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Microplastic abundance in gull nests in relation to urbanization

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ABSTRACT

Human activity and urbanization are having profound effects on natural landscapes and ecosystems. The presence and persistence of human-made materials such as microplastics can have major impacts on the health of organisms in both marine and terrestrial environments. We quantified microplastics in herring gull (*Larus argentatus*) and great black-backed gull (*Larus marinus*) nests at three colonies in the northeast United States that varied in their degree of urbanization: Jamaica Bay (JB) in New York City, Youngs Island (YI) on Long Island, New York, and Tuckernuck Island (TN) in Massachusetts. Nests in urban colonies contained a higher proportion of microplastics than those in the more remote colony. Our results link urbanization with microplastic accumulation in coastal environments and suggest that assessing microplastics in seabird nests could provide a means of evaluating microplastics encountered by seabirds and other coastal marine animals.

1. Introduction

Plastic pollution in marine environments is increasingly recognized as a complex and multi-faceted global environmental problem (Eriksen et al., 2013; Haward, 2018). Plastic materials have many desirable properties including strength, durability, low weight, resistance to degradation, and low production cost, which have in turn contributed to their role as a major pollutant in marine ecosystems (Gregory and Andrady, 2003; Laist, 1987). Global production of plastic resins and fibers has increased dramatically in recent decades from 2 million metric tons (Mt) in 1950 to an estimated 380 Mt. in 2015 (Geyer et al., 2017). Today, plastics are among the most ubiquitous pollutants in the world's oceans, entering marine systems via dumping from maritime activities and runoff from coastlines (Derraik, 2002).

Though definitions vary slightly, macroplastics and microplastics can be generally defined as plastics >5 mm in diameter and <5 mm in diameter, respectively (Arthur et al., 2009; NOAA, 2020). Both macro- and microplastics can have deleterious impacts on marine organisms (Gall and Thompson, 2015; Mattsson et al., 2017; Wright et al., 2013). While macroplastics pose a lethal threat to marine megafauna through entanglement and ingestion (Bjorndal et al., 1994; Coleman, 2018; Laist, 1997; NOAA, 2014), microplastics are a concern due to high surface area to volume ratios, which allow them to concentrate harmful pathogens and synthetic chemicals on their surfaces, many of which can bioaccumulate (Kirstein et al., 2016; Rios et al., 2007; Rochman et al., 2013). Thus, microplastics can act as vectors for contaminants throughout marine foodwebs in addition to posing a threat to the individual (Carbery et al., 2018; Colabuono et al., 2010; Wang et al., 2019). Occurring worldwide (Browne et al., 2011), a majority of microplastics in marine environments are secondary microplastics that result from the degradation or fragmentation of larger plastics (Gregory and Andrady, 2003). Discerning spatial and temporal patterns of plastic distribution in marine systems is critical to understanding the origin and ecological consequences of plastic pollution (Avio et al., 2017).

While several studies have sought to assess large-scale global distributions of microplastics (e.g., Cózar et al., 2014; Eriksen et al., 2013; Lebreton et al., 2012), the distribution of microplastics on smaller spatial scales has received less attention. Studies examining spatial trends in microplastics over smaller scales are needed to better understand how factors such as urbanization influence the distribution of microplastics and to inform local management of marine debris. Seabirds have been used as biological indicators of plastics (Ryan et al., 2009; Van Franeker et al., 2011; Van Franeker and Law, 2015) as they incorporate plastics into their nests and ingest macro- and microplastics while foraging (Cadée, 2002; Provencher et al., 2010; Savoca et al., 2016; Votier et al., 2011). Examining plastics within seabird nests provides a non-invasive means of assessing plastics encountered by seabirds and of assessing trends in space and time (Tavares et al., 2016). While many studies of plastics in seabird nests have focused on macroplastics (Jagiello et al., 2019; Tavares et al., 2019; Votier et al., 2011), we are not aware of any studies assessing microplastics in seabird nests.

Here, we examine the potential for using seabird nests to evaluate

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microplastic abundance relative to urbanization using herring gulls (*Larus argentatus*) and great black-backed gulls (*Larus marinus*) as study species. Gulls are well suited to studies assessing the impacts of urbanization as they show highly plastic behavior and thrive in both urban and more remote habitats (Fuirst et al., 2018; Shaffer et al., 2017). Additionally, they are prevalent coastal species in many parts of the world. We assess microplastics in gull nests at three colonies along the northeast of the United States that differ in the degree of urbanization and examine whether the abundance, type, and color of microplastics found in nests are linked to human pressure at the colony.

2. Materials and methods

2.1. Study area and sample collection

We collected nest samples from herring and great black-backed gulls during the chick-rearing period in 2018 at three study colonies along the northeast coast of the United States (U.S.), representing varying degrees of urbanization (Fig. 1). Jamaica Bay (JB) represents a highly urbanized site due to its proximity to New York City, the most populous city in the U.S., which has a population density of 27,012 people per square mile (United States Census Bureau, 2010). Young's Island (YI) is in Suffolk County, New York and represents an intermediate level of urbanization, with a population density of 1637 people per square mile (United States Census Bureau, 2010). Tuckernuck Island (TN) is located off the coast of Nantucket, Massachusetts, with a population density of 226 people per square mile, and represents the most remote colony (United States Census Bureau, 2010).

Nest samples were taken at random from colonies during tracking studies of herring gull habitat use (Fuirst et al., 2018) and were assumed to reflect the colony as a whole. Scoop samples of approximately 250 cm^3 of nest materials were taken by hand from the inner portion and outer edge of gull nests (Duffy and Campos de Duffy, 1986; Kim et al., 2017; Ramos et al., 2001) and assumed to represent the nest composition as a whole. Scoop samples were placed in plastic bags until further processing. Scoop samples were removed as consolidated masses, and no fallout of fine particulate matter was observed during the transferring of samples into plastic bags. A total of 82 herring gull nest samples were collected from all three colonies; 45 from JB, 23 from YI and 14 from TN. A total of 60 black-backed gull nest samples were collected from our two most urban colonies; 30 from JB and 30 from YI. Nest samples were brought back to the lab and allowed to air dry for a minimum of 2 months before processing.

2.2. Laboratory analysis

We assessed the presence, abundance, type, and color of microplastics within each nest sample. Samples were sieved using stacked 1.0 and 5.0 mm mesh sieves to separate nest and plastic materials into 3 size groups: >5 mm diameter, 1-5 mm diameter, <1 mm diameter. Large

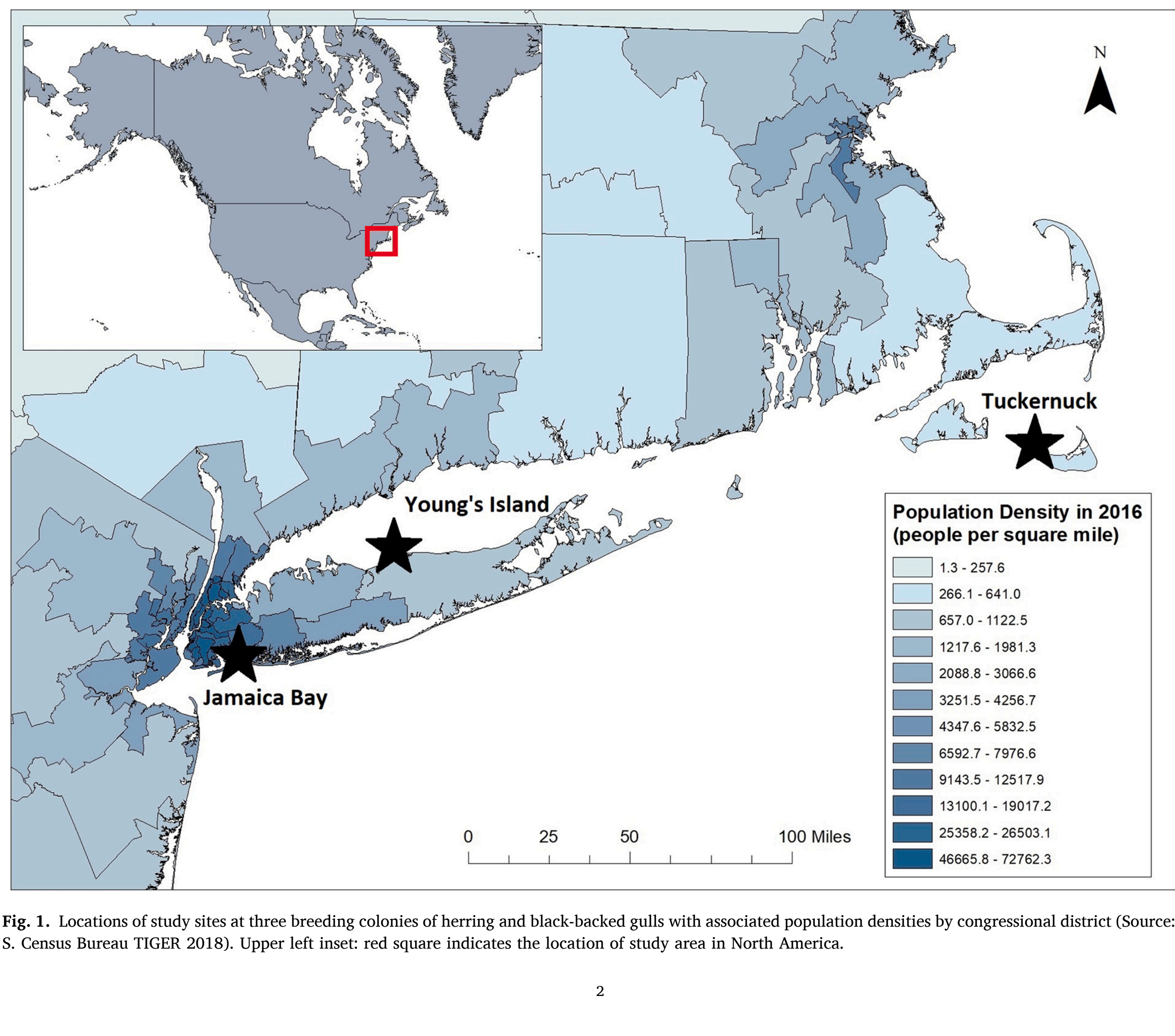

Fig. 1. Locations of study sites at three breeding colonies of herring and black-backed gulls with associated population densities by congressional district (Source: U. S. Census Bureau TIGER 2018). Upper left inset: red square indicates the location of study area in North America.

rocks and shells were removed before placing nest samples in the sieve to minimize fracturing of plastics that might occur during sieving. The presence of macroplastics (>5 mm) in nest samples was noted but not included in the analysis under the assumption that they were brought in purposefully by birds to use as nesting materials (Lopes et al., 2020; Votier et al., 2011). Microplastic pieces that were 1-5 mm in diameter, defined here as plastic pieces that passed through the 5 mm mesh but did not pass through the 1 mm mesh, were visually separated from natural nest materials with the aid of a 3″ diameter 5 diopter magnifying lamp (Brightech, Los Angeles, model #LTVP-CE-Bk). Because some biogenic material, such as fish bones, resemble plastic, an Olympus SZ60 microscope (Olympus, Tokyo, Japan) was used to further distinguish plastic and biogenic items. Only plastics 1-5 mm diameter were included in this analysis.

Microplastics were weighed to the nearest tenth of a milligram (mg) using a microbalance with readability up to 1×10^{-5} g while natural nest materials were weighed to the nearest hundredth of a gram (g) using a microbalance with a readability up to 1×10^{-3} g. Microplastic abundance was quantified for each nest by measuring the proportion of microplastic weight (mg) to natural nest material weight (g). Total number of microplastics in each nest was also quantified. Microplastics were then separated based on color and plastic type (rigid, flexible, coarse fibers, and foam). Rigid plastics included hard fragments and plastic resin pellets, flexible plastics included films and other pieces of plastic sheeting, and coarse fibers including various types of fishing line and net pieces. Plastic pieces that were of multiple colors were not included in the color analysis because they could not be sorted into any one color category, but all pieces were included in the plastic type analysis.

2.3. Statistical analysis

For herring and black-backed gulls, respectively, we assessed colony-level differences in the proportion of nests containing microplastics using a chi-squared test, where the expected values represented equal distribution of microplastics between colonies (i.e., the total number of nests across all colonies containing microplastics divided by the total number of nests sampled). Colony-level differences in microplastic abundance and total number of plastics per nest were assessed for herring gulls using Kruskal-Wallis tests with post-hoc Dunn's tests and

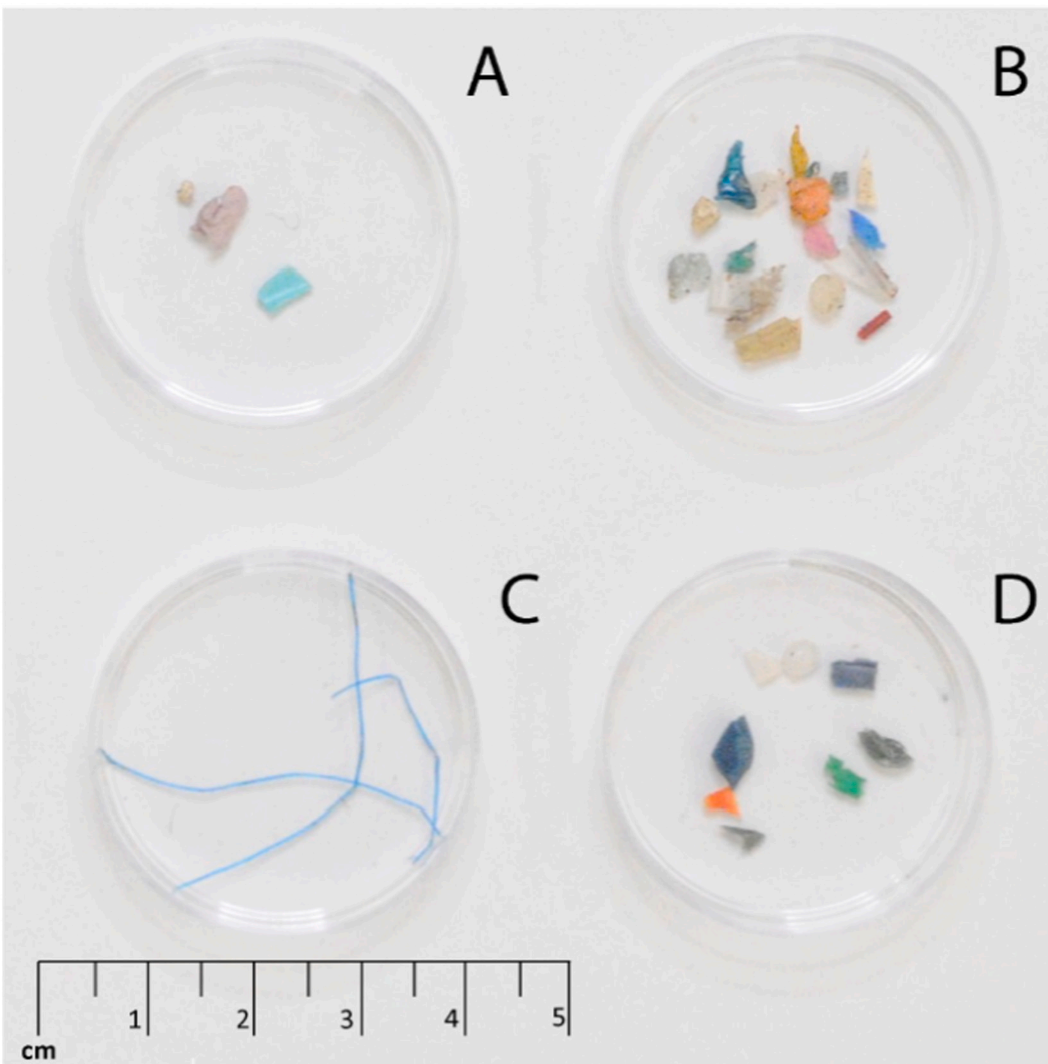

Fig. 2. Examples of microplastics found in gull nests, defined as any plastic particles that passed through 5 mm mesh but did not pass through 1 mm mesh of a sieve, for: Jamaica Bay sample number 5 (A; herring gull nest) depicting one rigid plastic and two foam pieces; Young's Island sample number 23 (B; herring gull nest) depicting many rigid plastics, one plastic resin pellet, and two foam pieces; Jamaica Bay sample number 31 (C; black-backed gull nest) depicting blue fishing twine; and Young's Island sample number 60 (D; black-backed gull nest) depicting all rigid plastics. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Bonferroni correction. As black-backed gull nests were only assessed at two colonies, colony-level differences for black-backed gulls were assessed using a Wilcoxon rank-sum test, as were within-colony species comparisons for both microplastic abundance and total number of plastics per nest. All statistical tests were performed in R version 4.0.2 (R Core Team, 2020) and all results were considered significant at $p < 0.05$.

3. Results

Microplastics were frequently observed in gull nests, occurring in 34.4% of herring gull nests and 43.3% of black-backed gull nests overall. Examples of microplastics observed in gull nests are shown in Fig. 2. The number of herring gull nests containing microplastics was not evenly distributed between the three study colonies ($\chi^2 = 8.07$, $p = 9.46 \times 10^{-3}$) with 47%, 56% and 0.07% of nests containing microplastics from JB, YI and TN, respectively (Fig. 3A). The abundance of microplastics per herring gull nest also differed significantly by colony (Kruskal-Wallis, $p = 5.914 \times 10^{-3}$; Fig. 4), with YI exhibiting a significantly higher abundance of microplastics per nest than TN (post-hoc Dunn's, $p = 2.00 \times 10^{-3}$). The abundance of microplastics at JB was higher than that of TN, though the difference was of borderline significance (post-hoc Dunn's, $p = 5.25 \times 10^{-2}$), and was not significantly different from that of YI (post hoc-Dunn's, $p = 1.57 \times 10^{-1}$). JB and YI both had a significantly higher number of microplastics per nest than TN (post-hoc Dunn's, $p = 3.78 \times 10^{-2}$; 2.30×10^{-3}; Fig. 5) but did not differ significantly from one another (post-hoc Dunn's, $p = 1.94 \times 10^{-1}$). Microplastic abundance and the number of plastics per nest did not differ significantly between species neither at JB (Wilcoxon rank-sum, $p = 4.21 \times 10^{-1}$; 6.40×10^{-2}) nor at YI (Wilcoxon rank-sum, $p = 7.15 \times 10^{-2}$; 8.81×10^{-2}).

The number of black-backed gull nests containing microplastics was not evenly distributed between JB and YI ($\chi^2 = 8.2127$, $p = 4.16 \times 10^{-3}$) with 23% and 63% of nests containing microplastics from JB and YI, respectively (Fig. 3B). Both the abundance of microplastics and number of microplastics per black-backed gull nest were significantly higher for YI than for JB (Wilcoxon rank sum tests, $p = 1.128 \times 10^{-2}$; $p = 1.074 \times 10^{-3}$; Figs. 4 and 5).

White, opaque, and blue plastics comprised over half of the microplastics found in nests from JB and YI for both species (Fig. 6A, 7A). Rigid plastics were the most common type of plastic in nests from YI for both species, while flexible plastics were the most common type found in nests from JB for both species (Fig. 6B, 7B). Only one nest with one microplastic piece was found at TN, which was a piece of black flexible plastic.

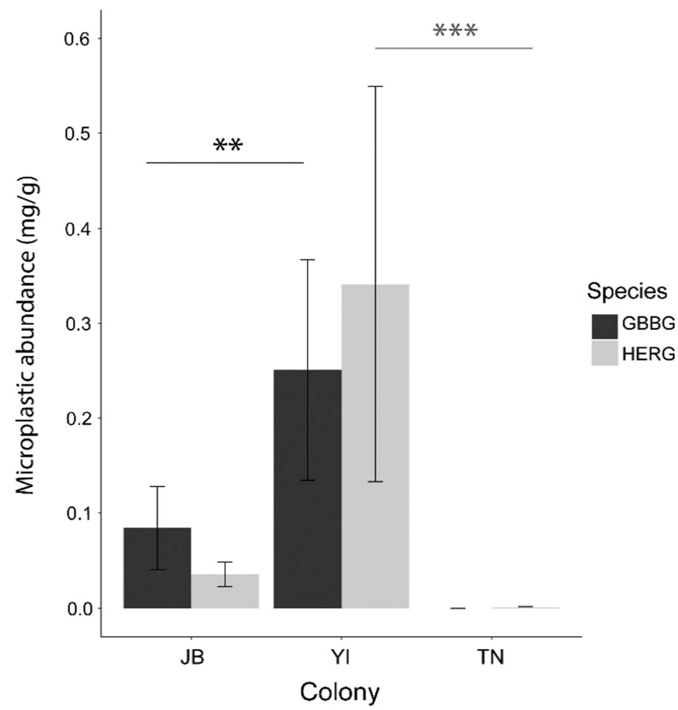

Fig. 4. Average microplastic abundance per nest for herring and black-backed gulls for each colony. Herring gull nests were collected at all three colonies while black-backed gull nests were only collected at Jamaica Bay (JB) and Young's Island (YI). Two asterisks indicate a *p*-value between 0.01 and 0.025, and three asterisks indicate a p-value between 0.001 and 0.01.

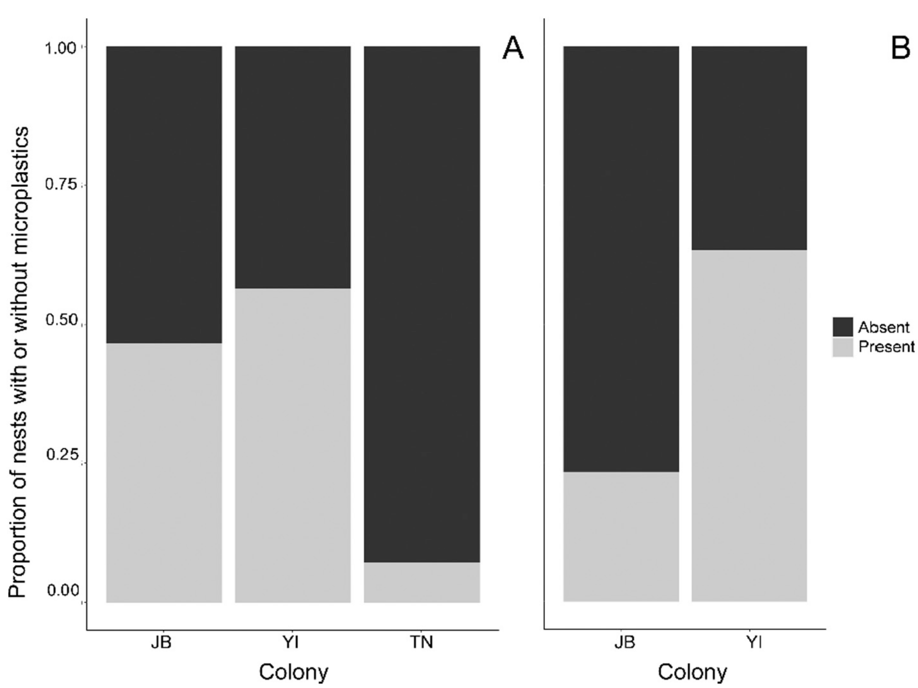

Fig. 3. A. Presence and absence of microplastics in herring gull nests in the three study colonies. B. Presence and absence of microplastics in black-backed gull nests in our two most urban colonies. JB = Jamaica Bay, YI = Young's Island, TN = Tuckernuck.

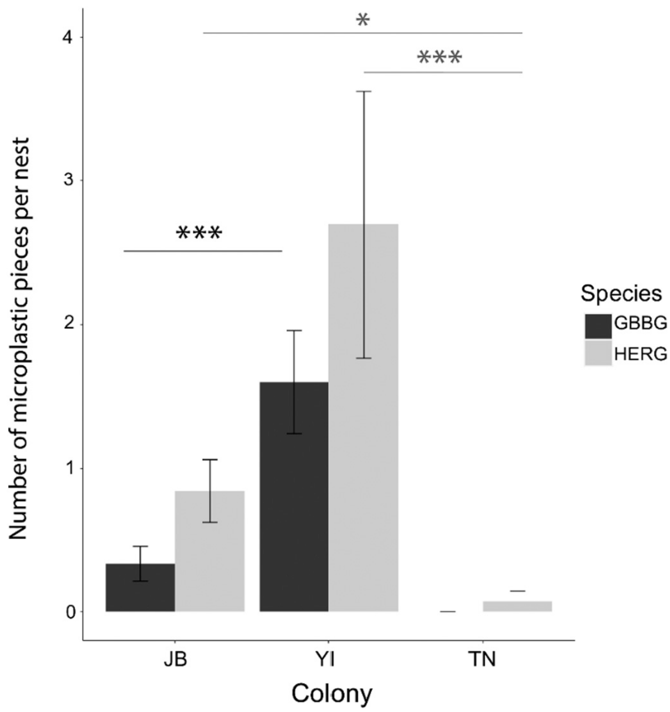

Fig. 5. Average number of microplastic pieces per nest for herring gulls for each colony and black-backed gull nests for Jamaica Bay (JB) and Young's Island (YI). Two asterisks indicate a p-value between 0.01 and 0.025, and three asterisks indicate a p-value between 0.001 and 0.01.

4. Discussion

4.1. Microplastic presence and abundance in relation to urbanization

Herring gull nests in more urban locations (JB, YI) showed a higher frequency and abundance of microplastics than at the less urban study site (TN). At the most remote study site (TN), only 1 of 14 nest samples contained microplastic, while approximately half of nests sampled at the more urban colonies contained microplastics at considerably higher levels (Fig. 4) which can most directly be linked to varying degrees of population density and urbanization.

For both herring and black-backed gulls, the presence, abundance, and number of microplastics was higher at YI than at JB despite the lower population density in proximity to YI. This suggests that other factors in addition to urbanization play an important role in microplastic abundance and distribution in this region. One potential factor that could explain our results is the difference in nesting materials used by gulls at JB and YI. Most nests of both herring and black-backed gulls from JB were comprised of sticks and some terrestrial plants opposed to dried marine grasses, which were more heavily observed in gull nests from YI. Microplastics in coastal waters are more likely to adhere to marine debris that washed up on land than to sticks and other terrestrial matter, which were most likely collected from farther inland on JB island. This difference in nest material selection could influence the exposure of microplastics by nesting birds, with JB birds being less exposed than birds from YI. Additionally, tides can play an important role in the collection of marine debris along shorelines (Eriksson et al., 2013). While the tidal range near YI is 7.27 ft, the tidal range near JB is 4.4 ft (NOAA, 2003). A larger tidal range could potentially trap more debris on shorelines or increase physical weathering of large plastics and thus provide an additional factor affecting microplastic deposition and accumulation.

Our results broadly demonstrate spatial patterns in microplastic distribution and abundance on relatively small spatial scales and suggest

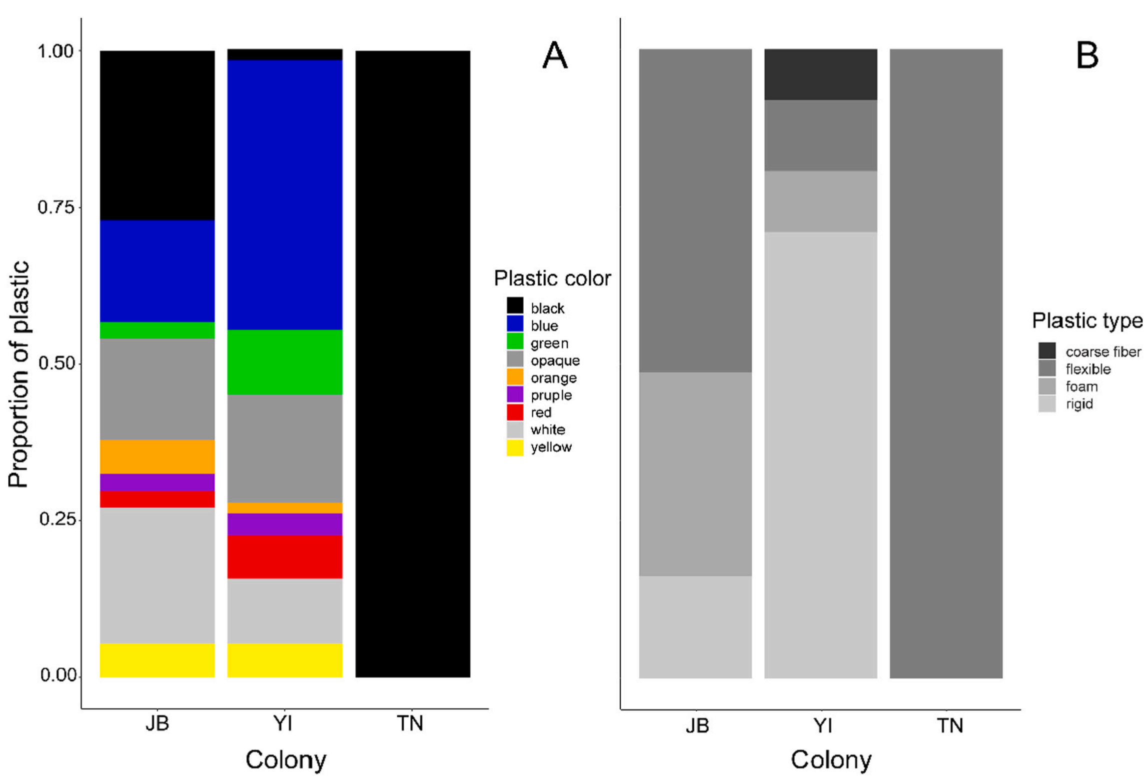

Fig. 6. A. Composition of microplastics by color in herring gull nests in all three study colonies. B. Composition of microplastics by type in herring gull nests in all three study colonies.

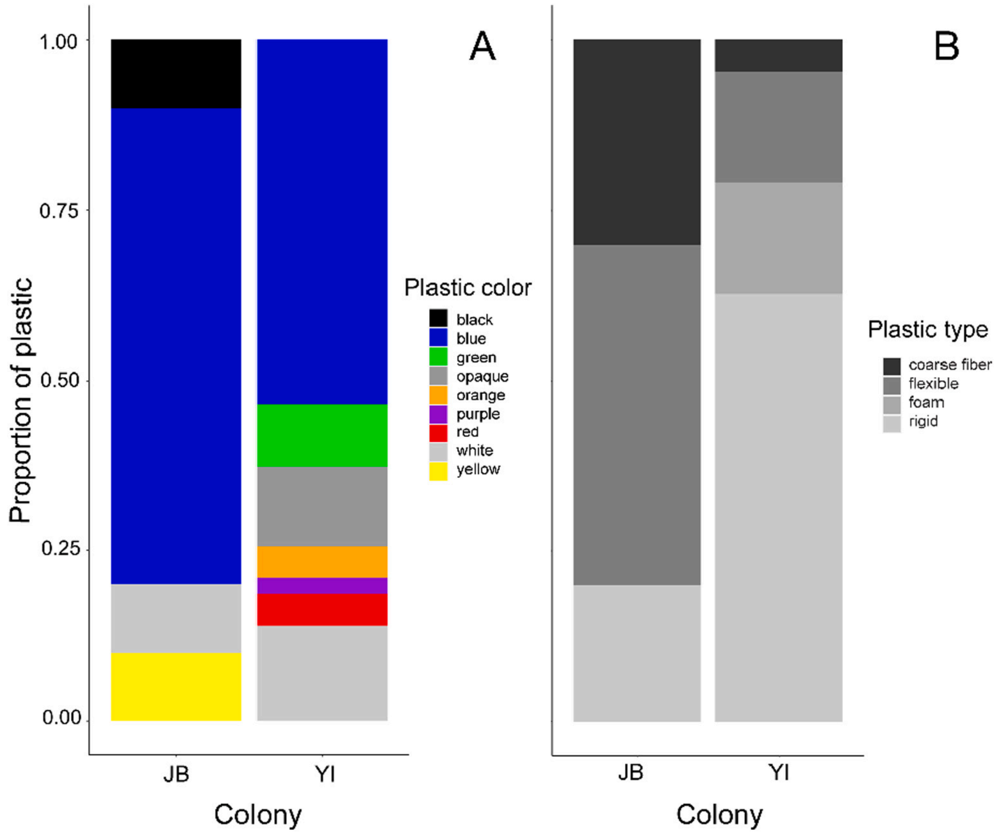

Fig. 7. A. Composition of microplastics by color in black-backed gull nests in two colonies (JB and YI). Fig. B. Composition of microplastics by type in black-backed gull nests in two colonies (JB and YI).

that urbanization may be an important factor influencing the distribution and abundance of microplastics. This finding is consistent with the few other studies that have examined microplastics abundance in coastal waters in relation to human population density (Browne et al., 2011; Luo et al., 2019; Yonkos et al., 2014). Studies at a range of spatial scales are needed to better understand the variety of factors driving microplastic pollution in marine and coastal environments. Additionally, repeating this study at a larger number of sites that vary in their degree of urbanization would help to further identify a link between urbanization and microplastic abundance in nearby coastal environments. While investigating trends in microplastic distributions at global scales is important for informing global policies, identifying regions of high microplastic abundance on the estuarine and inlet scales can help inform the management of marine debris on more local levels.

4.2. Sources of microplastics found in gull nests

Previous studies of herring gull foraging behavior at these three study sites (Fuirst et al., 2018; Thorne et al., 2020) highlighted that herring gulls from JB and YI primarily foraged in urban areas (i.e. shopping centers, parking lots, landfills, and urban parks) while gulls at TN primarily foraged in offshore waters or intertidal zones. Though these findings represent broad trends in foraging, a high degree of individual specialization with respect to foraging location was observed for herring gulls in urban colonies (Fuirst et al., 2018). Additionally, herring and black-blacked gulls differ substantially in their habitat use, with black-backed gulls primarily foraging in marine rather than urban environments (LH Thorne, KA Lato unpublished data). Though these two study species differ in their foraging behavior, they showed similar trends in microplastic presence and abundance in nests and thus suggest that microplastic presence and abundance in gull nests was not related to foraging movements. This is consistent with Thompson et al. (2020), who suggest that macroplastic abundance and distribution in herring gull nests likely does not reflect foraging locations. Additionally, our anecdotal observations suggested that plastic abundance in gull nests reflected plastic abundance along shorelines at our study sites. Therefore, we assume that microplastics found in both herring and black-backed gull nests reflect the color, type, and abundance of microplastics in the immediate nesting area. Future studies may consider quantifying the relationship between abundance and composition of plastic debris found at nesting sites and plastic debris found within gull nests.

4.3. Color and type of microplastics in gull nests

The types of microplastics found in both herring and black-backed gull nests differed between study colonies. Flexible plastics dominated nests for both species in the most urban colony assessed (JB) and in the most remote colony (TN), while the intermediate colony (YI) was dominated by rigid plastics for both species.

For both species, opaque, white, and blue microplastics were most frequently observed at the more urban study sites (JB and YI), which is consistent with other studies examining plastic incorporation in nests and plastic ingestion in seabirds (e.g. Lopes et al., 2020; Verlis et al., 2013). In these studies, it was unclear if this color distribution is reflective of the most common colors produced in industry or if seabirds preferentially uptake plastics of these colors. We suggest that microplastics found in nests entered secondarily during the nest building process rather than while foraging. Thus, color distribution, in addition to type distribution, is likely to reflect local trends in microplastic production or deposition rather than a preference in uptake by seabirds.

4.4. Using seabirds as indicators of microplastic abundance

With both species showing similar trends in microplastic distribution and abundance within colonies, our results suggest that microplastics in seabird nests can be used as indicators of microplastics in surrounding coastal environments and could provide cheap, easy, and non-invasive means of monitoring microplastics in marine and coastal environments. Additionally, seabird nests represent concentrated regions of microplastics within their habitat, providing a more efficient means of sampling microplastics than traditional sampling methods.

Methods such as plankton net sampling from the water column and sediment sampling from the benthos are traditionally used to sample microplastics. While these methods are widely used, they often require expensive equipment, are labor intensive, and may cause a disturbance in habitats (Prata et al., 2019). The tissues of marine megafauna, such as seabirds, have been proposed as useful indicators of microplastics in the marine environment as they reflect integration of microplastics into the food web (Fossi et al., 2014; Neves et al., 2015; Ryan, 2008). However, studies using tissue samples often require lethal sampling or collection of recently deceased individuals. Seabird nests have previously been used to reflect macroplastics in the marine environment (O'Hanlon et al., 2019; Tavares et al., 2016), but nests may provide particularly useful means of characterizing microplastics in surrounding habitat and aid in management practices for other coastal dwelling species. Future studies may use more detailed analyses, such as spectroscopy, to investigate plastic types or quantify plastics in a smaller size fractionation (Löder and Gerdts, 2015).

Results of our study suggest the occurrence, abundance, and overall number of microplastics in gull nests were reflective of broader trends, such as urbanization, while the type and color of microplastics observed (rigid/flexible/coarse fiber/foam) may be reflective of more local factors. Further studies of microplastics in nests of different seabird species could be useful for understanding how microplastic distributions may differ among urban locations and provide insight into spatial patterns and drivers of plastic pollution in coastal and estuarine environments.

CRediT authorship contribution statement

Kimberly A Lato: Conceptualization, Sample and data analysis, Writing- Original draft preparation. **Lesley H Thorne**: Conceptualization, Data analysis, Writing- Reviewing and Editing. **Matthew Fuirst**: Sample collection, Writing- Reviewing and Editing. **Bruce J Brownawell**: Conceptualization, Data Collection, Sample analysis, Writing-Reviewing and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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