

北京城区PM_{2.5}各组分污染特征及来源分析

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鄱阳湖流域水葫芦 (*Eichhornia crassipes*) 对水体微塑料的吸附截留效应

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摘要: 微塑料是环境中的新型污染物, 随着人们对微塑料污染的认识, 微塑料在河流和湖泊等淡水湿地环境中的迁移问题受到普遍关注. 中国内陆最大淡水湖鄱阳湖湿地受五河流域及其地表径流的影响, 湿地水环境中的微塑料污染问题也不容忽视. 为了解鄱阳湖各流域水体中微塑料的分布现状及水生植物对微塑料的吸附截留效应, 选择鄱阳湖流域的赣江、信江、抚河、修水和饶河这五河水系入湖段为研究区, 以各流域水体及其普遍存在的漂浮植物水葫芦 (*Eichhornia crassipes*) 为研究对象, 分析鄱阳湖五河流域水葫芦对水体微塑料的吸附截留特征, 探讨水生植物对水体环境中的微塑料是否具有吸附或截留效应, 阐明水葫芦对微塑料的吸附与水体赋存微塑料的相关性, 解析微塑料在湿地环境中的迁移特性, 为鄱阳湖湿地环境中微塑料的管控及污染治理提供一定的理论基础与依据. 在鄱阳湖流域赣江、抚河、信江、饶河和修水的五河水系入湖区和湖口出湖区共设置 18 个采样点, 分别采集水表漂浮的水葫芦整株样品和水深约 1 m 处的水样, 采用 HNO₃ (65%) - H₂O₂ (30%) 混合试剂消解水样后抽滤分离水体及水葫芦体表微塑料; 采用显微鉴定方法观察微塑料的颜色、粒径和形态等特征, 采用 Nano Measurer 1.2 软件统计各流域水体和水葫芦体表中分离出的微塑料丰度; 采用傅立叶变换红外 (FTIR) 光谱仪鉴定不同形态微塑料的聚合物成分. 鄱阳湖流域各水体微塑料丰度处于中度偏高水平, 丰度范围为 65.5 ~ 353 n·L⁻¹, 且以 0 ~ 0.5 mm 范围内的小粒径微塑料为主, 占各流域水体中微塑料的 80% 以上; 各流域水葫芦截留或吸附的微塑料丰度范围为 36 ~ 204 n·kg⁻¹, 且以 0 ~ 1.5 mm 范围内的小粒径微塑料为主, 所占比例达 80% 以上; 水葫芦吸附 0 ~ 0.5 mm 粒径范围内的微塑料丰度含量与水体中 0 ~ 0.5 mm 粒径范围内的微塑料丰度间呈显著相关, 水葫芦对水体中占比较高的小粒径微塑料具有明显的吸附效应. 鄱阳湖五河流域水体微塑料的聚合物成分以聚乙烯和聚苯乙烯为主体; 各流域水体微塑料的丰度处于较高水平, 以 0 ~ 0.5 mm 的小粒径微塑料为主, 对水体生物及水环境易构成生态风险. 各流域水葫芦对水体微塑料具有显著的吸附效应, 且以吸附 0 ~ 1.5 mm 的小粒径微塑料为主; 水葫芦吸附 0 ~ 0.5 mm 粒径范围内的微塑料丰度值与水体中 0 ~ 0.5 mm 粒径范围内的微塑料丰度间存在显著相关性; 水葫芦对水体中的小粒径微塑料具有较强的吸附效应, 可为水生植物吸附或截留水体环境中的微塑料提供一定的参考依据.

关键词: 鄱阳湖; 五河水系; 入湖区; 出湖区; 水葫芦; 微塑料

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Adsorption and Interception Effects of *Eichhornia crassipes* on Microplastics in Water of the Poyang Lake Basin

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Abstract: Microplastics are novel pollutants in the environment, and with the awareness of microplastic pollution, the migration of microplastics in freshwater wetland environments such as rivers and lakes has received widespread attention. The wetland of Poyang Lake, the largest inland freshwater lake in China, is influenced by the five river basins and their surface runoff, and the microplastic pollution in the wetland water environment cannot be ignored. In order to understand the occurrence of microplastics in the water bodies of Poyang Lake and the adsorption and interception effects of aquatic plants on microplastics, five river basins of Poyang Lake, including the Ganjiang River, Xinjiang River, Fuhe River, Xiushui River, and Raohe River, were selected as the study area, and the water samples of each basin and the prevalent floating plant *Eichhornia crassipes* were used as the research objects to study the adsorption and interception characteristics of microplastics in the water of the Poyang Lake basin. The study investigated the adsorption and interception characteristics of *E. crassipes* on microplastics in water bodies, explored whether the aquatic plants had adsorption or interception effects on microplastics in the water bodies, clarified the correlation between the adsorption of microplastics by *E. crassipes* and microplastics in the water bodies, analyzed the migration characteristics of microplastics in the wetland environment, and provided a theoretical basis for the control and pollution management of microplastics in the wetland environment of the Poyang Lake basin. A total of 18 sampling points were set up in the main entry areas of the Ganjiang River, Fuhe River, Xinjiang River, Raohe River, and

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Xiushui River, and the exit of the lake into the Yangtze River confluence area in the Poyang Lake basin, and water samples were collected from the all the *E. crassipes* floating on the water surface and water at a depth of approximately 1 m. Microplastics were separated from water samples and the plant surface at the root zone of *E. crassipes* by filtration; after the water samples were disintegrated with an HNO_3 (65%) - H_2O_2 (30%) reagent mixture, the microscopic identification method was used. The microplastics were characterized by color, particle size, and morphology, and the abundance of microplastics in the water and *E. crassipes* root zone was calculated using Nano Measurer 1.2 software, and the polymer composition of different forms of microplastics was identified via Fourier transform infrared (FTIR) spectroscopy. The abundance of microplastics in the water samples of the Poyang Lake basin was moderately high, ranging from 65.5 to $353 \text{ n}\cdot\text{L}^{-1}$, and the small-sized microplastics in the range of $0-0.5 \text{ mm}$ mainly accounted for more than 80% of the microplastics in the water samples of the basin. The abundance of microplastics retained or adsorbed by *E. crassipes* in the basin ranged from 36 to $204 \text{ n}\cdot\text{kg}^{-1}$, and the small-sized microplastics in the range of $0-1.5 \text{ mm}$ mainly accounted for more than 80% of the microplastics in the water bodies of the basin. The abundance of microplastics retained or adsorbed by *E. crassipes* in different watersheds ranged from 36 to $204 \text{ n}\cdot\text{kg}^{-1}$, and the proportion of small-sized microplastics in the range of $0-1.5 \text{ mm}$ was more than 80%. The abundance of microplastics in the particle size range of $0-0.5 \text{ mm}$ adsorbed by *E. crassipes* was significantly correlated with the abundance of microplastics in the particle size range of $0-0.5 \text{ mm}$ in the water bodies. The effect of *E. crassipes* on microplastics in the water column was significant. The polymer composition of microplastics in the water samples of the five river basins of Poyang Lake included mainly polyethylene and polystyrene, the abundance of microplastics in the water samples of the Poyang Lake basin was at a high level, and the main microplastics were of small particle size in the range of $0-1.5 \text{ mm}$, which easily pose ecological risks to the water body organisms and water environment. The abundance of microplastics in the range of $0-0.5 \text{ mm}$ particle size was significantly correlated with the abundance of microplastics in the range of $0-0.5 \text{ mm}$ particle size in the water body. *Eichhornia crassipes* also had a strong adsorption effect on microplastics in the water body, which can be used by aquatic plants to adsorb or retain microplastics in the water body. The strong adsorption effect of *E. crassipes* on microplastics in the water column can provide a reference for the adsorption or retention of microplastics in the water column.

Key words: Poyang Lake; five river system; inlets of the rivers; outlet of the lake; *Eichhornia crassipes*; microplastics

塑料制品因其化学性质稳定且制作成本低廉, 在日常生活中被广泛使用, 但由于废旧塑料的回收利用率较低^[1], 且在使用过程中因处理不当或回收利用不健全, 大量塑料制品被废弃后直接排放进入环境, 经日晒风吹雨打或物理、化学、生物和水力冲击等作用后, 逐渐转变为若干直径小于 5 mm 的塑料碎片或颗粒即为微塑料^[2]. 微塑料与大中塑料碎片相比, 因其更大的比表面积, 对环境各种污染物的吸附也更强^[3].

微塑料的研究最早始于 20 世纪 70 年代^[4,5], 但微塑料 (microplastic) 的概念直到 2004 年才首次提出^[6], 人们全面关注微塑料是从海洋生态环境中的细小塑料颗粒开始的^[7]. 目前, 关于微塑料的研究主要集中于海洋环境中的微塑料污染^[8,9]、土壤环境中微塑料的污染问题^[10]和淡水环境中的微塑料污染等方面^[11]. 其中, 关于海洋环境中微塑料的研究相对较多, 而内陆淡水环境中微塑料的污染研究尚处于起步阶段, 淡水湿地中的河流与湖泊是连接陆地环境与海洋环境的桥梁, 海洋环境中的大部分微塑料来源于内陆河流和湖泊等淡水环境^[12], 现有的研究已发现微塑料污染已普遍存在于淡水水体及湿地生态系统中^[13~15].

鄱阳湖是中国最大的淡水湖, 位于长江中游末段南岸, 上承赣江、抚河、修水、饶河和信江这“五河”之水, 下接长江, 经九江市湖口县城注入长江, 是长江流域重要的组成部分^[16]. 已有研究发现, 鄱阳湖典型区域的微塑料丰度已显著高于国内外一些沿海区域^[17~19]; 其水体、沉积物和野生鱼类等生物体均出现了微塑料物质^[20,21], 微塑料的广泛存在正在构成鄱阳湖区新的和潜在的生态危害.

水葫芦 (*Eichhornia crassipes*) 是一种多年水生植

物, 在中国本没有分布, 自 20 世纪 30 年代左右作为一种饲料被引进国内^[22], 现普遍分布于全国各地, 在鄱阳湖五河流域也普遍存在^[23]. 水葫芦具有发达的根系和根毛, 繁殖速度极快, 尤其在污染较严重的水域中生长繁殖更快, 对水体重金属污染物及氮磷营养盐等物质均具有较强的吸附作用, 目前关于水葫芦吸附重金属污染的研究较多^[24,25], 但对于水葫芦吸附截留微塑料的研究尚较少. 本文选择鄱阳湖流域的赣江、信江、抚河、修水和饶河这五河水系入湖段为研究区, 分析鄱阳湖五河流域水葫芦对水体微塑料的吸附截留特征, 探讨水生植物对水体环境中的微塑料是否具有吸附或截留效应, 阐明水葫芦对微塑料的吸附与水体赋存微塑料的相关性, 对于解析微塑料在湿地环境中的迁移具有独特意义, 以为鄱阳湖湿地环境中微塑料的管控及污染治理提供一定的理论基础与依据.

1 材料与方法

1.1 研究区概况

鄱阳湖地处江西省北部, 在北纬 $28^{\circ}22'$ ~ $29^{\circ}45'$, 东经 $115^{\circ}47'$ ~ $116^{\circ}45'$, 是中国最大的淡水湖, 也是中国仅次于青海湖的第二大湖. 鄱阳湖容纳了来自赣江、信江、抚河、修水和饶河这五河水系的水流, 是长江流域的重要组成和关键枢纽, 整个流域面积占长江流域面积的 9%, 年均入江水量约占长江径流量的 15.6%^[26], 对长江水量的调蓄极其关键, 并在降解污染物、调节整个长江流域的气候、保持水土和维系生态平衡等诸多方面具有非常重要的作用^[27].

1.2 样品采集与处理

水葫芦样品采集. 相继于鄱阳湖丰水期 (7 月中

2 结果与分析

2.1 微塑料的聚合物成分

红外光谱解析主要分两个波段: 分别为 $7.5 \sim 15 \mu\text{m}$ ($1333 \sim 667 \text{ cm}^{-1}$) 指纹区和 $2.5 \sim 7.5 \mu\text{m}$ ($4000 \sim 1333 \text{ cm}^{-1}$) 特征谱带区, 又称官能团区, 各类官能团的特征吸收峰会出现在该区域. 如果待测化合物在某些官能团应出峰的位置无吸收,

则说明该化合物不含此官能团. 选取样品中分离出的不同类型微塑料, 采用红外光谱分析其主要成分, 结果如图 2. 图 2(a) 为硬质塑料碎片类微塑料的红外图谱, 显示其聚合物成分为聚乙烯; 图 2(b) 为微球类微塑料, 通过光谱分析, 其成分为聚苯乙烯; 图 2(c) 为微塑料透明薄膜, 其成分为聚乙烯; 图 2(d) 为典型纤维类微塑料红外图谱, 成分为聚苯乙烯.

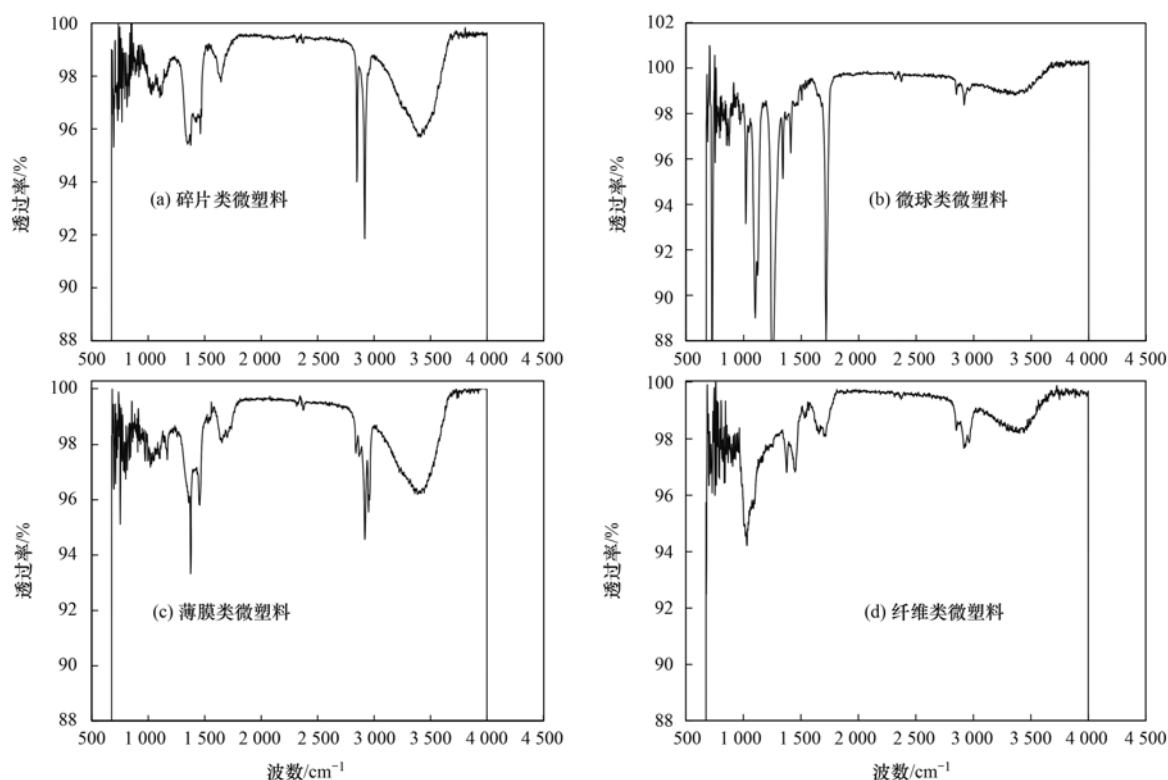


图 2 研究区主要类型微塑料红外光谱鉴定

Fig. 2 Infrared spectra of the main types of microplastics in the study area

2.2 鄱阳湖五河流域水体微塑料的分布特征

2.2.1 各流域水体微塑料丰度差异

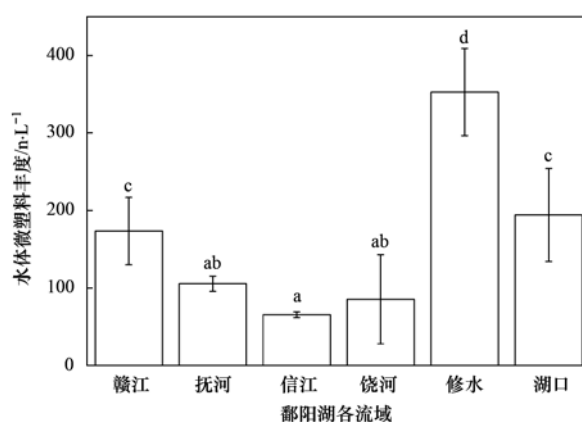
鄱阳湖五河水系及长江段出湖区各样点水体微塑料的丰度统计结果如图 3 所示. 不同区域水体中微塑料的丰度大小表现为: $353 \text{ n} \cdot \text{L}^{-1}$ (修水) $> 194 \text{ n} \cdot \text{L}^{-1}$ (湖口) $> 173 \text{ n} \cdot \text{L}^{-1}$ (赣江) $> 105 \text{ n} \cdot \text{L}^{-1}$ (抚河) $> 85 \text{ n} \cdot \text{L}^{-1}$ (饶河) $> 65.5 \text{ n} \cdot \text{L}^{-1}$ (信江), 不同区域丰度值表现出一定的显著性差异 ($P < 0.05$).

2.2.2 各流域水体微塑料颜色分布特征

鄱阳湖研究区各流域不同水体中不同颜色微塑料的组成特征如图 4. 各流域水体不同颜色微塑料的占比存在一定差异, 但多以红色微塑料为主, 占比均高出 40%, 显著高于其他各色, 抚河与修水流域的红色微塑料占比高达 70%.

2.2.3 各流域水体微塑料粒径分布特征

将鄱阳湖各流域水体中的微塑料按其粒径大小划分为 $0 \sim 0.1$ 、 $0.1 \sim 0.3$ 、 $0.3 \sim 0.5$ 、 $0.5 \sim 1.0$ 、



不同小写字母表示差异显著 ($P < 0.05$)

图 3 鄱阳湖各流域不同水体微塑料的丰度

Fig. 3 Abundance of microplastics in different waters of Poyang Lake basin

$1.0 \sim 2.0$ 和 $2.0 \sim 5.0 \text{ mm}$ 这 6 个等级, 分别统计分析各水体不同粒径微塑料的占比, 结果如图 5 所示. 在赣江、抚河和修水等流域 $0 \sim 0.1 \text{ mm}$ 的小粒径微

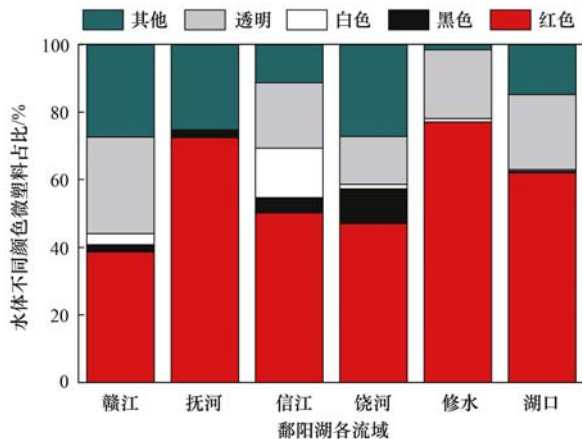


图4 鄱阳湖各流域水体中不同颜色微塑料的占比

Fig. 4 Proportion of microplastics with different colors in different waters of Poyang Lake basin

塑料占比较高,均超出50%,信江和湖口区域0~0.1 mm的小粒径微塑料占比偏低,约为20%~30%,而饶河区域的小粒径微塑料占比不足10%;总体上,全部流域0~0.5 mm粒径范围内的全部微塑料占比均超出80%;多数流域0.5~5 mm粒径范围的微塑料占比总和不足20%。

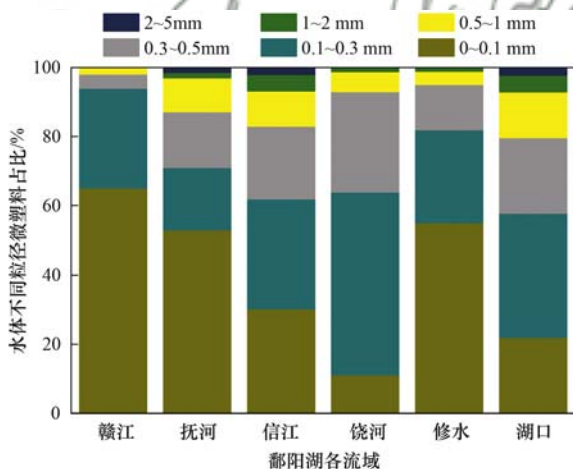


图5 鄱阳湖各流域水体中不同粒径微塑料的占比

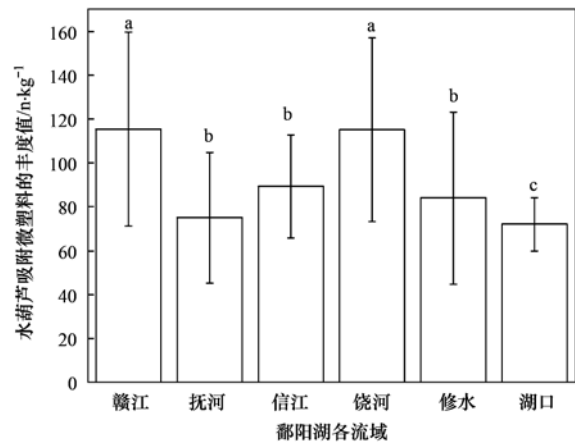
Fig. 5 Proportion of microplastics with different particle sizes in different waters of Poyang Lake basin

2.3 鄱阳湖五河流域水葫芦吸附微塑料的特征

2.3.1 五河流域水葫芦吸附微塑料的丰度差异

鄱阳湖五河水系赣江、抚河、信江、饶河、修水和湖口这6个区域采集的水葫芦均分离检测到微塑料,如图6所示。各流域水葫芦主要以其根系或植株体表吸附或截留的微塑料为主,微塑料的丰度范围约为36~204 $\text{n}\cdot\text{kg}^{-1}$,五河流域水葫芦吸附的微塑料丰度最高值出现在赣江和饶河区域,丰度低值出现在湖口汇入长江段区域。鄱阳湖和五河入湖段水葫芦吸附微塑料的丰度具有一定显著差异性($P < 0.05$),赣江和饶河入湖段水葫芦吸附的微塑料丰度较一致,均显著高于其它区域;而抚河、信江

和修水这3个入湖段水葫芦吸收的微塑料较一致,均显著高于湖口汇入长江段出湖区域。



不同小写字母表示差异显著($P < 0.05$)

图6 鄱阳湖流域水葫芦吸附微塑料的丰度

Fig. 6 The abundance of microplastics adsorbed by *Eichhornia crassipes* in Poyang Lake basin

2.3.2 五河流域水葫芦吸附不同形态微塑料的差异性

根据微塑料的形状差异将微塑料按不同形态划分为不同类型,主要有:纤维状、薄膜状、碎片状和泡沫状^[31]。而不同形态的微塑料聚合物成分存在一定差异,本研究薄膜状和碎片状微塑料主要成分为聚乙烯,纤维状和泡沫状微塑料主要成分为聚苯乙烯。结果显示(图7),水葫芦吸附纤维类和薄膜类微塑料的占比最高,而碎片类和泡沫类微塑料占比较低,尤其是泡沫类微塑料在各流域所占比例均较小,而在修水河段采集的水葫芦中未分离检测到泡沫类微塑料;其他3种类型的微塑料在各流域分布的水葫芦中均被检测到。赣江与饶河两河流域入湖段分布的水葫芦吸附或截留的微塑料类型及其占比含量均较接近;抚河流域及湖口段出湖区两地区微塑料

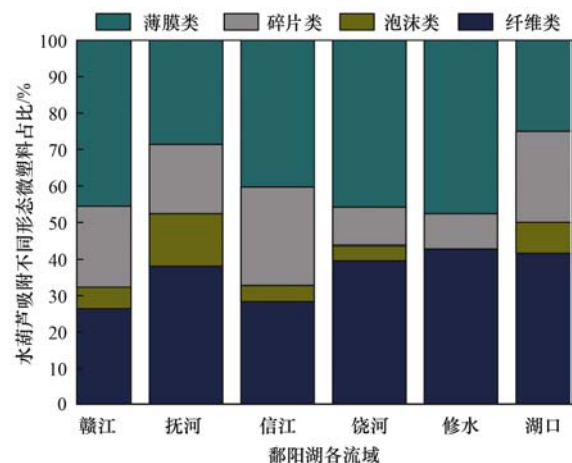


图7 鄱阳湖流域水葫芦吸附不同形态微塑料的占比

Fig. 7 Proportion of different microplastics adsorbed by *Eichhornia crassipes* in Poyang Lake basin

的分布也较类似. 信江和修水两河流域的微塑料类型及其占比与其他区域相比差异较大, 信江流域的水葫芦吸附或截留的微塑料类型以纤维、薄膜和碎片这 3 种类型为主, 且三者所占比例均较接近, 修水流域的水葫芦吸附的微塑料主要以薄膜类及纤维类为主, 碎片类微塑料占比比较小, 与其他区域的差异较显著.

2.3.3 五河流域水葫芦对不同颜色微塑料的吸附

从水葫芦及其根系体表分离检测到的不同颜色微塑料主要有蓝色、黑色、红色、绿色和透明色等, 其它含量极少的各色统称为其他色, 如图 8. 五河流域入湖段水葫芦体表对各类颜色的微塑料均有吸附, 且多以透明色为主, 各流域不同彩色微塑料占比呈现不一致, 但多数流域以蓝色及红色微塑料占比较高, 少数流域如抚河以黑色占比偏高. 湖口—长江段出湖区水葫芦所吸附的微塑料颜色以蓝色为主, 占比超出一半, 其次是透明色, 红色与黑色微塑料有一定占比, 绿色及其它色未观测到.

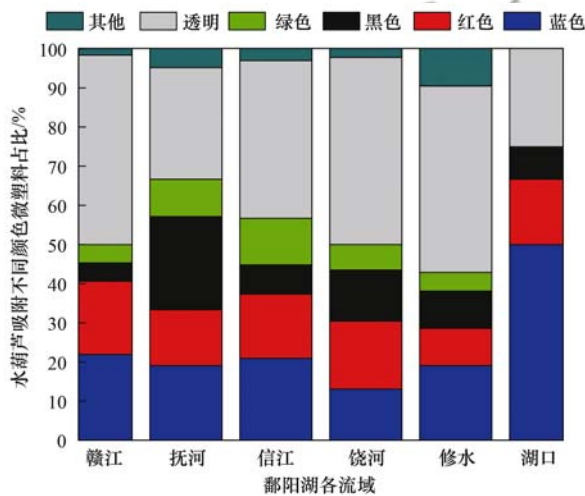


图 8 鄱阳湖流域水葫芦吸附不同颜色微塑料的占比

Fig. 8 Proportion of microplastics with different color adsorbed by *Eichhornia crassipes* in Poyang Lake basin

2.3.4 五河流域水葫芦吸附不同粒径微塑料的特性

对各流域采集的水葫芦体表吸附的微塑料进行分离提取, 根据其粒径大小归为以下 4 类, 分别为 0 ~ 0.5、0.5 ~ 1.5、1.5 ~ 3.5 和 3.5 ~ 5 mm, 鄱阳湖

各流域水葫芦吸附的不同粒径范围微塑料占比如图 9.

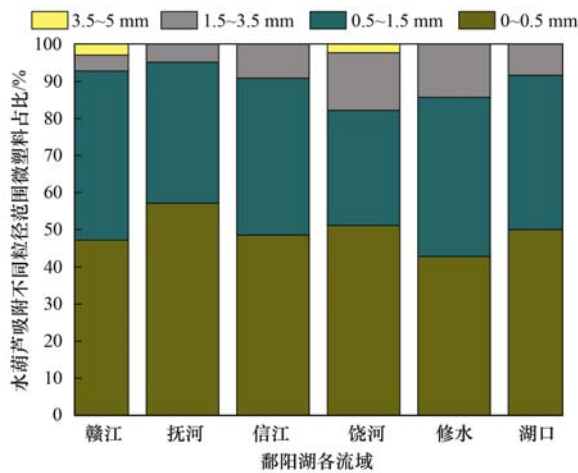


图 9 鄱阳湖流域水葫芦吸附不同粒径微塑料的占比

Fig. 9 Proportion of microplastics with different particle sizes adsorbed by *Eichhornia crassipes* in Poyang Lake basin

总体结果显示, 五河水系各流域水葫芦所吸附或截留的各粒径微塑料占比相一致, 均以 0 ~ 0.5 mm 或 0.5 ~ 1.5 mm 的小粒径微塑料占比较高, 粒径范围为 3.5 ~ 5 mm 的微塑料仅在赣江和饶河流域的水葫芦体表分离检测出. 各流域水葫芦所吸附或截留的微塑料各粒径范围的占比均表现为: 0 ~ 0.5 mm > 0.5 ~ 1.5 mm > 1.5 ~ 3.5 mm > 3.5 ~ 5 mm, 各流域粒径大小为 0 ~ 0.5 mm 和 0.5 ~ 1.5 mm 的微塑料占比较一致, 各自占比均达到 30% ~ 40%, 且两者的占比之和超出 80%.

2.4 鄱阳湖流域水葫芦吸附微塑料与水体微塑料的相关性

用 SPSS 对水体中微塑料数据和水葫芦吸附的微塑料从形态、粒径和颜色各方面进行相关性分析, 根据鄱阳湖流域水体中赋存的微塑料多以小粒径、轻质碎片类微塑料为主体的特性^[19], 分别筛选水体微塑料丰度、水葫芦吸附微塑料、水体中 0 ~ 0.5 mm 微塑料占比、水葫芦吸附 0 ~ 0.5 mm 微塑料和水中碎片微塑料等特征指标, 数据如表 1 所示. 结果显示, 水体中微塑料丰度和水体 0 ~ 0.5 mm 微塑料丰度、碎片类微塑料均呈极显著相关, 表明水体微塑料以 0 ~ 0.5 mm 碎片类微塑料为主体; 水

表 1 水体微塑料与水葫芦吸附微塑料间的相关性¹⁾

Table 1 Correlation between water microplastics and microplastics adsorbed by *Eichhornia crassipes* in Poyang Lake basin

		水体微塑料丰度	水葫芦吸附微塑料	水体中 0 ~ 0.5 mm 微塑料	水葫芦吸附 0 ~ 0.5 mm 微塑料	水体中碎片微塑料
水葫芦吸附微塑料	显著性(双侧)	-0.216				
水体中 0 ~ 0.5 mm 微塑料	显著性(双侧)	0.782 **	-0.207			
水葫芦吸附 0 ~ 0.5 mm 微塑料	显著性(双侧)	-0.257	0.711 **	0.478 *		
水体中碎片类微塑料	显著性(双侧)	0.761 **	-0.246	0.950 **	-0.088	
水葫芦吸附碎片微塑料	显著性(双侧)	-0.310	0.483 *	-0.278	0.405 *	-0.256

1) * 表示显著性相关($P < 0.05$), ** 表示极显著性相关($P < 0.01$)

葫芦吸附 0 ~ 0.5 mm 的微塑料和水体中的 0 ~ 0.5 mm 小粒径微塑料丰度间存在显著相关性;水葫芦吸附碎片类微塑料与其吸附 0 ~ 0.5 mm 粒径微塑料丰度显著相关;水葫芦吸附的微塑料与其吸附的粒径 0 ~ 0.5 mm 微塑料呈极显著性相关,并与其吸附的碎片微塑料呈显著性相关;水体 0 ~ 0.5 mm 微塑料丰度与水体中碎片类微塑料呈极显著相关。

3 讨论

3.1 鄱阳湖五河流域水体微塑料的赋存特征及其成因

本研究调查发现鄱阳湖水体流域微塑料已具有较高的丰度.有研究指出农业生产和人类活动是河流塑料废弃物的主要来源,微塑料的暴露丰度与当地经济发展现状密切相关.鄱阳湖五河流域各水体中的微塑料丰度达 $65.5 \sim 353 \text{ n} \cdot \text{L}^{-1}$,与发达国家及国内的淡水系统相比,均处于较高水平.如 Watkins 等^[32]的研究发现美国纽约伊萨卡的 6 个水库微塑料含量在 $700 \sim 2\,500 \text{ n} \cdot \text{m}^{-3}$ 之间;Park 等^[33]对韩国汉江的调查显示微塑料含量在 $0 \sim 42.9 \text{ n} \cdot \text{m}^{-3}$ 之间.国内如乌梁素海表层水体中微塑料丰度介于 $1.76 \sim 10.03 \text{ n} \cdot \text{L}^{-1}$ 之间^[34];滇池近岸水体微塑料丰度在 $800 \sim 6\,000 \text{ n} \cdot \text{m}^{-3}$ 之间,平均值为 $2\,867 \text{ n} \cdot \text{m}^{-3}$ ^[35].微塑料在水环境中的分布受许多因素的影响,如气象、水文、周边环境乃至生活污水排放等,它们均可能是导致鄱阳湖及其入湖支流微塑料丰度分布差异性的原因。

本研究从各流域水体中分离出的微塑料颜色种类多样化,不同流域水体微塑料颜色占比存在显著性差异,但多以红色居多,占比显著高于其他各色,多数流域水体红色微塑料超出一半以上,主要原因是鄱阳湖各流域主要受农业、渔业及人类其他活动的不同影响,微塑料来源极其广泛,彩色尤其是红色塑料用品因其代表吉祥喜庆,在广大乡村备受居民青睐,但大多塑料用品使用后因回收利用不当而进入环境成为废旧塑料与微塑料的主要来源。

各流域水体样品中分离出的微塑料粒径范围主要分布在 0 ~ 0.5 mm 之间,且随着粒径的增大其丰度逐渐减小. Di 等^[36]也在研究中指出粒径不足 $500 \mu\text{m}$ 的微塑料往往在水环境中最为丰富.类似的还有,越南西贡河水体微塑料以粒径小于 $250 \mu\text{m}$ 为主,很少有粒径超过 $1\,000 \mu\text{m}$ 的微塑料颗粒^[37];珠江广州段及其河口水体中超过 80% 的微塑料粒径小于 $500 \mu\text{m}$ ^[38];黄海和渤海海水中大部分微塑料粒径在 $50 \sim 500 \mu\text{m}$ 之间^[39],本研究与上述研究结果相符.小于 1 mm 的微塑料可能更容易被生物摄

入,对生物的威胁也可能更大,并对生物体具有广泛的影响,未来研究需要进一步关注小粒径微塑料。

3.2 水葫芦对微塑料的吸附效应及主要影响因素

从各区域水葫芦中提取出的所有微塑料类型中,纤维类微塑料和薄膜类微塑料占比最多.有研究表明,一件衣服洗涤一次排出的纤维可达到 1 900 个之多^[40],纤维被广泛用于衣物面料的制造,在某些城市的生活污水中的微塑料检测中,纤维类微塑料含量也很高^[41].本研究鄱阳湖各流域水葫芦所吸附的纤维类微塑料,与鄱阳湖流域及其五河水系受纳的生活污水有密切关联.薄膜类微塑料主要与农用薄膜、各种玩具以及各种各样商品包装袋有密切关系;泡沫塑料的来源与渔业活动密切相关,泡沫体微塑料因其质轻、绝热性能好和吸音效果好等特性,在日常生活中也被广泛应用,废弃后难以回收而更易进入水土环境中;而渔业活动使用的泡沫浮子也多由泡沫塑料制成^[42],近年来,随着鄱阳湖及其流域 10 年禁渔期的实施,泡沫类微塑料问题有望呈减少趋势.各种碎片类微塑料的来源相对较广泛,主要来源于生活中各种硬塑料例如塑料水瓶的老化与破碎,经过雨水冲刷和地表径流进入各水体后,随水流汇集到河流和湖泊中。

各流域水葫芦吸附或截留的微塑料中颜色丰富多彩,蓝色、红色、绿色、黑色和透明色等各色均占有一定比例,其中,以透明色和蓝色占比较高.水葫芦吸附透明色微塑料占比高的流域,其薄膜类微塑料占比也较高,表明不同流域水葫芦吸附或截留的透明色微塑料主要与薄膜类有关.除修水地区外,水葫芦吸附蓝色微塑料含量较高的流域其纤维类微塑料的含量也比较高,蓝色微塑料主要与纤维类微塑料中的尼龙纤维及化工纺织纤维具有一定的关联性.不同颜色微塑料与不同类型微塑料之间存在的关联性,有待未来更进一步研究。

各流域水葫芦所吸附或截留的微塑料多以 0 ~ 1.5 mm 的小粒径微塑料为主,表明水葫芦根系对于水体中的小粒径微塑料具有较好的吸附效应.主要原因有两方面,一是由于小粒径微塑料易漂浮于水体中,而大粒径微塑料因重力作用易沉降于沉积物中;二是由于水葫芦的须根系极其发达密集,长达 30 cm 左右,形成密集的网状结构,对水体中各种悬浮物质具有较好的过滤截留与吸附效能,对于水体中悬浮的微塑料也具有较好的吸附效应。

3.3 水体微塑料与水葫芦吸附微塑料的相关性

各流域水体微塑料的分布特性与水葫芦吸附微塑料的相关性表明,水葫芦吸附 0 ~ 0.5 mm 微塑料的丰度含量与水体中 0 ~ 0.5 mm 的微塑料丰度间存

在显著相关性,主要原因一方面是水体中微塑料以粒径小于 0.5 mm 的微塑料为主,占比达 80% 以上,另一方面是水葫芦具有发达密集的须根系,漂浮在水体表面并受水力作用而随处漂移,并有效吸附或截留水体表面漂浮的小粒径微塑料。另外,各流域的水文条件和自然地理环境条件均存在一定差异,也可能会导致各流域水葫芦吸附微塑料的效应有所不同。

各流域入湖段水葫芦中微塑料的丰度产生的差异性与多重因素有关,与水体环境中的微塑料类型及水葫芦的吸附特性均有一定关联性,其主要原因值得进一步深入研究与探讨。

4 结论

(1) 鄱阳湖五河流域水体微塑料聚合物成分以聚乙烯和聚苯乙烯为主体;各流域水体微塑料的丰度值达 $65.5 \sim 353 \text{ n} \cdot \text{L}^{-1}$,处于较高水平,且多以 0 ~ 0.5 mm 的小粒径微塑料为主,均占各流域水体微塑料总量 80% 以上,小粒径微塑料极易被水生生物摄入而构成更大威胁。

(2) 各流域水葫芦对水体微塑料均具有一定的吸附效应,且吸附微塑料的丰度值达 $36 \sim 204 \text{ n} \cdot \text{kg}^{-1}$ 。水葫芦对微塑料的吸附特性表现为以吸附小粒径的微塑料为主,粒径范围介于 0 ~ 1.5 mm 的微塑料占比达 80%。

(3) 水葫芦吸附 0 ~ 0.5 mm 粒径范围内的微塑料丰度值与水体中 0 ~ 0.5 mm 粒径范围内的微塑料丰度间存在显著相关性;水葫芦对水体中占比较高的小粒径微塑料具有较强的吸附效应,可为水生植物吸附或截留水体环境中的微塑料提供一定参考。

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