

北京城区PM_{2.5}各组分污染特征及来源分析

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鄱阳湖典型区铜锈环棱螺体内微塑料分布特征

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摘要: 微塑料能够被水生生物摄入并对其进行产生毒性效应。以5条汇入鄱阳湖河流的入湖口、鄱阳湖出湖口和南矶山自然保护区为研究区, 采集优势底栖动物铜锈环棱螺样品, 对其进行组织消解并分离其中的微塑料, 利用显微镜和红外光谱鉴定微塑料, 分析鄱阳湖典型区铜锈环棱螺体内微塑料分布特征。结果表明, 鄱阳湖典型区铜锈环棱螺体内微塑料丰度为 $(0.52 \pm 0.15) \sim (2.48 \pm 0.90) \text{ n} \cdot \text{g}^{-1}$, 赣江入湖口铜锈环棱螺体内微塑料丰度高于其他入湖口, 南矶山湿地自然保护区铜锈环棱螺体内微塑料丰度最小。研究区铜锈环棱螺体内微塑料以粒径小于1 mm的透明纤维为主。铜锈环棱螺肠道微塑料丰度高于肌肉组织。本研究表明人类活动是影响铜锈环棱螺体内微塑料丰度的重要因素, 对底栖动物中微塑料的调查有助于人们全面了解微塑料污染的生态风险。

关键词: 微塑料; 鄱阳湖; 铜锈环棱螺; 丰度; 分布

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Distribution Characteristics of Microplastics in *Bellamya aeruginosa* in Typical Area of Poyang Lake

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Abstract: A large number of studies have revealed that aquatic organisms can ingest microplastics. However, little research has been done on the ingestion of microplastics by freshwater benthic organisms. This study investigated the distribution characteristics of microplastics in *Bellamya aeruginosa* sampled from Poyang Lake, the largest freshwater lake in China. *Bellamya aeruginosa* samples were collected from seven sites, which included five rivers flowing into Poyang Lake, a nature reserve, and a lake outlet. The microplastics in *B. aeruginosa* were separated by tissue digestion and identified by microscopy and infrared spectroscopy. The results showed that the abundance of microplastics in *B. aeruginosa* in the typical area of Poyang Lake ranged from (0.52 ± 0.15) to $(2.48 \pm 0.90) \text{ n} \cdot \text{g}^{-1}$. The microplastic abundance in *B. aeruginosa* from the Gan River on average contained more microplastics than those collected from the other estuary because the Gan River flows through the densely populated city of Nanchang and has a large catchment area, the amount of microplastics discharged into the Gan River. Samples from the Nanjishan Wetland had the lowest average amount of microplastics. The microplastics in the *B. aeruginosa* samples were mainly fibers with a particle size of less than 1 mm, probably because small fiber particles are more likely to adhere. The abundance of microplastics in the gut of *B. aeruginosa* was higher than that in the muscle. Ingestion and adhesion may be two important pathways by which microplastics enter *B. aeruginosa*. This study suggests that human activities are an important factor affecting the abundance of microplastics in *B. aeruginosa*, thus demonstrating that effective protection can control microplastic pollution. The investigation of microplastics in benthic animals is helpful to comprehensively understand the ecological risks of microplastic pollution.

Key words: microplastics; Poyang Lake; *Bellamya aeruginosa*; abundance; distribution

近年来,微塑料(粒径 < 5 mm 的塑料颗粒)作为一种新兴的污染物引起了广泛地关注^[1]. 与海洋环境开展的大量深入研究相比,淡水系统中微塑料的研究是有限的^[2,3]. 有研究证实,微塑料在包括河流^[4]和湖泊^[5]等淡水系统中广泛存在. 湖泊作为微塑料的临时或长期沉淀区,塑料碎片可能在湖泊中长时间保存,成为下游环境重要的微塑料来源^[6]. 因此,需要深入研究湖泊微塑料污染及其对生物的毒理效应^[7].

有研究发现浮游生物^[8]、双壳类动物^[9]、鱼类^[10]、鸟类^[11]、鲸鱼^[12]甚至人类体内都有微塑料

的存在^[13]. 生物会误食微塑料从而阻塞其进食器官和消化道^[14],造成饱腹感并降低它们的进食率,进而导致生物能量缺乏、生长减弱、活动减少和繁殖能力减弱^[15]. 除了造成物理损害,微塑料还是有害微生物及对生物体具有化学毒性的增塑剂、着色剂和其他污染物的载体^[16]. 微塑料的污染直接威

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胁着生态、食品安全甚至人类健康^[17]. 由于底栖生物具有较强的滤水性和可食用等特点, 其对微塑料的累积受到了广泛关注. 现有研究多关注于海洋底栖生物对微塑料的累积及其毒理效应^[18]. Kolandhasamy 等^[19]的研究显示了浙江舟山渔场多种贻贝对微塑料的累积. Li 等^[20]的研究在东海钩旗岛附近的一个渔场的贻贝中检出微塑料. Scanes 等^[21]的研究表明微塑料可以进入海洋软体动物, 并强调需要监测海洋环境和水产养殖中的微塑料. 但是在纽约圣劳伦斯河沿岸带德莱赛尼贻贝中未检测到微塑料^[18]. 研究表明实验条件下, 微塑料对海洋贻贝的组织、细胞和分子水平均有直接的毒性作用^[22]. 微塑料对底栖动物有不利影响, 然而, 关于微塑料在底栖动物各种组织中的分布模式的数据有限, 尤其是微塑料在淡水底栖动物中的研究. 为了更好地理解微塑料对淡水水生生态环境的影响, 提高微塑料对淡水底栖动物影响的认识尤其重要.

鄱阳湖是中国最大的淡水湖, 是我国公布的首批国家重点湿地保护地区之一, 其生态地位十分重要^[23]. 铜锈环棱螺在鄱阳湖广泛存在, 是五河入湖口、出湖口和南矶山湿地自然保护区优势底栖生物^[24]. 它们通常在沉积物中活动, 通过过滤和刮食, 能够清除水环境中的浮游藻类和悬浮粒子, 增加水的透明度, 改善水环境, 是生态毒理学的一个指示物种^[25,26]. 有研究表明, 微塑料污染在鄱阳湖普遍存在^[5,27], 但是关于底栖动物体内微塑料的研究还未展开. 本研究重点关注底栖动物铜锈环棱螺, 分析不同环境(入湖口、出湖口和湿地)铜锈环棱螺微塑料的丰度和铜锈环棱螺体内微塑料的累积特征, 进一步探讨底栖动物体内微塑料累积的影响因素, 以期为鄱阳湖环境中微塑料污染的潜在生态风险评估提供重要依据.

1 材料与与方法

1.1 研究区概况

鄱阳湖是中国最大的淡水湖, 位于长江南岸, 江西省北部(北纬 28°22' ~ 29°45', 东经 115°47' ~ 116°45'), 是长江流域的一个重要的季节性湖泊, 汇集了赣江、修水、饶河、信江和抚河等河流, 经九江市湖口县城注入长江, 在调节长江水位和储存水资源方面发挥着重要作用^[28]. 无脊椎底栖动物以三角帆蚌、铜锈环棱螺和圆顶珠蚌等为优势种.

1.2 样品采集

采样工作于 2020 年 10 月进行, 在赣江北支、信江、饶河、修水和抚河入湖口、鄱阳湖出湖口以

及南矶山湿地国家级自然保护区共设置了 7 个样地(图 1). 每个样地设置 3 个样点, 样点之间至少间隔 3 km, 共计 21 个样点. 从每个样点采集 60 个样本, 随机分为 3 组重复, 每组 20 个样本. 使用不锈钢捞网收集样品后用铝箔包裹在 4℃ 的冷藏柜, 运送实验室后尽快处理.

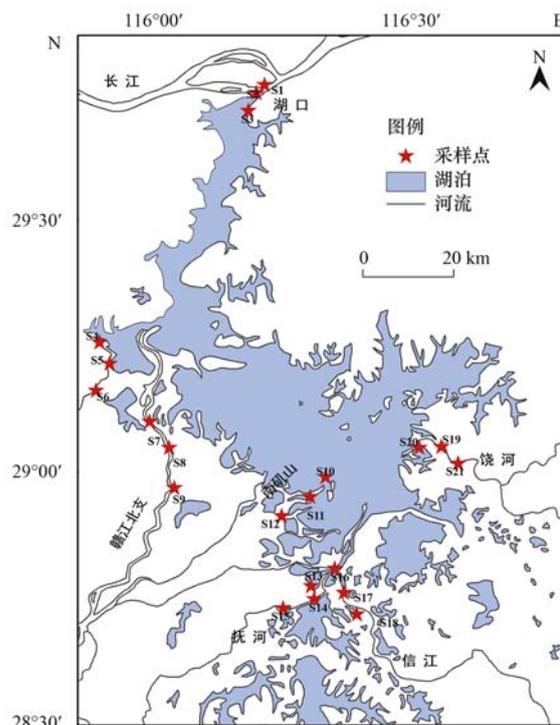


图 1 采样点位置及鄱阳湖周边河流分布示意

Fig. 1 Geographic position of sample sites and the distribution of rivers around Poyang Lake

1.3 样品处理

处理前测量铜锈环棱螺的生物数据(壳的长度、宽度和高度). 所有铜锈环棱螺的样品用双蒸水进行清洗再解剖. 为避免清洗过程中造成微塑料的损失, 仅对外壳清洗, 铜锈环棱螺的所有软组织和粘液进入下一步分析. 剖开软体部分, 获得肠道和肌肉组织, 用精密电子天平称重. 微塑料分离操作如下: 将样品放在 500 mL 的烧杯中, 先后加入 30 mL 由 H₂O₂ 和 HNO₃ 制成的混合试剂^[29]. H₂O₂ 与 HNO₃ 的比例为 1:3, H₂O₂ 浓度为 30%, HNO₃ 为 65%. 然后用铝箔覆盖烧杯口以防止污染, 置于恒温振荡水槽中加热到 60℃ 恒温振荡, 直至软组织全部消解完毕, 剩余的硝酸被蒸发掉. 烧杯放置冷却后, 将 500 mL 经 2 μm 滤膜过滤、密度为 1.2 g·cm⁻³ 的饱和氯化钠溶液, 加入到冷却的消解液中静置 24 h 浮选分离. 然后通过真空过滤装置(GM-0.33A)过滤上清液, 收集滤膜(孔径为 5 μm). 将滤膜保存于玻璃培养皿中, 盖上盖子置于烘箱烘干, 进行下一步分析.

1.4 微塑料的鉴定

将滤膜置于金相显微镜 NK-900(上海精密仪器公司)下,以从左到右的 Z 字形镜检,观察整个滤膜,对微塑料进行识别、计数和拍照,并记录其物理特性.为减少误差,以上鉴定操作均由同一个人完成.使用 Nano Measure 1.2 软件进行计数,颗粒大小被记录为微塑料颗粒最长边的长度^[30].记录微塑料的数量、形状、颜色和大小.微塑料形状分为:纤维、薄膜、颗粒和碎片.微塑料粒径分为:0~1、1~3 和 3~5 mm.

本研究中进行了微塑料回收率的测定,通过显微镜和红外光谱测定,从组织消化物中回收微塑料的比例为 90%.

1.5 数据分析

铜锈环棱螺样品中的微塑料丰度(湿重)以 $n \cdot g^{-1}$ 表示(平均值 \pm 标准差).使用 Arcgis 10.2 (ESRI, Redlands, CA, USA) 绘制样点地图,使用 Origin 2019 绘制图表.采用单因素方差分析 (ANOVA) 来检验不同样地样品的微塑料丰度差异.当 $P < 0.05$ 时,表示差异具有显著性统计学意义.

2 结果与分析

2.1 铜锈环棱螺体内微塑料丰度和分布

鄱阳湖典型区铜锈环棱螺微塑料丰度为 $(0.52 \pm 0.15) \sim (2.48 \pm 0.90) n \cdot g^{-1}$.南矾山湿地自然保护区铜锈环棱螺(S10~S12)微塑料的平均丰度显著低于五河入湖口(S4~S9 和 S13~S21)及出湖口(S1~S3) ($P < 0.05$).南矾山湿地自然保护区样品微塑料丰度为 $(0.52 \pm 0.15) n \cdot g^{-1}$,五河入湖口微塑料丰度($n \cdot g^{-1}$) 范围为: (1.67 ± 0.22) (抚河) ~ (2.48 ± 0.90) (赣江北支),以赣江北支铜锈环棱螺的微塑料丰度最高(图 2).五河入湖口、出湖口和南矾山湿地自然保护区的铜锈环棱螺体内微塑料的

分布如图 3 所示,微塑料丰度从高到低依次为:赣江北支 > 湖口 > 信江 > 饶河 > 修水 > 抚河 > 南矾山湿地自然保护区.

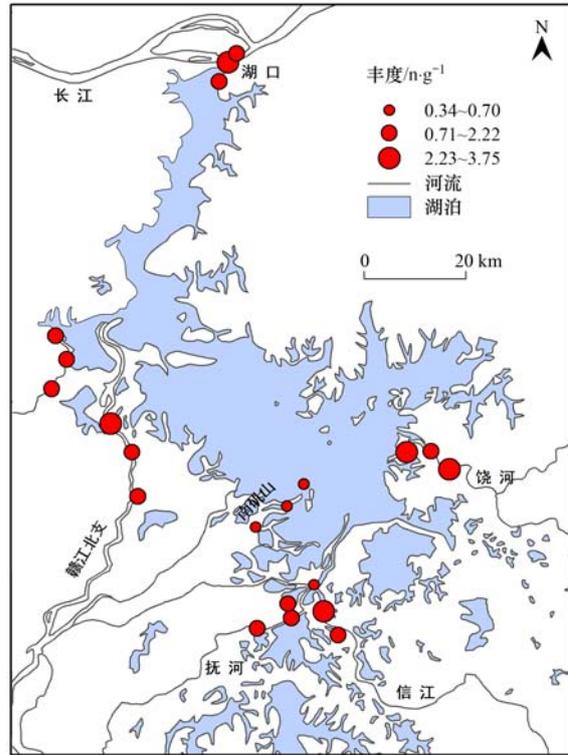
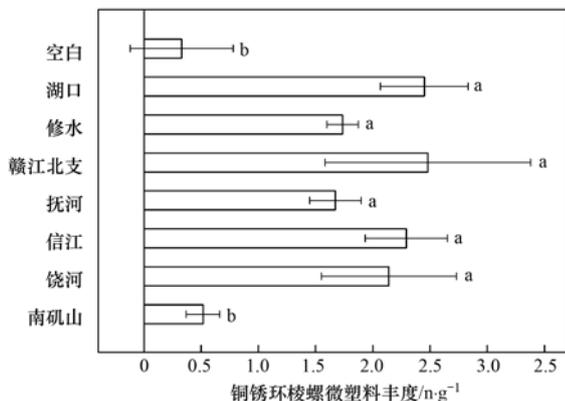


图 3 铜锈环棱螺微塑料丰度和分布情况

Fig. 3 Abundance and distribution of microplastics detected in *B. aeruginosa*

2.2 铜锈环棱螺体内微塑料的形状、颜色和粒径

鄱阳湖五河入湖口、出湖口和南矾山自然保护区铜锈环棱螺体内微塑料类型包括颗粒、碎片、薄膜和纤维这 4 种类型(图 4 和图 5).纤维在所有样点铜锈环棱螺体内所占比例均最高(约 50%~70%),薄膜在所有样点铜锈环棱螺中的所占比例最低(低于 10%).



不同小写字母表示差异显著 ($P < 0.05$)

图 2 铜锈环棱螺微塑料丰度

Fig. 2 Abundance of microplastics in *B. aeruginosa*

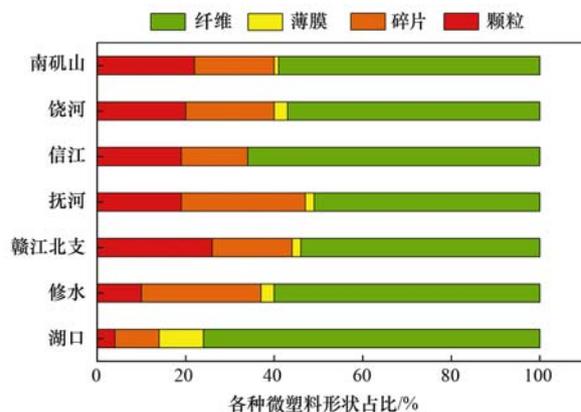


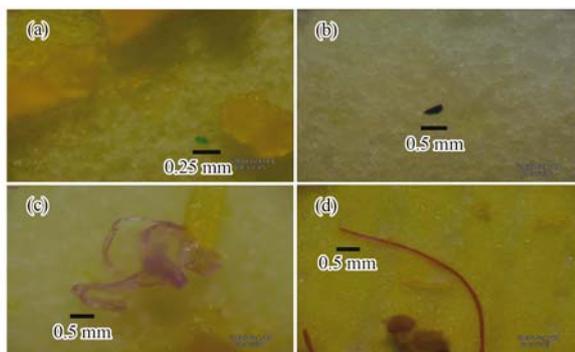
图 4 不同类型微塑料占比

Fig. 4 Four frequently observed shapes of microplastics (MPs)

研究区铜锈环棱螺体内微塑料粒径分为 0~1、1~3 和 3~5 mm.结果显示, < 1 mm 的微塑料最

多,占比40%左右,其次是1~3 mm微塑料,3~5 mm微塑料占比最少[图6(a)].

研究区铜锈环棱螺体内微塑料的颜色以彩色、黑色和透明为主[图6(b)].各样点除赣江北支和抚河入湖口铜锈环棱螺体内有白色微塑料外,其余样点组成和占比基本一致,其中透明微塑料占比比较大(约30%~60%).



(a)颗粒;(b)碎片;(c)薄膜;(d)纤维

图5 微塑料显微图

Fig. 5 Microplastic micrograph

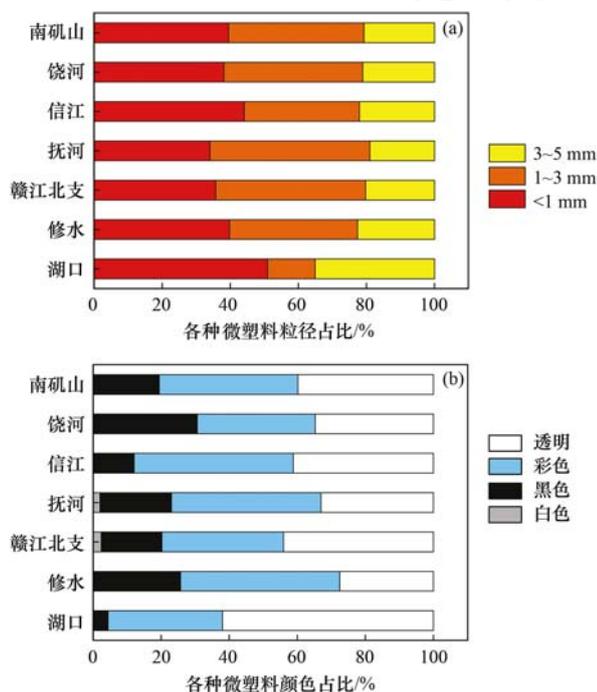
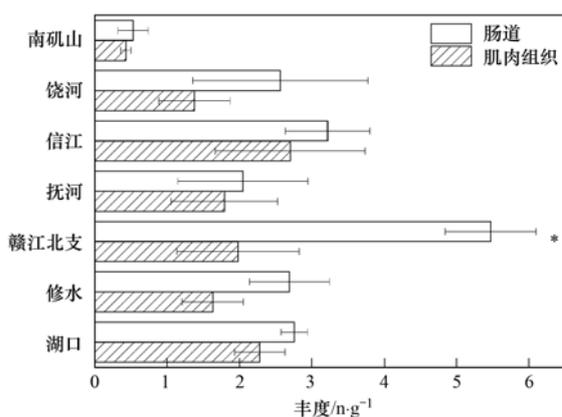


图6 不同样地微塑料粒径和颜色占比

Fig. 6 Comparison of microplastics by the categories of size and color in different sites

2.3 铜锈环棱螺不同部位微塑料丰度

本研究表明,鄱阳湖五河入湖口、出湖口和南矶山湿地国家自然保护区铜锈环棱螺肠道的微塑料含量均高于肌肉组织中,其中赣江北支铜锈环棱螺肠道的微塑料含量显著高于肌肉组织中($P < 0.05$),其余样点差异不显著($P > 0.05$)(图7).



*表示 $P < 0.05$

图7 铜锈环棱螺不同部位微塑料丰度比较

Fig. 7 Comparison of microplastic abundance in the different organs of *B. aeruginosa*

3 讨论

3.1 鄱阳湖典型区铜锈环棱螺体内微塑料的空间分布

本研究中赣江北支入湖口的铜锈环棱螺体内微塑料丰度最高,其次是信江入湖口和出湖口.赣江北支、饶河和信江均流经人类活动频繁的地区,居民生产生活产生的大量塑料垃圾会进入河流并在入湖口汇集,其次当地渔业、工业活动和防洪措施等遗留的塑料垃圾也会在入湖口汇集^[31, 32].人类的捕鱼活动使得渔网和渔线被遗弃在环境中,渔网和渔线在长期的环境影响下被分解成微小的纤维状碎片.工程中用于防洪的塑料编织袋以及农业生产中用于施肥的编织袋,都会降解并进一步产生大量的微塑料.在对五河入湖口水体与沉积物微塑料研究中,赣江与饶河的水体及沉积物均含有大量的微塑料^[27, 33].在本研究中,赣江北支、饶河和出湖口铜锈环棱螺体内均含有丰度较高的微塑料.与其他样点相比,南矶山湿地自然保护区受人类活动的影响小,环境相对封闭,微塑料输入也较少^[31],南矶山自然保护区铜锈环棱螺体内微塑料丰度显著低于其他样点.本研究表明环境中的微塑料含量越高,被铜锈环棱螺所摄取微塑料越多.这一结论在 Fernández 等^[34]的室内控制研究中被证实,其结果表明在高浓度微塑料中,贻贝对微塑料的摄入增加了.

3.2 铜锈环棱螺体内微塑料累积分布

本研究中鄱阳湖典型区铜锈环棱螺微塑料丰度为 $(0.52 \pm 0.15) \sim (2.48 \pm 0.90) \text{ n} \cdot \text{g}^{-1}$,有研究表明韩国市场双壳类体内微塑料的平均丰度为 $(0.15 \pm 0.20) \text{ n} \cdot \text{g}^{-1}$ ^[35].中国青岛当地市场双壳类样品中微塑料的丰度为 $0.16 \sim 0.74 \text{ n} \cdot \text{g}^{-1}$ ^[36].印度东南部马纳尔湾牡蛎中微塑料的平均丰度为 $(0.81 \pm$

0.45) $n \cdot g^{-1}$ [37]. 在中国东海枸杞岛的田间调查中发现贻贝体内微塑料丰度为 3.69 ~ 9.16 $n \cdot g^{-1}$ [20]. 中国黄海底栖动物组织中微塑料丰度为 1.7 ~ 47.0 $n \cdot g^{-1}$ [38]. 而在美国劳伦斯河贻贝中未检测到微塑料 [39]. 太湖的河蚬体内微塑料平均丰度值为 0.2 ~ 12.5 $n \cdot g^{-1}$ [40], Su 等 [41] 的研究表明长江中下游河蚬体内平均丰度值 0.4 ~ 5.0 $n \cdot g^{-1}$, 可见, 鄱阳湖典型区底栖动物体内微塑料丰度水平在国内外海洋和淡水底栖动物处于中等水平.

本研究中, 铜锈环棱螺体内最常见的微塑料形状是纤维, 占比为 51% ~ 76%. 铜锈环棱螺所摄取微塑料颜色以透明为主, 从粒径上来看, < 1 mm 的颗粒数量最多. 研究表明韩国市场双壳类体内微塑料的形态和尺寸以碎片和小于 300 μm 的颗粒为主, 分别占微塑料总量的 76% 和 65% [35]. 纤维微塑料是中国青岛当地市场双壳类样品中分离出的最主要的微塑料, 占总数的 70% 以上 [36]. 印度东南部马纳尔湾牡蛎中纤维是主要的微塑料类型, 其中 0.25 ~ 0.5 mm 的聚乙烯纤维最为常见 [37]. Wang 等 [38] 的研究表明, 中国黄海底栖动物中以纤维、透明和小微塑料为主. 中国山东半岛周边扇贝体内微塑料颜色以黑色、透明和蓝色为主, 微塑料的尺寸范围为 5 μm ~ 1 mm [42]. 本研究结果与以往研究的结果相一致. 这可能是因为纤维颗粒更容易被粘附. 此外, 纤维状的微塑料容易与其他物体纠缠在一起, 且具有一定程度的柔韧性, 不容易破碎, 使得纤维比其他形状的微塑料更难从生物体内排出 [34]. 摄入的微塑料颗粒的形状也与其在生物体内的停留时间有关, 纤维会在一些生物群体中积累 [38]. 微塑料的颜色也被认为是摄入的微塑料的一个重要影响因素, 生物会优先摄入更可能与猎物相似的颜色 [43]. 粒径较小的微塑料更容易进入生物体 [44], 且粒径小的微塑料的排出效率低于粒径大的微塑料, 其更容易在生物体内残留 [45, 46].

3.3 微塑料在铜锈环棱螺特定部位的赋存情况

本研究中赣江北支铜锈环棱螺肠道中的微塑料含量显著高于肌肉组织中, Kolandhasamy 等 [19] 的研究发现, 微塑料在不同肌肉器官中的丰度明显不同, 肠道中的微塑料丰度最高. Von Moos 等 [45] 的研究表明残留贻贝体内的微塑料主要在消化腺. 研究表明扇贝的肛门、肠道和肾脏中微塑料的浓度明显高于其他组织 [42]. 因为生物会由于无法区分微塑料和食物颗粒而误食微塑料 [34]. 本研究中铜锈环棱螺经常生活于水生植物、岸边的岩石和多色腐殖质沉积物上. 它使用其腹足的收缩来爬行, 并通过刮食的方式获取食物, 铜锈环棱螺在刮食时可能误食微塑料, 生

物摄入的微塑料会在肠道中积累. 此外, 研究发现粘附也可能是生物摄入微塑料的另一种机制 [19], 微塑料的粘附导致了那些不参与摄入过程的器官中微塑料的积累. 铜锈环棱螺在爬行时微塑料被粘附在腹足表面的粘液上, 进而进入体内, 导致了微塑料在肌肉组织中的积累.

微塑料被生物摄入后, 就会以粪便颗粒的形式被排出, 或者在组织中累积, 从而会对生物体产生威胁 [34]. 微塑料进入生物体内可能的影响包括肠道堵塞、进食和能量分配的改变, 并对广泛的生理过程产生连锁反应 [47]. 有研究表明接触微塑料后, 海洋贻贝粪便和假粪便产量增加, 表明贻贝对非食用颗粒的排斥机制 [9]. 有研究观察到微塑料不仅附着在贻贝表面, 而且与足部融合. 由于足部对贻贝的健康至关重要, 微塑料的加入可能会损害足部的功能 [20]. 有研究显示微塑料会增强贻贝组织对其他污染物的吸收, 这表明微塑料可能提供了接触疏水污染物的额外途径 [48]. 微塑料在生物体内的积累可能对食物网构成威胁, 还需要进一步研究 [39]. 本研究结果表明, 微塑料污染在铜锈环棱螺中广泛存在, 而螺作为当地的特色食物之一, 其微塑料污染可能会对人类的食品安全造成威胁 [40], 本研究促进了人类接触微塑料现状的认识, 并强调需要监测湖泊环境和水产养殖中的微塑料, 以保障水产品安全.

4 结论

本研究表明, 微塑料在鄱阳湖五河入湖口、出湖口和南矶山自然保护区的铜锈环棱螺中广泛存在, 其丰度为 $(0.52 \pm 0.15) \sim (2.48 \pm 0.90) n \cdot g^{-1}$, 南矶山自然保护区的铜锈环棱螺丰度显著低于其他河口样品 ($P < 0.05$). 铜锈环棱螺体内微塑料类型主要包括颗粒、碎片、薄膜和纤维这 4 种类型, 粒径以 < 1 mm 为主, 颜色多为透明或彩色. 铜锈环棱螺肌肉组织中微塑料的丰度低于肠道中, 这可能与其刮食的取食方式有关, 其对微塑料的摄取, 也可能是微塑料颗粒被其腹足粘液所粘附导致.

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