Spatial Trends and Drivers of Marine Debris Accumulation on Shorelines in South Eleuthera: The Bahamas Using Citizen Science

Tendencias Espaciales e Impulsores de la Acumulación de Desechos Marinos en las Costas del Sur de Eleuthera, Bahamas: Utilizando la Ciencia Ciudadana

Tendances Spatiales et Moteurs de l'Accumulation de Débris Marins sur les Rives du Sud d'Eleuthera, aux Bahamas: À l'aide de la Science Citoyenne

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EXTENDED ABSTRACT

Marine litter, commonly known as marine debris, is a multifaceted environmental problem with few universal solutions (Ambrose et al. 2019 UNEP and NOAA 2011, Kershaw 2016, Löhr et al. 2017). Marine debris, predominately plastic pollution, has become a global environmental problem that has gained considerable awareness and notoriety for its impacts on marine organisms, ecosystems and human health (Ambrose et al. 2019, Derraik 2002). Marine organisms of both spectrums of the food chain are negatively impacted by plastic pollution via the consequences of ingestion or entanglement of or in the material (Ambrose et al. 2019, Gall and Thompson 2015, Worm et al. 2017).

There is a paucity of information on the abundance and distribution of marine debris on beaches throughout The Bahamas, making it challenging to inform policy aimed at identifying sources and mitigating local contributions (Ambrose et al, 2019). This study provides the first report of the spatial distribution of macro plastic debris on beaches in South Eleuthera and examined tools such as citizen science, beach debris monitoring, fetch modeling, relative exposure index modeling and predictive mapping to aid in mitigation and management strategies for marine debris in The Bahamas. Here, trained citizen scientists quantified debris type and abundance on 16 beaches within three coastal exposures: The Atlantic Ocean, Great Bahama Bank and The Exuma Sound in South Eleuthera, The Bahamas. Marine debris, larger than 1mm, on each beach was monitored twice in one year between March - May 2013 and September-November 2013, at the same location, verified using GPS. Approximately, 93% of all debris types collected were plastic materials with plastic fragments ≤ 2.5 cm as the most dominant. There proved to be a spatial difference ($p = < 0.0001$) in plastic debris abundance between coastal exposures with Atlantic Ocean beaches demonstrating larger amounts of plastic debris by weight.

The Bahama Islands are dependent on its seas to maintain a gross domestic product (GDP) of US$2.7 billion through tourism and harvest of marine resources (Ambrose et al. 2019, Buchan 2000, Patil et al. 2016, Bahamas Ministry of Tourism 2016). The Bahamas' orientation to ocean currents such as the Gulf Stream and those associated with the North Atlantic gyre make it a sink for marine plastic debris as it receives waste outputs from the subtropical gyre onto its shores (Ambrose et al. 2019, Buchan 2000, Lachman et al. 2017). In 2010, estimated levels of existing plastic marine debris for The Bahamas were between 200 - 533 million MT, with a projected increase of up to 687 million MT by 2025, most of which is projected to have entered the Caribbean Sea (Ambrose et al. 2019, Jambeck et al. 2015, Patil et al. 2016). High concentrations of stranded marine litter on Bahamian beaches can potentially reduce local tourism income by 40% representing losses of up to US$8.5 million/year (Ambrose et al. 2019, Krelling et al. 2017).

The island of Eleuthera, located within the central Bahamas, extends 177 km. Three coastlines, divided amongst North and South Eleuthera give us the basis for the study areas; the Atlantic Ocean (AO), Exuma Sound (ES) and the Great Bahama Bank (BB). Due east of the island is the AO, characterized by its deep waters and circulating currents of the North Atlantic Gyre (Law et al., 2010). Sixteen beaches throughout South Eleuthera were monitored for this study and ranked geographically based on their exposure to the three major coastlines. Each beach was monitored twice, once in Spring (March - May 2013) and replicated in Fall (September - November 2013), at the same location, verified using a handheld

Garmin GPSMAP® 76 GPS. Citizen scientists teams consisting of a minimum of 4 individuals, were mobilized during each monitoring event, where two surveys were performed to assess macro and micro plastic debris concentrations using a modified protocol developed by the 5 Gyres Institute based on NOAA Marine Debris Shoreline Survey Field Guide (NOAA 2012).

Ninety-three percent (93%)of all debris collected was plastic, representing a total of 5,489 plastic pieces weighing 62,200 g (± 945.6 SE) (Figure 1). Plastic was the most dominant debris type found across all beaches and showed a significant difference in concentrations across coastal exposures ($p = < 0.0001$). Metal 1%, glass 2%, rubber 3%, paper and processed lumber 1% and cloth 0% accounted for 7% of debris collected. More than 98% of plastic debris was collected by weight from all beaches with AO beaches 1 - 4, having the highest volumes of plastic debris.

Abundance and distribution of plastic varied per m^2 of beach with lower mean abundances of plastic occurring per m^2 at AO sites compared to ES and BB beaches (Figure 2A). There was a significant difference ($p = < 0.0001$) in mean number of plastic items/m^2 at all beaches. Beach 16, 1.98 (± 1.12 SE) and beach 8, 1.48 (± 0.60 SE) had the highest levels of plastic items/m^2 (Figure 2A). Comparatively, higher abundances of plastic debris occurred at AO beaches compared to other coastal exposures. Weight of plastic items/m^2 was higher at AO beaches (Fig. 2B). There was a significant difference ($p = < 0.0001$) in mean weight of plastic items/m^2 at all beaches with beach 1, 16.3 g (± 3.33 SE) and 3, 13.02 g (± 2.74 SE) having the heaviest weight of plastic items/m^2 (Figure 2B).

Wind speed and direction was documented for a total of 4,839 days from January-December 2006 - 2014. Mean wind speed was calculated for each cardinal direction with northern wind directions N (0°) 27.08 km/h., NW (315°) 23.38 km/h, NNW (337.5°) 22.83 km/h., having the highest mean wind speed. Most days, wind blew from E (90°), ESE (112.5°), SE (135°), SSE (157.5°), and S (180°) with the strongest days with wind > 40 km/h coming from N (0°). Less frequented beaches, predominately on the AO coast, which were furthest from habitation were the most polluted. There proved to be a significant spatial difference ($p = < 0.0001$) in plastic debris abundance between coastal exposures AO, ES and BB with AO beaches demonstrating larger amounts of plastic debris by weight. Spatial abundance and distribution of plastic debris between beaches and coastal exposures was significant ($p = < 0.0001$) with a clear variation in significance between beaches. Fetch values varied with study location and wind direction. Sites exposed to the AO had fetch values of 1000 km for wind directions N (0°), NNE (22.5°), NE (45°), ENE (67.5°) and E (90°). Comparatively, ES and BB exposed beaches had lower fetch values from either wind direction due to their proximity to land masses. Fetch, as a wind factor, and beach orientation have been shown to influence debris accumulation (Eriksson et al. 2013, Walker et al. 2006). Fetch projection models showed AO beaches with winds generated from N (0°), NNE (22.5°), NE (45°), ENE (67.5°) and E (90°) to have the largest fetch distances ≥ 1,000 km. REI values for each beach encompassed wind directions from 0-360°. AO beaches had a higher REI value, 2906, compared to ES, 570, and BB, 142, sites. No correlation was found between REI for wind directions between 0-360° and mean plastic/m^2. Effective monitoring and removal of marine debris from Bahamian shorelines may prove challenging given the geographic diversity of the archipelago and its remote coastal areas. Therefore, an understanding of where and how marine

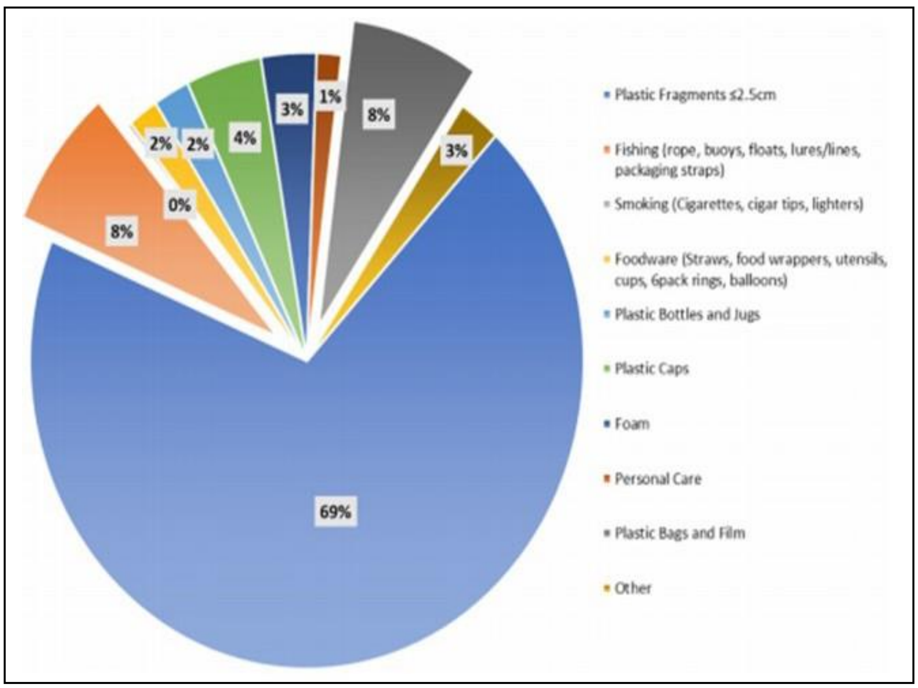

Figure 1. Percentage of plastic types collected

debris accumulates is paramount for optimizing clean-up efforts related to marine debris management that will mitigate threats to local ecosystems and economy. More data must be gathered using an updated methodology that would require reliable high-resolution oceanographic models, knowledge of the local wind fields and the influence of local topography on debris accumulation (Ambrose et al. 2019, Critchell and Lambrechts 2016).

This study offers baseline data on the spatial trends of plastic debris around coastlines of South Eleuthera and can infer extensive marine debris abundance and distribution patterns for the wider Bahamas (Ambrose et al. 2019). As evidenced by our findings, high densities of plastic debris are marooned onto local shorelines, emerging concerns of potential threats to the ecological and economic wellbeing for the archipelago (Ambrose et al. 2019). Understanding the key drivers of debris deposition requires additional research on localized beach variability and small scale and large-scale oceanic processes such as currents, bathymetry, wind and wave patterns of The Bahamas and subsequently the Wider Caribbean Region (Ambrose et al. 2019). Marine debris surveys must be scaled up to include surface sampling for plastic concentrations in and around Bahamian waters (Ambrose et al. 2019).

The absence of adequate scientific research, assessment and monitoring creates barriers to addressing marine debris solutions (Ambrose et al. 2019). Information conducted within this study is critical to understanding marine debris source, abundance, distributions and impacts at both national, regional and global scales and can inform feasible and effective management schemes at all levels (Ambrose et al. 2019). Data derived from this study can be used as a metric to evaluate the effectiveness of single use plastic policies and can advise on adaptive management strategies to improve legislative efficacy (Ambrose et al. 2019). Continued research will be crucial as positive results due to interventions, can create a ripple effect for more single use plastic policies and potential marine debris management plans across different jurisdictions (Ambrose et al. 2019).

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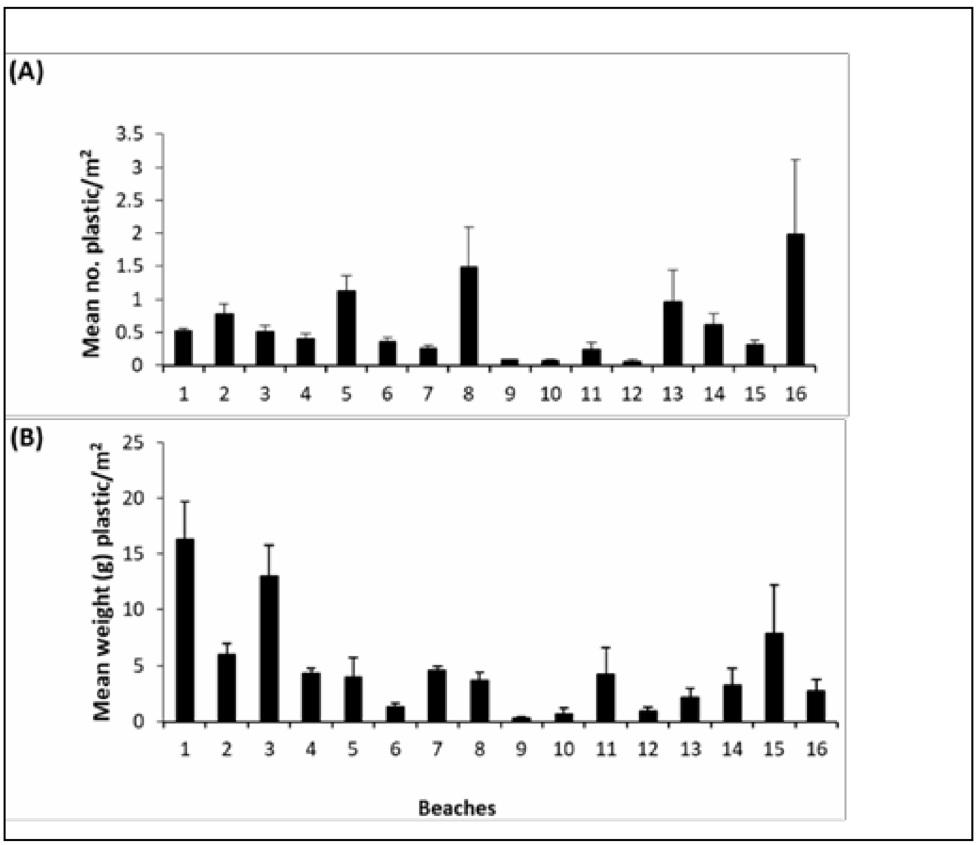

Figure 2. (A) Mean number of plastic items/m^2; (B) mean weight (g) of plastic items/m^2. Error bars indicate ±SE of each sample (n = 8) taken at each beach, except beach 7 where (n = 4).

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