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Seasonal deposition of marine debris on an important marine turtle nesting beach in Costa Rica

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ABSTRACT

Marine debris pollution poses a threat for wildlife and can negatively impact the economy of communities whose livelihoods depend on tourism. Playa Norte, in northeastern Costa Rica, is an important nesting ground for four marine turtle species identified as vulnerable or endangered on the IUCN Red List. It is highly polluted but has low human occupancy. We conducted accumulation rate surveys following a standardized marine debris protocol from March 2016 to January 2018. Macro-debris was categorized by size and material type. Of the 191,030 debris items retrieved during the two-year study period, 96.2% of them were plastic. Debris accumulation was higher during the dry season (January – September). This study contributes towards understanding the drivers of marine debris pollution in critical wildlife nesting habitats; and informs managers and the local community on possible strategies to prevent and reduce marine pollution, thereby aiding in tourism derived economies.

Approximately 80% or more of the anthropogenic debris that accumulates on shorelines, land, ocean surface or seabed is plastic (Barnes et al., 2009; Derraik, 2002; Nelms et al., 2016), and often comprised primarily of packaging and single-use items (Jambeck et al., 2015). Plastics are ubiquitous, they are present in the ocean surface, in benthic zones, and in Arctic ecosystems (Barnes et al., 2009; Bergmann et al., 2016). Eriksen et al. (2014) estimated that there are 5.25 trillion plastic particles weighing 268,940 tons floating at sea. Marine turtles, marine mammals and seabirds are the most commonly reported groups to be negatively impacted by plastic pollution (Gall and Thompson, 2015), but a recent review shows a total of 914 species have been reported to have ingested or being entangled in litter (Kühn and van Franeker, 2020).

Six of the seven marine turtle species are listed under the International Union for Conservation of Nature (IUCN) Red List (the seventh species lacks data to determine their conservation status; IUCN, 2021); and 100% of the species have been impacted by marine debris entanglement and ingestion (Kühn and van Franeker, 2020). Their life history traits make them susceptible to a range of anthropogenic stressors (Donlan et al., 2010). Debris entanglement or ingestion poses particular problems (Nelms et al., 2016; Schuyler et al., 2014). For example, marine debris on nesting beaches poses a threat for loggerhead (*Caretta caretta*) nesting females through entanglement while egg laying and debris may impede hatchlings from exiting the nest (Do Sul et al., 2011). Özdilek et al. (2006) found that debris on nesting beaches in Turkey was an obstacle for green turtle (*Chelonia mydas*) hatchlings trying to reach the sea and increased the probability of hatchlings being eaten by ghost crabs (*Ocypodinae* spp.). Chacón-Chaverri and Eckert (2007) report debris on nesting beaches fatally trapped leatherback (*Dermochelys coriacea*) hatchlings in Southeast of Costa Rica, and altered patterns of access for nesting females which may deter them from nesting. Further, small plastic debris in beach sediment can lower the subsurface temperature and increase permeability and thermal insulation, which can influence eggs' incubation periods and increase the probability of lower numbers of female hatchlings (Carson et al., 2011). Given their conservation status and the severity of marine plastic pollution, more work is required to quantify the number and type of marine debris on nesting beaches (Ribic et al., 2010).

The efficacy of methods used to sample beach litter depends on the objectives of the study and whether the type of litter sampled is accumulated, fresh tidal or both (Velander and Mocogni, 1999). Methods should consider beach topography and location in relation to wind currents and the amount of natural debris which may hinder the monitoring of litter (Velander and Mocogni, 1999). Accumulation surveys encompass the initial removal of debris from a designated area followed by subsequent surveys to record and remove new debris

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(Lippiatt et al., 2013). This type of survey has been used to understand marine debris trends and drivers in the North Atlantic (Ribic et al., 2010), North Pacific (Murray et al., 2018), Gulf of Mexico (Wessel et al., 2019) and Panama's Caribbean coast (Garrity and Levings, 1993). The data collected over time provides information on the influx, life cycle and movement across the shoreline. A drawback from accumulation surveys is that they require considerable effort in comparison with other shoreline surveys (e.g., standing stock surveys) and are more time consuming because they must be conducted routinely (Ryan et al., 2009). In addition, net accumulation can be influenced by different factors such as weather events (e.g., storms or floods), or by the lateral influx of debris from neighboring shorelines (Lippiatt et al., 2013). Nevertheless, by conducting a total cleanup of the site, accumulation surveys are important to reduce the impact of marine debris pollution on critical wildlife habitats (Lippiatt et al., 2013).

In this study, we assessed the seasonal deposition of marine debris in Playa Norte, an important nesting beach for several species of marine turtles in Costa Rica, by conducting accumulation surveys. Specifically, we evaluated the characteristics (i.e., amount, material type and length) of marine debris present on Playa Norte and determined if there was a seasonal pattern of marine debris deposition.

Playa Norte (4.8 km long beach) is located in the North East coast of Costa Rica, on the Caribbean Sea (Start: 10°35′38.4216″N–83°31′31.2234″W; End: 10°38′2.8536″N–83°32′29.8674″W; Fig. 1). According to the last population census there were only 65 people living along this transect (Ramirez, 2019). The beach is closed to the public from March to October, it can only be accessed by boat, and the only tourist attraction is a small hotel at the end of the beach. Yet, Playa Norte is polluted with macro-debris (items larger than 2.5 cm; Lippiatt et al., 2013). The east coast of Costa Rica is west and downwind from the Caribbean Current and is likely a significant source of debris for Playa Norte (Wilber, 1987). The seasons in the study area are approximately divided into rainy (November–January) and dry (January–September; Lewis et al., 2010).

Leatherback, green, hawksbill (*Eretmochelys imbricata*), and occasionally loggerhead turtles, nest on Playa Norte annually (Pheasey et al., 2018). Leatherbacks nest between February and June, greens between June and October, and hawksbills nest throughout both seasons in low numbers (Pheasey et al., 2021). The species are listed on the IUCN Red List: leatherbacks and loggerheads as vulnerable, green turtles as endangered and hawksbills as critically endangered (IUCN, 2021). Tortuguero National Park, located approximately 8 km from Playa Norte, is one of the most important nesting sites for green turtles in the world and has the largest population in the Atlantic (Velez-Espino et al., 2018); a considerable proportion of this population also nests in Playa Norte (48–284 green turtles per year; Velez-Espino et al., 2018).

Data on the quantity and types of marine litter on Playa Norte were collected from March 2016 to January 2018 by staff and volunteers from the Caño Palma Biological Station, following the standardized National Oceanographic and Atmospheric Administration (NOAA) Marine Debris Protocol (Lippiatt et al., 2013). The survey followed a transect (length: 100 m, width: highest tide line) starting at the Tortuguero River mouth. Twenty-two surveys were carried out over the two-year period. Following the initial clean-up on March 2016, surveys were carried out every 28 days (±4 days) during low tide with the exception of three months (August, September 2016 and March of 2017), when no surveys were conducted due to high turtle nesting activity and lack of volunteers.

Following a standardized protocol, surveyors collected and recorded anthropogenic debris between 2.5 and 30 cm in length identified as "regular" debris (plastics, metal, glass, rubber, processed lumber, cloth/fabric and other), and items larger than 30 cm were collected and recorded as "large" debris (as in Lippiatt et al., 2013). Large debris items (e.g., processed lumber, rubber pipes, bed parts, crates, etc.) were measured and categorized separately. Ancillary data was also recorded: coordinates at the start of the shoreline section, date, width of the beach, start and end time, season (wet or dry), storm activity during the survey, and number of volunteers participating in the survey.

Because of heteroscedasticity, which is expected in small samples,

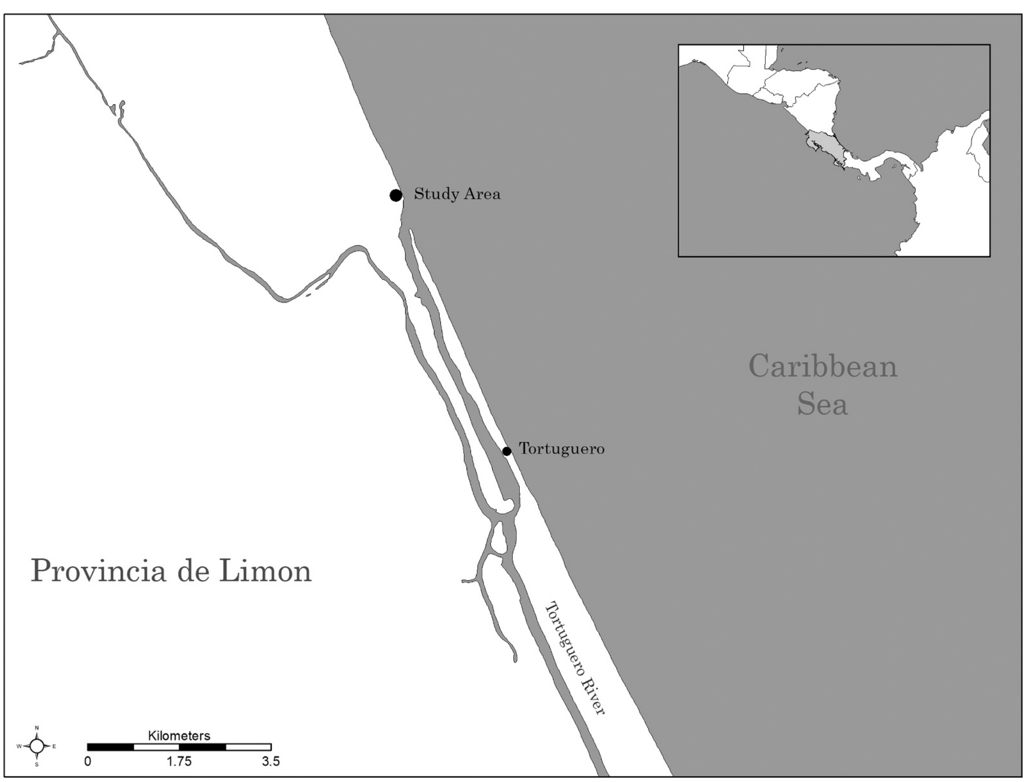

Fig. 1. The study area is located in Playa Norte, in the North East coast of Costa Rica, on the Caribbean Sea. The survey transect (100 m) started at the Tortuguero River mouth. Playa Norte is located north of Tortuguero National Park, one of the most important nesting sites for green turtles in the world.

the assumptions of a general linear model were not met. Therefore, in SPSS (Statistics v24), we used a model that assessed the relationship between marine debris (a linear response) and time in months (a circular explanatory variable). We used a basic cosine and sine regression model to analyze seasonal annual patterns (Pewsey et al., 2013) where the X axis represents the months of the year (1 = January and 12 = December.) The month numbers are viewed like hours on a 12-h clock face. For example, March as the third month was equivalent to 3 o' clock, which is 90 degrees (or π/2r). The sines and cosines of these angles were computed and used as the two explanatory variables. The regression assumptions of the model were met. The monthly total debris was highly skewed to the right in its distribution, so we calculated the logarithm of the initial values for improved model fit which is usually done in these cases (Tabachnick et al., 2007).

The first site cleanup resulted in 50,704 debris items collected and recorded. Including initial clean-up, a total of 191,030 debris items were collected over the course of the study, of which 189, 965 were regular items (2.5–30 cm) and 1065 were large items (>30 cm). Plastics accounted for 96.21% of items found; together, metal (0.19%), glass (0.18%), rubber (0.38%), processed lumber (2.53%), clothing/fabric (0.48%), and unclassifiable items (0.03%) accounted for less than 5% of the total debris count. Plastic fragments were the most commonly found debris (Table 1).

Total debris accumulation seemed to be higher in the drier months (ANOVA, $F(2,16) = 8.553$, $p = 0.003 < 0.01$), peaking on the third month (March; Fig. 2). The cosine component of month significantly predicted log total debris ($b = -0.164$, $t(16) = -2.220$, $p = 0.041$), and the sine component of month also predicted log total debris ($b = 0.337$, $t(16) = 3.489$, $p = 0.003$). The highest accumulation rates of debris occurred in March (2.39 items/m/month) and May (1.7 items/m/month) of 2016. The average debris (±SD) concentration during the dry season was higher (1.59 items/m/month ±2.4) compared to the rainy season (0.58 items/m/month ±0.177). The average debris concentration over the study period was 1.32 items/m/month ±2.001.

The surveys on Playa Norte revealed accumulation rates similar to those found by Wessel et al. (2019) in Dauphin Island in the Gulf of Mexico (1.21 items/m/month). Deposition was higher during the dry season (January – September), and lower during the rainy season (November – January), following peak accumulation rates during spring months (March–May) in the northern Gulf of Mexico (Wessel et al., 2019), April–May in Australia (Brennan et al., 2018), and March and June in the West Coast of the US (Murray et al., 2018). Similar to trends of shoreline marine debris pollution along the Caribbean coast (Ambrose et al., 2019; Garrity and Levings, 1993; Ribic et al., 2011; Wessel et al., 2019), plastic fragments represented the most common type of plastic debris (probably a result of degradation), followed by plastic jugs or containers cap, and foamed plastic/sponges (Table 1). Following Blickley et al. (2016) and Ribic et al. (2012), we grouped the debris materials into 32 categories (Table 1). Most debris (77.89%) was categorized as having a general source, which means they could have originated either in-land or the ocean (Ribic et al., 2012), 19.94% were land-based, and 2.15% were ocean-based.

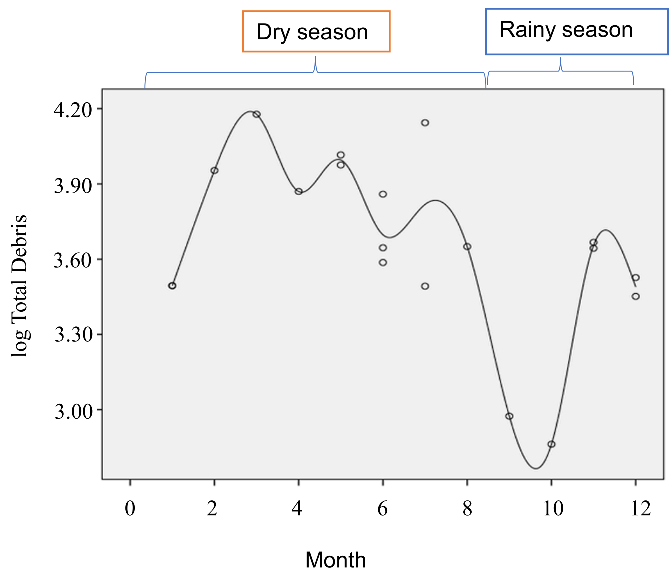

Fig. 2. Seasonal variations in debris deposition in Playa Norte. The numbers on the X axis correspond to each month of the year, January being 1 and December being 12. Debris deposition was higher during the dry season (January – September), and lower during the rainy season (November – January).

Table 1
Indicator items classified by source category (see Blickley et al., 2016 and Ribic et al., 2012) presented with total counts. The top five plastic items are bolded.

Ocean-based	Land-based	General-source
Synthetic rope (3563)	Food Wrappers (**6722**)	Bottles (2658)
Buoys & floats (84)	Cigarette filters/cigars (161)	Jugs or containers (1769)
Fishing lures & line (129)	Disposable cigarette lighters (379)	Plastic jugs or containers cap (**24,505**)
Net fragments (344)	6-pack rings (10)	Plastic bags (3050)
Gloves (5)	Plastic cups (1907)	Miscellaneous plastics (116,117; **fragments 114,351**)
	Plastic utensils (1926)	Miscellaneous aluminum (149)
	Straws (1710)	Miscellaneous glass (166)
	Lollipop stick (**6224**)	Miscellaneous rubber (295)
	Balloons (69)	Other/unclassifiable (46)
	Personal care products (1728)	
	Needle/syringe (120)	
	Electric cable (24)	
	Toys (531)	
	Foamed Plastic/ Sponges (**10, 541**)	
	Metal cans (218)	
	Processed lumber (4764)	
	Paper and cardboard (60)	
	Clothing/ shoes (1006)	
Total debris: 4125 Percentage: 2.15%	Total debris: 38,100 Percentage: 19.94%	Total debris: 148,805 Percentage: 77.89%

Rivers are a major entry point of marine litter to the ocean (Nelms et al., 2016; UNEP, 2016). Estimates suggest that approximately 80% of beach litter is transported by nearby rivers (Rech et al., 2014). It is possible that land-based litter accumulating in Playa Norte was a result of the Tortuguero River transporting debris from adjacent communities, some of which had to resort to illegal dumping of debris in the river given the lack of proper waste disposal facilities. Lebreton et al. (2017) suggested that plastic input from Central American rivers usually peaks between June and October, which corresponds with the season with highest debris accumulation in our findings. Land-based litter inputs also depend on direct storm water runoff and wind currents. This study did not analyze precipitation patterns, but it is likely that extreme weather events do affect the amount of debris deposited on shorelines (Ribic et al., 2011, 2012; Murray et al., 2018).

Our study site is part of the largest area of lowland Atlantic tropical wet forest in Central America. Annual rainfall may exceed 5000 mm, and heavy rainfall and flooding is normal between November and January (Lewis et al., 2010; Rapp et al., 2014). We suggest that higher debris accumulation during drier months was due lower rain and/or flooding events which pull debris off of the beach and back into the ocean.

Precipitation patterns and river hydrodynamics can influence the rate at which rivers retain and transport plastics (Lebreton et al., 2017).

Future research could include measuring Tortuguero River's average depth and total precipitation between sampling visits to evaluate the relationship between these factors and accumulation rates of marine debris. Given the limited access to waste disposal methods in communities surrounding Playa Norte, providing nearby villagers safe and effective waste disposal is imperative for reducing local litter input into the Tortuguero River.

Higher debris accumulation during the dry season corresponds with leatherback, hawksbill and green turtle nesting (February–October). Poaching of eggs and females (Pheasey et al., 2021) and domestic dog predation (Pheasey et al., 2018) already pose a significant threat to marine turtles in Playa Norte. Given the additional threats of marine debris to these already vulnerable species (Duncan et al., 2017; Wilcox et al., 2018), our findings suggest debris removal efforts should be prioritized as a conservation effort, especially during the dry season.

Ocean-based litter was probably related to local fishing activities and to the transport of debris from adjacent coasts and the Caribbean waters in general. The movement of debris in the Northeast of Costa Rica is likely influenced by the Northern Trade winds, the primary forcing for surface currents in the Caribbean (Andrade et al., 2003). Deeper currents may have been an important factor as well. Globally, the five main convergence zones of marine debris are located in the subtropics (Eriksen et al., 2016; Maximenko et al., 2012). Subtropical gyres can transport marine debris more than 1000 km away from land (Debroas et al., 2017). The study site is adjacent to the Panama – Colombia gyre, as well as marine current patterns of the Guyana Current, which flows into the Caribbean Sea from the northeast coast of South America (Coe et al., 1997). Eddies in the Caribbean transfer and mix together these waters, and can influence the dispersal of pollutants by sweeping near-shore waters into the deep ocean and vice-versa (Richardson, 2005).

There is a need to expand data collection to understand sources, trends and debris, both from land-based and ocean-based sources in Playa Norte. Ribic et al. (2012) provides useful information for monitoring ocean-based debris on shore by assessing monthly spatial commercial fisheries activity in the area. Related to data collection is the public participation in scientific studies. While engaging volunteers and citizen scientists in beach cleanups and other conservation efforts has proven to influence policy change and produce high-quality data (Ambrose et al., 2019; Cox et al., 2012), the data are subject to volunteers' work and availability, which can sometimes present limitations like lack of attention to protocol and problematic standardization when participants are not properly trained (Burgess et al., 2017).

In 2010 alone, Jambeck et al. (2015) estimated that 99.5 million MT of plastic waste was produced in coastal regions, highlighting the importance of mitigating land-based litter inputs. Understanding the factors influencing marine debris deposition in Playa Norte is critical for protecting the habitats of at-risk nesting marine turtles, and can inform managers and the local community on possible strategies that could be used to prevent and reduce marine pollution, thereby aiding in tourism derived economies.

CRediT authorship contribution statement

M. Damian – analysis and writing.

A. Harris – supervised and participated in data collection and writing.

J. Assuage – initiated and designed methodology, supervised and participated in data collection and writing.

G.S. Fraser – analysis and writing.

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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