西沙群岛海域表层海水中微塑料的组成与分布特征

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摘要 西沙群岛作为我国最大的海洋珊瑚礁区, 目前对于微塑料这类新型海洋污染物的研究仍鲜见报道. 本研究以西沙群岛海域30个表层海水中采集的微塑料为样本, 对微塑料的空间分布、组成及可能的来源进行了定性和定量分析. 结果表明: (1) 微塑料广泛存在于西沙群岛海域表层海水中, 丰度在10~130个/m³, 长度多在1~3 mm之间(64.8%), 形态主要为纤维和薄膜, 颜色多属透明(56.8%)和蓝色(40.2%), 化学组分主要是聚对苯二甲酸乙二醇酯(56.2%)和聚丙烯(20.3%). (2) 微塑料在西沙群岛海域表层水体中空间分布不均, 其分布主要受海水运动、人类活动以及地形地貌特征的影响. 与国内外已有研究结果相比, 西沙群岛海域表层海水中的微塑料整体处于较低的含量水平. (3) 对微塑料形态特征和化学组成的分析表明, 西沙海域高强度的渔业活动以及岛上人类活动释放的塑料垃圾可能是其主要来源.

关键词 微塑料, 表层海水, 分布组成, 西沙群岛

近年来, 海洋微塑料污染已发展成为全球性的重大环境问题^[1]. 目前, 凡是直径小于5 mm的塑料纤维、颗粒或薄膜即可认定为微塑料^[2]. 与大尺寸的海洋塑料垃圾相比, 微塑料在环境中丰度更高、分布更广, 在全球水体、沉积物、大气、冰川中都有广泛分布, 是一类新兴的环境污染物^[3]. 由于微塑料粒径小, 极易被不同营养级生物摄入体内, 所以微塑料及其负载污染物可在生物体中蓄积、迁移与传递, 危及生态环境安全与人体健康^[4]. 2011年, 联合国环境规划署(UNEP)将微塑料污染列为全球面临的一个新的环境问题和挑战, 并敦促各沿海国家尽快加强海洋微塑料的科学研究和相关法律工作. 据统计每年约有115~241万t塑料垃圾经

全球河流汇入海洋^[5], 塑料污染每年造成的海洋生态经济损失高达130亿美元. 我国作为塑料生产与使用大国, 所面临的微塑料污染问题尤为严峻. 然而, 目前我国有关海洋微塑料研究尚处于起步阶段, 对于微塑料污染分布及生态影响仍缺乏深入认识.

西沙群岛是我国最大的珊瑚礁分布海域, 以珊瑚和贝屑为主组成的珊瑚岛礁40余座, 拥有珊瑚生物54种、珊瑚礁鱼类432种、底栖甲壳动物41种、贝类26种. 珊瑚礁生态系统具有十分重要的生态、经济、国土和文化价值, 但珊瑚礁也是一个敏感脆弱的生态系统, 易受到环境变化和人为活动的影响^[6,7]. 众多研究证据表明, 微塑料能在生物体中积累, 从而对生物体自

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身及食物链(网)产生危害^[8]. 西沙群岛海域的微塑料污染极有可能威胁到该区域内的水生生态安全, 然而目前关于微塑料这类环境新型污染物在西沙海域的时空分布、污染来源等仍缺乏量化研究. 鉴于西沙群岛海域具有丰富的生物多样性以及南海重要的国防地位, 开展西沙群岛海域的新型污染物微塑料相关研究意义重大.

1 材料与方法

(i) 调查站位. 2019年4~5月在南海西沙的永兴岛和七连屿海域(16°36'~17°00'N, 112°12'~112°30'E)共采集了30个表层海水样品, 采样布设站位见图1.

(ii) 样品采集. 将不锈钢潜水泵(220 V)用钢丝绳(直径3 mm)连接于船舷绞车. 采样时, 将潜水泵吊出下放至0.5~1 m水深处, 收集100 L的表层海水样品于去离子水润洗过的海洋桶中. 使用20 μm 孔径的微孔尼龙滤膜(Millipore, NY20)现场负压过滤海水样品, 得到的滤膜样品小心放入洁净玻璃培养皿中, 并用锡纸覆盖保存. 在采集微塑料样品的同时, 各站位均采集了海水悬浮物样品, 并现场测定了海水的pH、温度、盐度和溶解氧. 微塑料样品的采集、预处理、室内分析与鉴定方法参照文献^[9].

(iii) 样品处理. 将现场过滤得到的滤膜转入250 mL干净玻璃锥形瓶内, 用少量去离子水仔细冲洗培养皿内部并一同转入锥形瓶, 加入150 mL过氧化氢溶液(体积分数30%)并用锡纸封口, 在80 r/min、65°C的条件下于恒温振荡箱中消解24 h, 去除样品多余有机杂质. 消解完成后, 将滤纸取出并用去离子水仔细冲洗, 随后移出全部液体并用20 μm 孔径的尼龙滤膜过滤, 滤膜保存于洁净培养皿中, 锡纸封盖保存以备镜检.

(iv) 样品分析. 使用奥林巴斯体式显微镜(SZX10, Tokyo, 日本)镜检分类微塑料. 利用显微镜自带影像系统(DP80, Tokyo, 日本)对微塑料进行拍照, 由Image J软件(National Institutes of Health, 美国)测量微塑料尺寸. 根据形状、颜色和粒径特征对其进行分类, 然后从各采样点随机选取部分微塑料样品进行成分分析. 使用配备MCT检测器的显微红外光谱仪(Nicolet iN 10, Thermofisher, 美国), 在4000~400 cm^{-1} 波长范围内对样品连续扫描16次, 利用配套的OMNIC软件进行数据库检索, 成分鉴定条件为匹配度大于80%.

(v) 质量控制. 海上现场采样过程中, 于采样点附近将润湿的20 μm 孔径滤膜置于洁净培养皿中作为环境背景值. 室内实验开始前, 实验者佩戴棉质实验服、

图1 西沙群岛微塑料采样站位图

Figure 1 The sampling stations of microplastics in Xisha Islands

口罩和丁腈手套, 70%酒精擦洗实验桌面, 使用 $0.7\ \mu\text{m}$ 孔径的玻璃纤维滤膜(Whatman, GF/F)过滤去离子水. 实验中设置室内环境污染背景对照及实验组空白对照, 并及时用锡纸覆盖容器.

2 结果

2.1 微塑料的丰度及空间分布

在采集到的30个表层海水样品中均检测出微塑料, 表明在西沙表层海水中微塑料普遍存在. 微塑料的丰度在 $10\sim 130\text{个}/\text{m}^3$ 之间, 平均丰度为 $54.7\text{个}/\text{m}^3$. 全部站位中, 丰度小于 $10\text{个}/\text{m}^3$ 的站位有4个, 占总数的13%; 丰

度在 $10\sim 100\text{个}/\text{m}^3$ 之间的站位有24个, 占比80%; 丰度大于 $100\text{个}/\text{m}^3$ 的站位有2个, 分别为S2和S21站位, 含量均为 $130\text{个}/\text{m}^3$ (图2).

2.2 微塑料的形态特征

样品测试结果显示, 微塑料的长度范围在 $0.02\sim 5\text{ mm}$ 之间. 检测出的大部分微塑料长度小于 3 mm , 其中长度在 $0.02\sim 1\text{ mm}$ 的约占总数的32.1%, 长度介于 $1\sim 3\text{ mm}$ 的约占64.8%, 只有极少一部分微塑料的长度大于 3 mm (图3).

将微塑料样品按颜色不同分为五类: 透明、蓝色、黑色、绿色和红色. 不同颜色微塑料所占比例分

图2 微塑料在西沙群岛表层水体中的丰度与分布

Figure 2 Abundance and distribution of microplastics detected in surface seawaters of Xisha Islands

图3 微塑料样品的形态特征。(a) 尺寸; (b) 颜色; (c) 类型

Figure 3 Morphological characteristics of microplastic samples. (a) Sizes; (b) colors; (c) types

别为: 透明56.8%、蓝色40.2%、黑色1.2%、绿色1.2%、红色0.6%(图3)。

检测出的微塑料按其形态可划分为两类: 纤维和薄膜(图3)。纤维状指直径较小, 长径较大, 呈现细丝状的塑料; 薄膜状指表面较平整, 厚度较小的塑料。其中纤维状微塑料是主要表现形态, 占比99%; 薄膜状微塑料检出较少, 仅占总数的1%。

2.3 微塑料的化学组成

对样品中的116个疑似微塑料使用MCT检测器的显微红外光谱仪进行检测, 结果如表1所示。西沙海域表层水体中微塑料的主要化学组分是聚对苯二甲酸乙二醇酯(PET), 占比56.2%; 聚丙烯(PP)占比20.3%, 聚醋酸乙烯酯占比6.3%, 其他各种成分占比17.2%。

表 1 西沙海域表层水体中微塑料的化学组成

Table 1 Chemical compositions of microplastics in the surface seawaters of the Xisha Islands

塑料的化学成分	英文名称	百分比 (%)
聚对苯二甲酸乙二醇酯	Polyethylene terephthalate	56.2
聚丙烯	Polypropylene	20.3
聚醋酸乙烯酯	Poly(vinyl acetate)	6.3
聚酰胺	Polyamide	4.7
聚乙烯	polyethylene	4.7
聚酯	Polyester	3.1
(氰乙烯-丙烯-丙烯酸酯)共聚物	Poly(acrylonitrile-styrene-methyl acrylate)	3.1
聚(5-甲基己内酰胺)	Poly(5-methyl caprolactam)	1.6

3 讨论

3.1 微塑料的分布及其影响因素

通过研究发现,微塑料广泛分布于西沙海域表层水体中,但其分布不均。海洋中微塑料的分布受多种因素影响,主要包括:污染源、地形和水动力条件等^[10]。从微塑料丰度分布(图2)可以看出近岸站位普遍偏高,表明陆源输入应该是微塑料的主要来源之一^[11]。相关研究表明在开阔海域微塑料的分布主要受海流运动影响^[12],取样时正值南海春夏季风转换期,随着东北季风的衰退,西南季风逐渐形成,在西沙群岛附近主要为东北向海流^[13],表层流会对海水中的微塑料进行输运,并且由于浅水珊瑚礁和环礁的三维结构会显著降低波浪能,容易导致较多的微塑料在珊瑚礁周围沉降与累积^[14,15]。

然而在调查中发现仍有部分近岸站位(S12、S19、S22)的微塑料丰度较低。为了进一步了解造成微

塑料分布不均的原因,通过Pearson分析法对微塑料及主要环境因子进行相关性分析。结果显示微塑料的丰度与海水pH、温度、盐度、悬浮物、溶解氧以及离岸距离之间的相关性并不显著(表2),与李征等人^[16]在海州湾的研究结果有所不同。其原因可能是西沙海域属于开阔海域,平均水深较浅、悬浮物浓度较低,环境因子之间的差异并不显著,同时亦表明在西沙海域这些环境因子并不是影响表层海水中微塑料分布的主要因素。考虑到西沙海域复杂的海底地形条件,岛礁周边地形较陡,小型侵蚀冲刷槽高度发育,是内潮的多发区,内潮波会引起强烈的海水混合或形成上升流^[17],使部分中深层水到达海表面,这种海水混合会导致污染物浓度的稀释,这有可能是部分近岸站位微塑料丰度较低的原因。

总体而言,陆源输入主要影响沿岸和近岸海域内的微塑料分布,距海岸较远的开阔海域,微塑料的分布主要受海水运动影响,人类活动以及地形地貌特征亦是影响微塑料分布的主要因素^[18]。微塑料在海洋中的不均匀空间分布可能是多种因素共同作用的结果。

3.2 微塑料丰度分析

目前微塑料样品的采集方法通常包括拖网取样、潜水泵取样以及两种方式的混合取样^[19],但网具/滤膜孔径的选择会影响实际的检测结果,孔径较大意味着可能会遗漏部分较小的微塑料,得出的调查数据可能比实际偏低^[20]。本研究选取了一些在近似孔径条件下的研究成果进行对比,结果如表3所示。与国外相比,西沙海域表层海水中微塑料丰度要远低于太平洋东北部^[21]和韩国东南沿岸^[22],与吉隆坡(关丹港)的微塑料丰度相近^[23]。与国内相比,调查区微塑料丰度低于黄海北

表 2 微塑料丰度与环境因子之间的相关性^{a)}

Table 2 Correlation between microplastic abundance and environmental factors

项目	微塑料	pH	温度	盐度	悬浮物	溶解氧	离岸距离
微塑料	1						
pH	0.344	1					
温度	0.383	0.455*	1				
盐度	-0.260	0.438*	0.105	1			
悬浮物	0.207	-0.210	-0.329	-0.218	1		
溶解氧	0.026	-0.352	-0.531**	-0.525**	0.298	1	
离岸距离	0.106	-0.124	-0.016	-0.337	0.336	0.341	1

a) **表示双尾检验在0.01水平下相关性显著,*表示双尾检验在0.05水平下相关性显著,N=30

表 3 国内外部分海区的微塑料特征的比较

Table 3 Comparisons on microplastic characteristics in some sea areas at home and abroad

研究水域	丰度(个/m ³)	主要类型	孔径(μm)	数据来源
太平洋东北部	8~9200	纤维、碎片	62	[21]
韩国东南沿岸	260~1410	泡沫、薄膜、纤维	50	[22]
吉隆坡(关丹港)	130~690(140~150)	纤维、碎片	20	[23]
黄海北部	545±282	薄膜、纤维	30	[24]
中国沿岸贻贝养殖区	680~6440	纤维、碎片	20	[25]
南海	300~7467	纤维、碎片	44	[26]
南海渚碧礁	1400~8100	微珠、纤维	50	[27]
南海西沙海域	10~130	纤维、薄膜	20	本研究

部^[24], 但与沿岸贻贝养殖区^[25]以及整个南海的微塑料丰度^[26]相比差距较大, 尤其是南海的渚碧礁海域, 微塑料平均丰度高达 4933 ± 1369 个/m³^[27]. 从国内外的对比情况来看, 目前西沙海域表层海水中的微塑料整体处于较低的含量水平. 但由于本研究选用的滤膜孔径是 20 μm, 能否反映西沙海域微塑料的真实含量水平还有待进一步研究.

3.3 微塑料污染来源解析

基于物理形态和化学组分的精细分类有助于更准确地反映微塑料的潜在来源^[28]. 在表层海水样品中, 纤维是主要的微塑料表现类型(99%), 颜色多为透明(56.8%)和蓝色(40.2%). 纤维是微塑料中的一类, 在河流、河口、海洋水生系统和生活污水中被证明是主要的微塑料形态^[29]. 合成纤维广泛用于服装制造和生产工具(渔网、绳索、鱼线等), 已有研究表明海岸线周边环境中很大一部分纤维可能来自清洗衣物产生的生活污水^[30]. 在我们的研究中, 纤维平均直径为 1.42 mm, 大于 1 mm 的纤维占 67.9%, 而污水处理系统排放的纤维长度通常介于 0.355~1 mm 之间^[31]. 此外检测出的纤维化学成分主要是 PET(56.2%)和 PP(20.3%), 这两种成分的塑料抗腐蚀性和抗剪切性能力较差, 意味着它们一旦长时间暴露在自然环境中, 将经受紫外线辐射、高温、剪切力等长期的物理化学作用, 最终会降解、分裂成为尺寸更小的塑料颗粒, 粒径甚至小于 100 μm^[32], 因此表层海水中大直径的微塑料纤维表明其被搬运的时间和距离不是很长, 推断西沙海域高强度的渔业活动可能是其主要来源. 考虑到本次调查海域环绕永兴岛和七连屿, 近年来政府加大了西沙岛礁的开发和建

设力度, 岛上人类活动频繁, 并且前人在西沙主要岛礁的土壤样品($60\pm3\sim610\pm11$ 个/kg)^[33]以及栖息的海鸟体内均检测出微塑料^[34], 由此我们推断岛上人类活动产生的塑料垃圾亦可能是表层海水中微塑料的来源之一.

3.4 展望

研究表明, 海洋微塑料已成为珊瑚礁生态系统中的一类新型污染物, 并可能对珊瑚礁生态系统产生重要影响^[35,36]. 在西沙群岛的珊瑚骨骼表面及珊瑚骨骼内均存在微塑料的积累, 在珊瑚礁鱼类样品的消化道和鳃中也均检测出微塑料^[37], 微塑料在生物体内的富集会产一定的危害和毒性效应, 从而可能影响生物群落的结构和组成^[38]. 在后续研究中我们将加强西沙群岛海域微塑料污染生态效应方面的研究.

4 结论

(1) 微塑料广泛存在于西沙海域表层海水中, 平均丰度 54.7 个/m³; 尺寸范围主要介于 1~3 mm 之间, 占比为 64.8%; 形态主要为纤维和薄膜, 颜色多属透明和蓝色; 化学成分主要为 PET 和 PP, 分别为总体的 56.2% 和 20.3%.

(2) 微塑料在西沙海域表层水体中分布不均, 其分布主要受海水运动、人类活动以及地形地貌特征的影响. 与国内外已有研究结果相比, 西沙海域表层海水中的微塑料整体处于较低的含量水平.

(3) 纤维是西沙海域表层海水中主要的微塑料表现形态, 其物理形态和化学成分的分析表明西沙海域高强度的渔业活动以及岛上人类活动释放的塑料垃圾可能是其主要污染来源.

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Summary for “西沙群岛海域表层海水中微塑料的组成与分布特征”

Composition and distribution of microplastics in the surface seawater of Xisha Islands

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Marine microplastics are emerging pollutants in the ocean and have become a major global environmental issue in recent decades. However, microplastic pollution has not been frequently studied in the oligotrophic oceanic regions around the Xisha Islands, the largest marine coral reef area of China. In this study, microplastics in surface seawater were sampled from 30 stations in the region around the Xisha Islands. Marine microplastics were classified via a microscopic method using an Olympus stereo microscope. Microplastic photographs were taken by an inner imaging system, and the size of the microplastics was estimated using Image J software. Additionally, a portion of the microplastic samples was randomly selected for component analysis based on the shape, color, and size of the particles.

Our results indicate that microplastics are widely distributed in the surface seawater of the Xisha region. The abundance of microplastics was in the range of 10–130 pieces/m³, with an average value of 54.7 pieces/m³. The size range of microplastics was 0.02–5 mm with the length of 0.02–1 mm accounting for 32.1% and the length of 1–3 mm accounting for 64.8% of the total abundance. The microplastics from the Xisha region can be classified into five color types, namely transparent, blue, black, green, and red, with the average percentages being 56.8%, 40.2%, 1.2%, 1.2%, and 0.6%, respectively. Moreover, the local microplastics can be divided into fiber and film according to their morphology with fiber accounting for more than 99% of the total abundance. Polyethylene terephthalate (PET) and polypropylene (PP) were the two major chemical components of the microplastics, accounting for 56.2% and 20.3% of the chemical components, respectively.

The average concentration of microplastics in Xisha region is relatively lower than that in many other regions of the South China Sea, as well as that in other regions of the global oceans. Our results suggest that the spatial distribution of microplastics is influenced by water movement, anthropogenic activities, and topographic features in the Xisha region. Although there is a large spatial variation in the surface seawater in the Xisha region, the concentration of microplastics in the near-shore stations is typically high, which may indicate that the microplastics in these areas originate from terrestrial sources. On the other hand, a reduced wave energy due to the topographic structure of shallow coral reefs allows more microplastics to settle and accumulate in the nearshore waters around the islands. Meanwhile, there were nearshore stations (S12, S19, S22) with low microplastic abundance, particularly in areas with high internal tides caused by local topography, strong mixing or upwelling induced by internal tides, and waves. These phenomena can bring subsurface waters to the surface and thus lead to the dilution of surface seawater pollutants at the nearshore stations.

Analysis of microplastic morphology revealed the presence of large-diameter microplastic fibers in the surface seawater of the Xisha region, which may indicate that these microplastics are young in age. Most likely, they originated from recent fishery activities in the region, as both PET and PP are common types of plastics used in local fishery operations. Furthermore, microplastics have already been found in local soil samples and in the bodies of seabirds living on the Xisha Islands, due to an increase in island development and construction. Therefore, plastic waste discharge caused by increasing human activities may be another important source of microplastics to the surface seawater of the Xisha region.

microplastics, surface seawater, distribution and composition, Xisha Islands

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