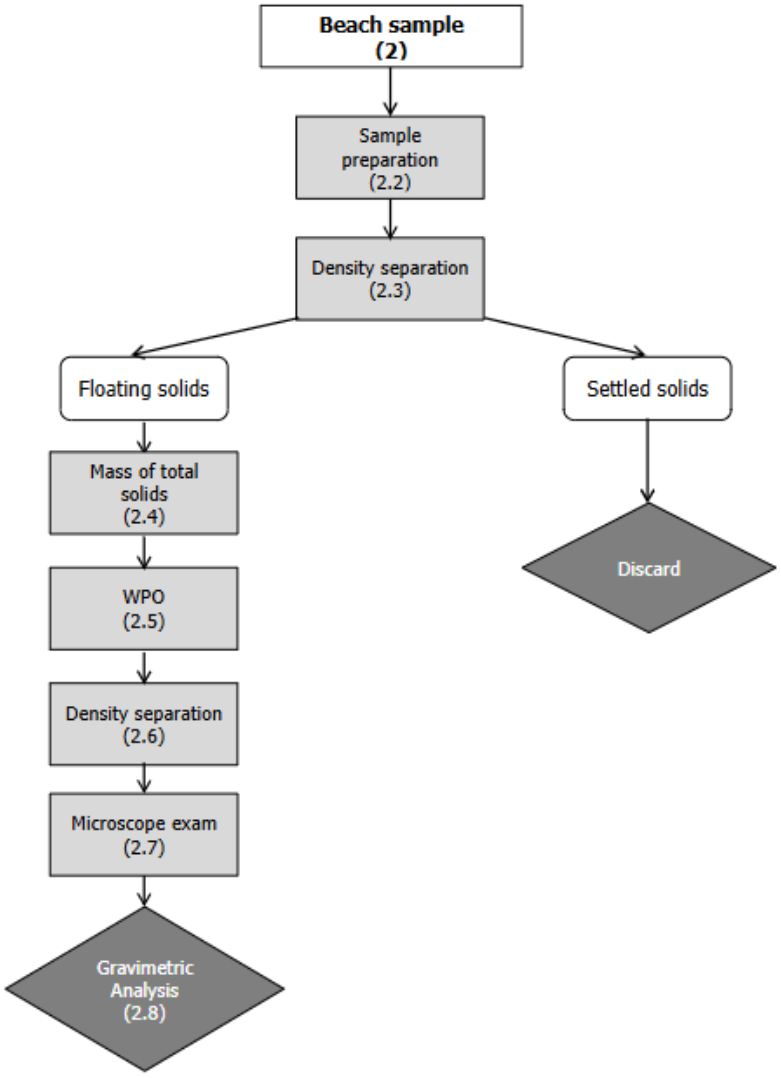

Figure 5. Flow diagram for the analysis of microplastics in beach samples. Note numbers refer to the numbers in this section (From NOAA and University of Washington [13]).

5.3.3. Microplastics in bed samples

Sediment samples are first collected using a corer or grab sampler (e.g., Ponar). The dried sediments are then disaggregated and sieved through a stack of 5 mm and 0.3 mm sieves. The microplastics retained on the 0.3 mm sieve undergo wet peroxide oxidation (WPO) with an Fe(II) catalyst to digest labile organic matter, a process that leaves the plastic debris unaltered. Subsequently, the WPO mixture is subjected to density separation in a sodium chloride solution, where the plastic debris floats and is separated from denser mineral components. Finally, the floating plastics are collected on a custom 0.3 mm filter, air-dried, and weighed for concentration determination.

Various common plastics, such as polyethylene with a density of 0.91–0.97 g/mL, polypropylene with a density of 0.94 g/mL, polyvinyl chloride with a density of 1.4 g/mL, and polystyrene with a density of 1.05 g/mL, can be measured using this technique. Plastic fragments with sizes ranging from 5 mm to 0.3 mm analyzed by this method, are considered as microplastics. The operational definition of microplastic fragments in this method is: any solid material that falls within the appropriate size range, is resistant to wet hydrogen peroxide oxidation, can be flotated in a solution of 5 M sodium chloride (d = 1.15 g/mL) or approximately 5.4 M lithium metatungstate (d = 1.62 g/mL), and exhibits positive results through visual inspection under a 40x microscope.

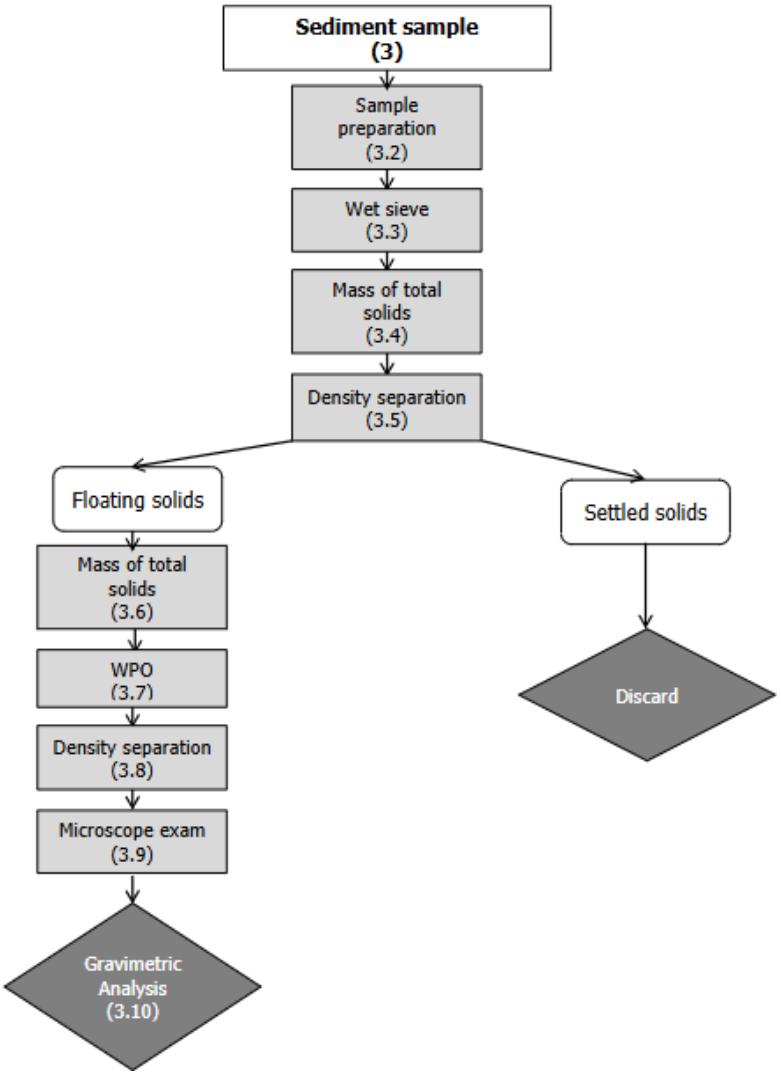

Figure 6. Flow diagram for the analysis of microplastics in bed samples. Note numbers refer to the numbers in this section.

6. Expected results

The idea is to establish a complete, standardized process covering everything from sample collection and pretreatment to analysis. This would reduce research errors and improve global data interoperability, thereby enhancing the reliability of the baseline. Meanwhile, as many microplastic particles of different sizes and shapes as possible should be collected for research, to ensure sufficient and comprehensive data is acquired.

Disclosure statement

The author declares no conflict of interest.

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