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Which color are you?: A pilot study on microplastic accumulation in sediments from the Bulgarian Black Sea

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Abstract. Microplastic (MP) pollution in marine sediments is an emerging environmental concern, yet data on MP color and size in the Black Sea are scarce. This pilot study analyzed sediments from five Bulgarian coastal locations. These results provide baseline information on MP color and size in Bulgarian Black Sea sediments and highlight the importance of further studies on the environmental behavior and management of colored MPs.

Key words: Black Sea, sediments, microplastics, pollution.

Introduction

The Black Sea basin, being the largest land-locked basin in the world, is subjected to considerable anthropogenic pressure from river and canal discharges, navigation, fisheries, tourism, and recreational activities, which collectively contribute to substantial anthropogenic pressure resulting in widespread and site-specific pollution (Simeonova & Chuturkova, 2020). In addition, land-based pollution represents the primary threat to the Black Sea marine environ-ment, responsible for over 70% of total marine pollution. More recently, marine litter (ML) has emerged as an additional concern in this enclosed sea, which is highly vulnerable to environmental degradation due to its extremely slow water renewal, limited vertical mixing, and dynamic surface circulation. To quantify the extent of ML pollution and inform mitigation strategies, numerous surveys have been conducted in recent years by the Black Sea littoral countries (Chuturkova & Simeonova, 2021; Bekova & Prodanov, 2023; Prodanov & Bekova, 2023). What is more, plastic represents 45–90% of ML, and an estimated average of 8.3 million tons of marine plastic per year comes from land-based sources (Ballerini et al., 2022). However, studies on microplastic (MP) accumulation in water, sediment, or biota samples from the Bulgarian Black Sea are relatively limited (Berov & Klayn, 2020; Georgieva et al., 2023; Toshkova et al., 2024; Bobchev et al., 2024; Glevitzky et al., 2025).

Thompson et al. (2004) first defined MPs as synthetic solid particles ranging in size from 1 µm to 5 mm, which are insoluble in water (Kumar et al., 2025). As explained further by Cincinelli et al. (2021), MPs may originate from the breakdown of larger plastic litter through plastic materials, such as polypropylene (PP), polyethylene (PE), polystyrene (PS), polyvinyl chloride (PVC), polycarbonate (PC), polyamides (PA), polyester (PES), and PE terephthalate (PET), degradation by UV radiation, physical forces, or already be manufactured in such a small size (i.e., use in cosmetic products). MPs are now ubiquitous, transported by both aquatic and atmospheric pathways, and found in virtually every environmental compartment, from deep ocean trenches to high-altitude mountain ranges (Allen et al., 2019). Moreover, MPs can float at the sea surface or sink

and thus accumulate in the sediments (Cincinelli et al., 2021).

According to Chiaia-Hernández et al. (2020), sediments act as both sources and sinks of pollutants, playing a crucial role in transferring toxic substances across terrestrial and aquatic environmental compartments. Chronic, low-level pollution inputs to sediments occur widely, ranging from regional to global scales, through riverine transport, runoff, industrial activities, and atmospheric deposition. Furthermore, sediments can experience severe pollution either continuously, as in harbors, waste discharge sites, and areas of naval activity, or episodically, due to accidental events, such as oil spills and fires.

Several optical techniques have been developed to detect and characterize MPs, such as Fourier Transform Infrared (FTIR), Raman, and Laser Direct Infrared (LDIR) spectroscopy. Traditional methods, such as FTIR and Raman spectroscopy are widely used for MP identification, but they are time-consuming and often require labor-intensive sample preparation, making them less practical for large-scale environmental monitoring (Deraik, 2002). Thus, LDIR has recently been introduced as an alternative technique for MPs in environmental samples to overcome these challenges (Tian et al., 2022). Powered by Quantum Cascade Laser (QCL) technology, LDIR offers high-resolution analysis, producing a reflectance spectrum in just 1 s (Ghanadi et al., 2024). In addition, the analysis of MP particles by LDIR can generate rapid information on particle size, shape, and composition (López-Rosales et al., 2024). By processing samples in minutes or hours, not days, LDIR allows a higher sample throughput with minimal operator intervention. This can reduce costs and potential errors, and give you the results you need really fast (Hildebrandt et al., 2022; Hansen et al., 2023).

This work aimed to assess the colors of the MP in sediments from five locations along the Southern Bulgarian Coast.

Materials and methods

Study area and sample collection

Five locations near the town of Sozopol (Fig. 1), Southern Bulgarian Black Sea coast, were selected – Smokinia Beach (Location 1), Haramanite Beach (Location 2), Central City Beach of Sozopol (Location 3), Midenia Beach (Location 4), and Gradina Beach (Location 5). These locations are very popular in the summer season for national and international tourists. Three replicate samples were collected from the same locations, and each sample weighed approximately 1 kg as described by Yu et al. (2024). All surface sediment samples (upper layer of 5 cm) were collected once in the summer of 2025 with a stainless shovel and placed in aluminum foil bags and stored in an insulated cooler box with cooling units (4 ◦C) until they were transported back to the external and accredited laboratory. There, the samples were air-dried and sieved through a 5 mm stainless steel sieve, placed in new aluminum foil bags, and further processed for MP extraction and analysis.

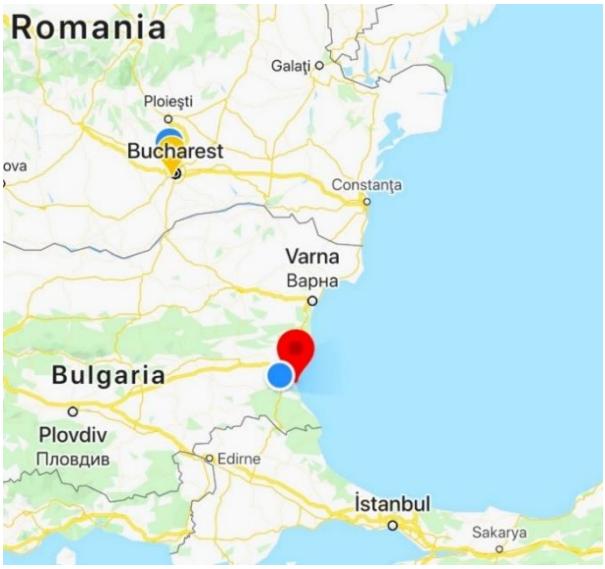

Fig. 1. Location of the town of Sozopol in Bulgaria.

MP extraction

The extraction method followed Peñalver-Sole et al. (2025) with slight modifications, meaning 1 g of sample was weighed in a 20 mL glass vial, digested by adding 4 mL of 30% H_2O_2, and heated at 60◦C for 2 hours, while the mixture was magnetically stirred. Thereafter, at room temperature, a density flotation process was applied by adding 10 mL of 2M NaCl solution, shaking manually for 1 min, and letting the mixture rest for 1 h. Finally, the solution obtained from the sediments was filtered through 0.8 µm pore size metal filters, and the portion retained on the filter was preserved in ethanol for subsequent evaporation at room temperature overnight and LDIR analysis.

MP analysis

The MP analysis of sediments also followed Peñalver-Sole et al. (2025) - an Agilent 8700 LDIR (Agilent Solutions, Inc., USA) imaging system was used, and the operation of the instrument was automated with Agilent Clarity version 1.1.23 software. The particle size range, which was monitored, was classified into five categories following Cheng et al. (2025) with slight modifications: < 50 µm, 51–100 µm, 101–300 µm, 301–1000 µm, and 1001-5000 µm. However, only the largest MP's colors could be determined under a microscope (Leica DM 2000 LED, Germany), and therefore these results will be further discussed below.

Quality Assurance/Control (QA/QC)

Strict QA/QC procedures were applied to prevent contamination and ensure data reliability. All glassware and tools were rinsed with filtered deionized water and covered to avoid airborne particles. Procedural blanks accompanied each batch of sediment samples, and replicate analyses verified consistency. All reagents were prepared with ultrapure water, and all processing was conducted in a clean environment under minimal air movement.

Statistical analysis

All MP abundances were expressed as the number of particles per unit mass of dry sediment (items/kg d.w.). The Excel program (Microsoft, USA) was used for the MP quantitative analyses. The results are presented as average.

Results and Discussion

MPs were detected at all sampling locations and in all analyzed samples. However, the largest particles (1001–5000 µm) were the least abundant. In Location 1, 43495 MPs were detected, of which 4 (0.0092%) were in the 1001–5000 µm range. In Location 2, 17937 MPs were found, with 2 (0.0112%) in this size range. Location 3 yielded 40371 MPs, including 4 (0.0099%) in the largest size category. In Locations 4 and 5, only 1 MP in the 1001–5000 µm range was detected in 13999 and 17448 MPs, corresponding to 0.0071% and 0.0057%, respectively. Overall, these results indicate that the vast majority of MPs were smaller than 1001-5000 µm, with large particles representing only a negligible fraction of the total. The colors in the range 1001-5000 µm were further determined. In addition, the analyzed MP samples exhibited a range of colors. Blue and transparent MPs were the most frequently observed, with 3 samples each (25%). White and black MPs were less common, with 2 samples each (16.7%), while red and green MPs were rare, each detected in a single sample (8.3%) (Fig. 2).

According to Assim et al. (2024), the primary characteristics of MPs include their shape, color, size, and available functional groups. Plastics can acquire color through two main processes—internal and external coloring—using dyes or pigments. Unlike dyes, pigments are generally insoluble in water, oils, and polymers but can be uniformly dispersed within materials to provide color. Some pigments can absorb ultraviolet (UV) light, which helps delay photo-degradation and extends the lifespan of plastic products (Zhao et al., 2022). However, as Zhao et al. (2022) explain, plastics are prone to aging under exposure to solar radiation, wind, wave action, mechanical abrasion, thermal oxidation, and biodegradation. Aging alters the color of plastics, and conversely, color influences the degree of solar energy absorbed by plastic surfaces. Thus, color not only affects the photoaging of plastics but also impacts microbial colonization, pollutant adsorption and release, and the overall ecotoxicological behavior of MPs. Furthermore, the leakage of colorants from MPs, along with dyes and pigments from surrounding environments, can influence degradation processes, aging dynamics, and interactions with other pollutants and ecosystems. Last but not least, both the color and shape of MPs are key factors determining their likelihood of ingestion by aquatic organisms (Li et al., 2023).

Blue is a prevalent color, particularly in fibers. Blue fibers are often mistaken for prey like copepods or fish eggs. It comes from synthetic textiles (clothing), ropes, and fishing gear. Transparent is a very common MP's color, especially for fragments and films. It comes from degraded packaging, plastic bags, and bottles. It is harder to see visually in water, often identified only under a microscope. White (milky) color is also common in MPs, coming from polystyrene foam products and packaging debris (fragments or films). Black can be found in fragments and films, and its origin is from degraded plastics, such as tires, black packaging, and industrial waste. However, com-

paratively little attention has been devoted to the color of MPs, particularly black plastics, which are among the least recyclable materials and contribute substantially to both environmental MP and overall plastic waste (Turner, 2018). Carbon black is an effective pigment used to enhance the durability of plastic products with a long intended service life, such as drainpipes, window frames, and waste bins. Nevertheless, its use is less appropriate for short-life polymers, including bottle caps and packaging materials. The incorporation of carbon black also affects plastics utilized in marine applications—such as fishing nets, buoys, and lobster pots—which frequently become marine litter (Turner, 2018). Turner (2018) further highlights that black polymers pose particular challenges due to their composition and detection difficulty during recycling. Approximately 15% of all household plastic waste consists of raw black plastic materials, which are extensively used in various industries, including food packaging, toys, kitchen-ware, trays, and electronic devices. Furthermore, because of their low commercial value, affordability, and the lack of efficient sorting technologies, most of the black plastics are discarded after a single use, ultimately accumulating in landfills, incinerators, rivers, and marine environments (Choi et al., 2021).

The other colors, such as red and green, have moderate occurrence, and their origin is from cosmetic microbeads, colored fibers, and fishing gear. Our findings are in agreement with Serranti et al. (2018), who found in a complex field study that the most diverse coloration was observed in fragments, and fishing lines were strongly associated with blue, turquoise, and green colors.

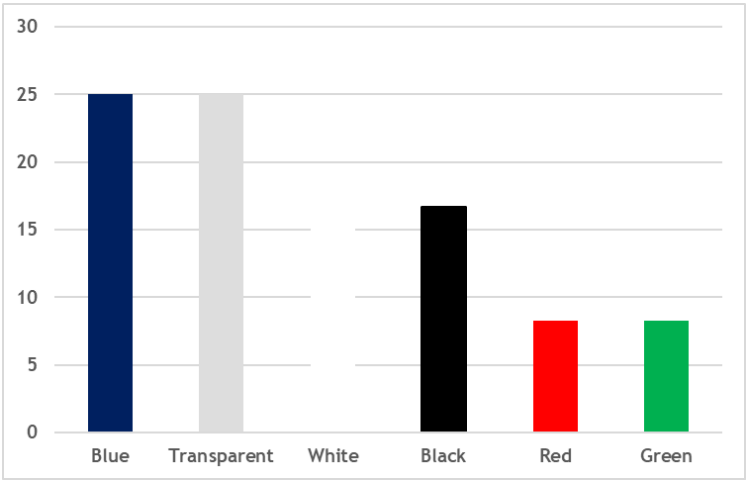

Fig. 2. Color percentage of MPs in sediment samples from the southern Bulgarian Black Sea (class range 1001–5000 µm).

Conclusions

Colored plastics can give rise to colored MPs, as well as to leaked colorants and paint particles. Consequently, proper waste management strategies are needed for all colored plastics, colored MPs, and MPs in general. However, the effects of paint and leaked colorants on the surrounding environment, MP formation, aging, and their implications for MP waste management have received limited attention and remain important issues that require further investigation.

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