Wildlife and macro-debris pollution: examples from marine and freshwater environments

by Melina Damian Flores

supervised by Gail Fraser

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Abstract

Anthropogenic debris pollution is a problem affecting numerous wildlife species worldwide. Plastic, which makes up of most of the debris pollution found in natural areas, poses a threat to the survival of organisms primarily through entanglement and ingestion and ecological indicators species can play an important role in monitoring pollution levels in wildlife habitats. This portfolio examines anthropogenic debris pollution in two different environments: marine and freshwater. The marine environment is an important marine turtle nesting beach on the northeast coast of Costa Rica, Playa Norte, in the province of Limon. The specific objectives of the study in Playa Norte are to understand the characteristics (i.e.: type, size) of marine debris present in the beach, determine if there is a seasonal pattern of marine debris deposition and identify the possible sources of debris. The freshwater environment is Tommy Thompson Park in Toronto, Ontario, Canada. The study consists in assessing the incidence of anthropogenic debris in double-crested cormorant nests. Specifically, it examines the frequency and characteristics (i.e.: type, colour, size) of debris and how the frequency and type of debris compare to their surrounding environments (terrestrial and aquatic). The portfolio closes up with a reflection on the role of environmental education in addressing the problem of plastic pollution through education and awareness. My objective is to highlight the urgent need to address anthropogenic debris pollution as a pressing environmental concern that impacts marine and freshwater ecosystems alike, as well as to be able to provide solutions and recommendations for monitoring and mitigating this issue in important wildlife habitats.

Foreword

This portfolio seeks to address an issue that has been of my interest ever since I was young. Wildlife conservation has always been my favourite field among environmental issues, as well as plastic pollution. During my time in the Master in Environmental Studies (MES) program, the interdisciplinary nature of the Faculty of Environmental Studies allowed me to shape my research interest in the right direction. On my first summer, I did a three-month internship as a marine turtle monitoring intern in Costa Rica at Caño Palma Biological Station, which is funded and supported by the Canadian Organization for Tropical Education and Rainforest Conservation (COTERC). During my internship I acquired exceptional skills and experience working in range of different wildlife monitoring programs with different wildlife species: marine turtles, mammals, macaws, otters, caimans and snakes. The beach where the endangered turtles nested was covered in debris, most of which was plastic. I felt the urge to get involved in any way I could to help mitigate the problem, which is when I volunteered to take on the role to analyse the research findings of a debris monitoring program that started in 2016 but remained inconclusive, and it is presented in chapter two of this portfolio. The case study presented in chapter three also examines how this type of pollution is prevalent in double-crested cormorant nests, and seeks to address if the species is an effective ecological indicator for monitoring macro-debris pollution levels in Lake Ontario.

The three of components of my MES Plan of Study are 1) wildlife conservation 2) environmental education and 3) determinants of pro-environmental behaviours. The research presented in this portfolio takes particular interest in components one and two. Both case studies I present here examine the implications of plastic (and other macro-debris) pollution on wildlife conservation and their environment. My work primarily fulfills my objective 1.1 “To gain a general understanding on the main concepts, debates, methods, challenges and opportunities in wildlife conservation and natural resource management” by deepening into how macro-debris pollution affects different environments at comparable extents. The closing part of this portfolio, a reflection in environmental education, also outlines the way in which my MES degree accomplished my learning objective 2.2 “To learn and put in practice environmental education teaching skills and methods to educate a targeted audience about plastic pollution, and address the ways in which they can negatively or positively influence their surrounding environment”.

The effects of macro-debris pollution on wildlife conservation is well-documented, yet a lot of work remains to be done to educate the general population about the causes of the problem and the ways in which different levels of society can work together to mitigate it. My hope with the research completed for this portfolio is to provide valuable information for decision makers about the urgency to address this issue at a scientific and policy level, as well as to illustrate how valuable environmental education can be in promoting responsible citizenship to tackle the problem. For me, the work presented here is just the start of a long journey I plan to establish on the path of wildlife conservation and environmental education, one for which the MES program has given me the knowledge and skills necessary to succeed in achieving such objective.

Dedication and acknowledgements

This work is dedicated to the Venezuelans struggling through the worst socioeconomic and political crisis that Venezuela has gone through in decades. During my completion of the MES program, many Venezuelan lives were lost due to the crisis, many migrants risked their lives fleeing by foot to neighboring countries, and many of us who live abroad were sometimes silenced by more privileged and racially powerful voices. Venezuela is the country that raised me and made me the person who I am today, and my work goes to all the brave ones who stayed back home defending our country, and facing the precarious living conditions in which they are obliged to live in today. I cannot live there to physically help those in need, but I can succeed academically and professionally abroad to show the world the talented youth that Venezuela raises. My heart and soul are with my homeland, and even though I'm far, it lives in me and it is shown here through my work.

I would like to thank first and foremost my parents, for their unconditional love and support throughout every step completing this Master degree and for giving me the best two young sisters I could have ever asked for – they are both my treasure and my biggest motivations! Thank you also to both my supervisor and advisor: Gail Fraser, for her continuous teachings and detailed feedback throughout the research process, she made all my learnings smoother and my academic obstacles easier to overcome; and Sheila Colla, for her constant support and encouragement throughout my studies and her help navigating other challenges outside the academic field. Also thank you to John Lima, my special person, his love and happiness made me stronger and made stressful times pass faster. And I'm also grateful with Tanya Chung-Tiam-Fook, who taught me how to see life in a different way, to be aware of my inner nature and guided me and supported me throughout my last academic year.

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CHAPTER ONE

INTRODUCTION

Debris in marine and freshwater environments are human made items that end up in the aquatic environment (Lippiatt et al. 2013; Gall and Thompson, 2015). For marine environments I refer to marine debris; debris in freshwater environments are referred to as anthropogenic debris. The National Oceanic and Atmospheric Administration (NOAA) defines macro-debris as those being larger than 2.5 cm (Lippiatt, Opfer and Arthur, 2013). My research focuses on macro-debris pollution in both marine and freshwater ecosystems.

There are many types of marine debris, yet plastics constitute most of which is found in the natural environment and they can take hundreds to thousands of years to degrade (Barnes et al., 2009). Plastic pollution has many detrimental effects on wildlife. In a review of marine debris pollution, Gall and Thompson (2015) report that 693 species were affected by marine debris; a 49% increase from the 267 species reported by Laist (1997). Drift plastics can also transport and absorb pollutants from the water that bioaccumulate and move through the food chain (Holland, Mallory and Shutler, 2016; Zarfl and Matthies, 2010), impact benthic biota by inhibiting gas exchange and causing hypoxia or anoxia and facilitate the introduction of alien species (Derraik, 2002).

In chapter two of this portfolio I present a scientific research study carried out on the beach Playa Norte (translated as “North Beach”), in the Caribbean coast of Costa Rica. The methodology used follows the NOAA Marine Debris Protocol (Lippiatt, Opfer and Arthur, 2013) for monitoring accumulation rates of marine debris in marine environments. All four species of marine turtles that nest in Playa Norte are listed under the International Union for Conservation of Nature (IUCN) Red List as vulnerable, endangered or critically endangered (IUCN, 2018). Their populations are in decline (Velez-Espino et al., 2018) and entanglement and ingestion of plastics often result in mortality (Nelms et al., 2015). During my internship at Caño Palma Biological Station, my duties focused on daily patrols to Playa Norte (4.8km long) to tag and monitor nesting marine turtles. During day patrols, volunteers on shifts took large black garbage bags to the surveys to collect plastic bottles on the way back to the station to be later recycled. The beach was covered in all types of debris (bottles, shoes, fishing nets, tooth brushes, straws, and we even saw a TV stranded once!), and for us to fill up a large garbage bag with only plastic bottles (because those were the only ones that could be recycled in the nearest facility) would take only a few minutes – there were marine debris everywhere, many times we could feel how we were walking on plastics rather than sand. The area surrounding the study site doesn't have proper waste disposal facilities; in addition, some debris found on the beach was recognized by locals to be of foreign origin (judging by product brands and readable labels), which suggests that there were a number of factors influencing marine debris deposition. Figure 1-a and 1-c depict the marine debris pollution along Playa Norte. Figure 1-b shows the forest being used as a dumpster by locals, primarily because of the lack of alternatives to dispose human-made waste. Figure 1-d is a picture of myself with other volunteers during a beach cleanup. Research on marine debris occurrences on breeding beaches will contribute to the broader conservation strategy for marine turtles (Velez-Espino et al., 2018).

(a) (

b)


(c)

(d)


Figure 1 – Imagines from Playa Norte, Costa Rica. Figure 1-a and 1-b were taken in the beach, and show the amount of debris polluting the site. Figure 1-c shows garbage being dumped in the forest by locals. Figure 1-d depicts myself and other volunteers during a beach cleanup where the study site was located.

In chapter three of this portfolio I present research that examines the incidence of anthropogenic debris pollution in double-crested cormorant nests. Both marine turtles at Playa Norte and double-crested cormorants at Tommy Thompson Park in Toronto, Canada, could be used as ecological indicators (Durant et al. 2009). Ecological indicators can be used to "assess the condition of the environment, to provide an early warning signal of changes in the environment, or to diagnose the cause of an environmental problem" (Durant et al., 2009). When species are used as ecological indicators, it is expected that the responses of the chosen species are representative of the responses of other species within a habitat or community (Canterbury et al., 2000). Nelms et al. (2015) suggest that marine turtles are often indicators of broader marine conservation issues. Birds in general are used as ecological indicators of a wide variety of ecological change (Furness & Greenwood, 1993). The frequency of plastics in double-crested cormorant nests could be used as an indicator of the availability of plastics in their environment (Provencher et al., 2014). Documenting anthropogenic debris incidence in their nests could also be used to determine the risk that other species may be facing from debris pollution in their surrounding environment. Double-crested cormorants collect nesting material from the water surface, but they also dive to collect seaweed, which increases their risk of becoming entangled in plastics while foraging for food or for nesting material (Podolsky & Kress, 1989). Figure 2-a shows a double-crested cormorant nest built with yellow rope and other colorful synthetic strings in Tommy Thompson Park, Toronto. Figure 2-b was also taken at the study site and it shows myself prior to starting one of the surveys. Figure 2-c and 2-d both depict anthropogenic debris found in a single double-crested cormorant nest. Surveying nests for the presence of anthropogenic debris provide a non-invasive method of tracking these items used by cormorants and could provide a representation of anthropogenic debris influx in colonies (Tavares et al., 2016). Both case studies in chapter two and three were produced as stand-alone science papers; therefore, the use of figures and bibliographic sources are organized as individual pieces.

(a) (b)

(c) (d)

Figure 2 – These images correspond to the case study presented in chapter three, *Incorporation of anthropogenic debris into double-crested cormorant nests, Toronto, Ontario.* Figure 2-a and 2-b were taken at the study site, Tommy Thompson Park. Figure 2-c and 2-d show anthropogenic debris items found in a single double-crested cormorant nest.

Ultimately, I culminate the last section of this portfolio with a reflection on how I perceive environmental education to be a powerful tool for change. In the courses I took as part of my Environmental/Sustainability Diploma in the MES program I learned many valuable lessons that allowed me to understand the importance of the non-scientific community to become aware and actively engaged in the making of solutions for mitigating environmental problems, such as plastic pollution. Readings like Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teaching of Plants by Robin Wall Kimmerer, The World Becomes What We Teach: Educating a Generation of Solutionaries by Zoe Weil, Mobilizing the Green Imagination: An Exuberant Manifesto by Anthony Weston and Pedagogy of the Oppressed by Paulo Freire, were among the most influential throughout the completion of my diploma.

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CHAPTER TWO

CASE STUDY I

Accumulation Rates of Marine Debris on an Important Marine Turtle Nesting Beach in Costa Rica

Melina Damian[a], Anna Harris[b], Gail Fraser[a], Josaphine Aussage[b]

Faculty of Environmental Studies, York University, 4700 Keele St, Toronto, ON M3J 1P3, Canada[a]

Canadian Organization for Tropical Education and Rainforest Conservation (COTERC), Limón Province, Pococí, Costa Rica[b]

Corresponding author: G.S. Fraser, gsfraser@yorku.ca

Abstract

Marine debris pollution poses a threat for wildlife and can negatively impact the economy of communities whose livelihoods depend on tourism. The beach Playa Norte, in northeastern Costa Rica, is an important nesting ground for four marine turtle species all identified on the IUCN Red List. It is highly polluted but has low human occupancy suggesting that marine debris deposition is primarily influenced by external factors. We conducted accumulation rate surveys following a standardized marine debris protocol. Macro-debris was categorized by size and material type. The quantity, concentration (number of debris items per m^2) and type of marine debris is presented and examined with local environmental variables. Plastic items accounted for over 90% of debris and accumulation rates were higher during the dry season (January – September). This study contributes towards understanding the drivers of marine debris pollution in critical habitats; and informs managers and the local community on possible strategies to prevent and reduce marine pollution, thereby aiding in tourism derived economies.

Keywords:

Plastic pollution • Marine Litter • Debris Accumulation Monitoring • Playa Norte • Costa Rica

Introduction

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., 2015), and it is comprised primarily of packaging and single-use items (Jambeck et al. 2015). With the exception of plastics that have been incinerated, it has been estimated that all plastics ever produced still persist in the environment in some form (Thompson et al., 2005; Geyer et al. 2017). Aside from plastics that are currently being used, only 9% of all plastics ever produced have been recycled, and 60% have become trash and are currently accumulating in landfills or in the natural environment (Geyer et al., 2017). Plastics are ubiquitous, they are present in the ocean surface, in benthic zones, and even 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. Degradation rates of plastics vary depending on the type and chemical properties of the polymer, but estimates suggest that their longevity ranges between hundreds to thousands of years (Barnes et al., 2009). Mass production of plastics started in the 1950's, since the 1970's its annual production has quintupled, and by the 1980's the detrimental effects of plastic pollution on wildlife were well documented (Cozar et al., 2014; Wilber, 1987). Ingestion and entanglement are the main threats, but other hazards include reproductive failure, drowning, suffocation, lacerations and starvation due to gut obstruction (Derraik, 2002; Gall and Thompson, 2005). Marine turtles, marine mammals and seabirds are the most commonly reported species to be affected by plastic pollution (Gall and Thompson, 2005; Laist, 1997).

All known species of marine turtles are affected by entanglement or ingestion of marine debris (Nelms et al., 2015), and plastic ingestion by marine turtles is a global increasing trend (Schuyler et al. 2014). Marine turtles have slow maturity rates, are long-lived, low juvenile survivorship and migratory, factors which make them susceptible to a range of anthropogenic stressors (Donlan et al., 2010). Six of the seven marine turtle species are listed under The International Union for Conservation of Nature (IUCN) Red List, while the seventh species lacks data to determine their conservation status (IUCN, 2018).

Marine debris on nesting beaches presents a threat for nesting females through entanglement, while egg laying and debris may impede hatchlings from exiting the nest (Do Sul et al. 2011; Nelms et al., 2015). 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*) and debris traps leatherback (*Caretta caretta*) hatchlings in a Caribbean beach in the Southeast of Costa Rica (Chacon-Cheverry and Ekert, 2007). Similarly, changes to the integrity and functioning of habitats are also a threat to marine turtles. For example, litter can impact biodiversity, abundance and community structure of benthic megafauna by providing refuge and hard surface to organisms that wouldn't otherwise be present (Katsanevakis et al., 2007); and small plastic debris in beach sediment can lower the subsurface temperature and increase permeability and thermal insulation negatively affecting incubation periods and increasing the probability of lower numbers of female hatchlings (Carson et al., 2011). The presence of debris can also alter patterns of access for nesting females which may deter them from nesting (Chacon-Cheverry and Ekert, 2007). Given the conservation status of marine turtles and the severe plastic pollution problem on nesting beaches, more work is required to quantify amount and origins of marine debris on nesting beaches (Ribic et al., 2010).

Wind and marine currents, along with regional human density are the main factors influencing marine debris deposition (Wessel et al., 2009). Wind drives the surface currents in the subtropical gyres. These currents are influenced by the Coriolis effect, which in turn cause the Ekman spiral that creates the surface currents that carry the floating debris towards the centre (Sebille et al., 2012). There are 11 gyres in the ocean and five main convergence zones of marine debris, all located in the subtropics, centered approximately at 30° latitude commonly referred to as "great ocean garbage patches" (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). A 22-year study found that the main accumulation zone of plastic debris in the North Atlantic gyre is located between 22° and 38°N, but the fate of floating marine debris is dependent on where it enters the marine environment in relation to the gyre (Law et al., 2010). In 1991, the Caribbean region was designated by the International Maritime Organization as a Special Area under Annex V of the MARPOL treaty, given that the enclosed nature of the Caribbean waters increases the accumulation of debris which poses a threat to biodiversity, fishing and tourism activities (Garrity and Levings, 1993). The overall direction of the waterflow in the Caribbean Sea is northwestward, blending North Atlantic surface waters, Amazon and Orinoco Rivers' water, and local freshwater runoff from South America together (Gyory et al., 2008). 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). The Caribbean Current and the Panama-Colombia Gyre are the dominant surface currents in the Caribbean Sea (Coe et al., 1997; Andrade et al., 2003). The Panama-Colombia Gyre (also referred to as "southwest Caribbean gyre") is a counterclockwise circulation that affects Nicaragua, Costa Rica, Panama and north of Colombia shorelines (Figure 1; Gyory et al., 2008). The southwestern part of this gyre encompasses the eastern Costa Rican coast, where the main current is approximately 50-km wide (Richardson, 2005). The east coast of Costa Rica is located to the west and downwind of the Caribbean Current, a location that is a potential removal area of debris from the North Atlantic gyre flow (Wilber, 1987). In addition to marine currents, some of the factors that affect the transport and spatial variability of drifting plastics at sea are the vertically blending of buoyant plastic pieces on the surface ocean (Reisser et al., 2015), the hydrographical patterns and seafloor bathymetry (Ramirez-Llodra et al., 2013), and wave motion and tidal dynamics (Rech et al., 2014).

Some habitats have physical characteristics that make them prone to higher incidence of marine debris, such as a frontal system or discharging rivers (Nelms et al., 2015). Rivers are a major entry point of marine litter to the ocean, especially those draining areas with high population density and industrial development (UNEP, 2016). Rivers worldwide release approximately between 1.15 and 2.41 million tonnes of plastics into the ocean every year (Lebreton et al., 2017). Schmidt et al. (2017) assert that plastic concentrations can be up to 40 to 50 times higher in rivers than in marine environments. Some estimates even suggest that approximately 80% of beach litter is transported by nearby rivers (Rech et al., 2014). For example, in the Danube river, the second largest river in Europe, floating plastic particles outnumbered fish during day time surveys and it was estimated that it delivers 173.6 kg of plastic per hour into the Black Sea (Lechner et al., 2014). The top ten dirtier rivers globally contribute to 88–95% of plastic waste input into the oceans (Schmidt et al., 2017).

Precipitation patterns, soil characteristics and river hydrodynamics can influence the rate at which rivers retain and transport plastics (Lebreton et al., 2017). Extreme weather events can either scour or increase the amount of debris on the shore as a result of deposition (Ribic et al., 2012). The climate in the Caribbean coast is categorized as dry-winter tropical, with significant interannual variations (Giannini et al., 2000). Precipitation in this region results from strong northeasterly trades during July and August that flow on shore perpendicular to the central Costa Rican cordillera (Rapp et al., 2014). The northeast trade winds produce precipitation patterns in the Caribbean coast of Costa Rica (Waylen et al., 1996). In addition to wind, marine currents, river transport and precipitation, some of the other factors that increase the transport of plastics into the marine environment are aquaculture, shipping and fishing activities (Lebreton et al., 2017). Similarly, the geographic features of the shoreline also affect the rates of debris deposition (Rech et al., 2014).

There are different methods that permit the sampling of beach litter and debris, their efficacy depending on the objectives of the study and whether the type of litter that needs to be sampled is accumulated, fresh tidal or both (Velander and Mocogni, 1999). When choosing a method, it is important to consider the topography of the beach and location in relation to wind currents and the amount of natural debris present (which may hinder the monitoring of man-made debris) (Velander and Mocogni, 1999). Accumulation and loading rates surveys require an initial cleanup of the area of study, followed by regular surveys to record and remove any new debris (Lippiatt, Opfer and Arthur, 2013). The data collected over time provides information on the influx of debris, as well as the life cycle and movement of debris across the shoreline. A drawback from accumulation rates surveys is that they require a considerable amount of effort in comparison with other shoreline surveys and are much more time consuming because they must be conducted routinely (Ryan et al., 2009). In addition, net accumulation rates 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, Opfer and Arthur, 2013). Nevertheless, by conducting a total cleanup of the site, accumulation rates surveys are important to reduce the impact of marine debris pollution on critical habitats (Lippiatt, Opfer and Arthur, 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).

In this study we assessed the accumulation rates of marine debris in Playa Norte, an important nesting beach for marine turtles in Costa Rica. Specifically, we evaluate the characteristics (i.e.: amount, material type and length) of marine debris present on the beach, determine if there is a seasonal pattern of marine debris deposition and identify the possible sources (i.e.: transported by the nearest river, through precipitation events or by marine currents) of debris.

Methods

Study site

Playa Norte Beach is a beach located in the North East coast of Costa Rica, on the Caribbean Sea (0°35'36.8"N 83°31'28.0"W). It is an important nesting ground for marine turtles, specifically leatherbacks (*Dermochelys coriacea*), greens, and hawksbills (*Eretmochelys imbricata*) – and occasionally loggerheads (*Caretta caretta*). Playa Norte is a highly polluted area posing a threat to nesting females, their eggs and emerging hatchlings. At Playa Norte, there are currently no large-scale beach cleanup efforts other than that from volunteers and staff from the Caño Palma Biological Station.

Playa Norte is approximately 4.8 km long. According to the last census from the National Institute of Statistics and Census of Costa Rica, in 2011 there were 65 people living along this transect (Ramirez, 2019). The closest village to Playa Norte is San Francisco de Tortuguero (*San Francisco*), and it has 597 habitants (2011 census; Ramirez, 2019). Neighboring San Francisco is the village of Tortuguero, a much larger village with 1,015 habitants as of 2011 (but unofficial estimates from Tortuguero's Community Association suggest the current population is closer to 1,500). Tortuguero National Park is one of the most important nesting sites for green turtles in the world, and the largest population in the Atlantic (Velez-Espino et al., 2018); a considerable number of this population also nests in Playa Norte (Velez-Espino et al., 2018). Leatherbacks and hawksbills also nest in Playa Norte annually, and loggerheads were last recorded nesting in 2006 (Pheasey and Fernandez-Porras, 2015). These four species are on the IUCN Red List: leatherbacks and loggerheads as vulnerable, green turtles as endangered and hawksbills as critically endangered (IUCN 2018). Illegal poaching of eggs and females, illegal harvesting at sea, marine traffic and pollution are the main threats to nesting marine turtles in Playa Norte Beach (Velez-Espino et al., 2018).

Survey design

Data on the quantity and types of marine debris accumulated on Playa Norte was collected from March 2016 to April 2017 by staff and volunteers from the Caño Palma Biological Station, following the standardized NOAA Marine Debris Protocol (Opfer, Arthur and Lippiatt, 2013). The survey followed a transect (length: 100m, width: highest tide line) starting at the Tortuguero river mouth (Figure 2). Twenty-two surveys were carried out over the course of two years. The survey was undertaken every 28 days (with a margin of 4 days) during low tide with the exception of three months (Aug, Sept 2016 and March of 2017).

Surveyors collected and recorded anthropogenic debris between 2.5-30 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). In addition, we collected ancillary data for each survey: coordinates at 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. Width and length were measured and recorded for large debris, which were given individual categories names. Macro-debris item concentration (number of debris items/m^2 per transect) was calculated using the following equation (NOAA Marine Debris Protocol; Lippiatt et al., 2013):

C = n / (w*l)

Where:

C = concentration of debris items (number of debris items/m2),

n = number of macro-debris items observed,

w = width (m) of shoreline section recorded during sampling (i.e, transect width),

l = length (m) of shoreline sampled = 100 m.

As part of the monitoring activities at Caño Palma Biological Station, river depth and total precipitation was recorded daily using a metric tape measurer and a rain gauge, respectively.

Statistical Analysis

We used average river depth between sampling visits, total precipitation between sampling visits, width of the beach (total area), and inter-sampling day as the explanatory variables. To evaluate the relationship among these variables and accumulation rates of marine debris we used a series of generalized linear models using a number of diagnostic plots. Then we tried to fit a general linear model using the same predictors and outcome variable because there weren't any influential cases.

Because of homoskedasticity, which is expected in small samples, the assumptions of a general linear model were not met. Therefore, we used a model that assessed the relation between a linear response (marine debris) and a circular explanatory variable (time in months). Therefore, we used a basic cosine and sine regression model to analyze 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-hour 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 using SPSS Statistics v24. The regression assumptions of the model were met. The monthly total debris was highly skewed to the right in its distribution, so we took the logarithm of the initial values for improved model fit which is usually done in these cases (Tabachnick et al., 2007).

<u>Results</u>

On the first total site cleanup 50,704 debris items were collected, recorded and removed. A total of 191,030 debris items were collected over the course of the study, of which 189,965 were regular items (2.5 – 30cm) and 1,065 were large items (>30cm); debris accumulation on subsequent visits fluctuated over the study period (Figure 3). The highest accumulation rates of debris (excluding the months confounded by the lack of prior month's surveys) occurred in March's second visit in 2016 (2.39 items/m^2/month) and July 2017 (1.29 items/m^2/month). The average debris concentration over the study period was 1.32 items/m^2/month (SD= 2.001). Plastics accounted for 96.2% of items found; together, metal, glass, rubber, processed lumber, clothing/fabric, and unclassifiable items accounted for less than 5% of the total debris count (Figure 4). Plastic fragments were the most commonly found debris (Table 1).

Total debris seemed to be higher in the drier months (ANOVA, $F(2,16)=8.553$, $p = .003 < .01$), with a peak on the third month which corresponds to March. The cosine component of month significantly predicted log total debris ($b = -0.164$, $t(16) = -2.220$, $p = .041$), and the sine component of month also predicted log total debris ($b = 0.337$, $t(16) = 3.489$, $p = .003$). According to Lewis' (2009), the seasons in Caño Palma are divided into rainy season (November-January) and dry season (January-September). The model suggests that overall debris accumulation was higher in the dry season (Figure 5).

None of the predictors from the GLM models used explained accumulation rates of debris ($p > 0.05$). Due to the missing three months of survey data (i.e., August, September and October 2016), we also examined the patterns between April 2017 and January 2018 (a period during which we had consecutive data points). The average river level and total precipitation between surveys follow a similar trend, both are lowest in May 2017 and highest in December 2017. While debris accumulation rates appear to follow to some extent river level and precipitation patterns this was not reflected in the GLM. Beach width, appeared to have an opposite trend to debris accumulation (Figure 6).

Discussion

The surveys on Playa Norte revealed high rates of anthropogenic debris deposition, where plastic was the most commonly found item, reflecting the trends of marine debris pollution found in other shorelines along the Caribbean coast (Garrity and Levings, 1993; Ribic et al., 2011; Wessel et al., 2019). Plastic fragments represented the most commonly found plastic debris (probably a result of degradation), followed by plastic jugs or containers cap, and foamed plastic/sponges being the third most commonly found plastic items. An analysis on the seasonal variation of accumulation rates revealed that accumulation rates are higher during the dry season (January – September), and lower during the rainy season (November – January). However, the explanatory variables considered in our analysis did not explain debris accumulation rates on Playa Norte.

While 24 months of accumulation rates were measured, part of the statistical analysis was still constrained due to a small sample size. Further, wind speed and direction should have been incorporated into the precipitation metric, as well as monthly wave could have been complemented with monthly wave height measurements and beach slope to calculate Relative Tide Range and Intertidal Area (as in Blickley et al., 2016). An additional limitation was the location of the river depth metric. The river depth measured was that of the Caño Palma canal, which is a canal of river that flows into Laguna Cuatro canal, approximately 4.8 km from where the sampling site was. We used this measurement, however, because the depth the Tortuguero River (the one adjacent to the study site) directly affects the depth of the Caño Palma canal. Staff from the Caño Palma Biological Station assert that the Caño Palma canal height is influenced by the rivers feeding into the area because they all have the same outlet (personal communication). Caño Palma Biological Station was the only organization measuring river depth daily, and MINAET (the Costa Rican Ministry of Environment, Energy and Telecommunications) used it as the official indicator for the area. On the other hand, it is important to remark that the data collection for this study was heavily dependent on volunteers' work and availability. If the inter-sampling date would have remained constant at 28-day intervals, as stipulated in the NOAA Marine Debris Monitoring Program (Lippiatt et al., 2013), perhaps that would have normalized results and we could have found a significant relationship between number of days between sampling surveys and debris accumulation on the beach.

The accumulation rate of marine debris in Playa Norte was likely a result of two main drivers: marine currents and the Tortuguero River. The type of land use through socioeconomic activities and population size of nearby areas may influence the debris found on coastlines (Rech et al., 2014). While the 4.8 km that comprise Playa Norte were highly polluted with marine debris, and accumulation rates of the transect studied likely resembled that of the rest of the beach, it is unlikely that the local population influenced the rates due to low population density along the transect line. Additionally, Playa Norte can only be accessed by boat, and even though there is a small hotel at the end of the beach, tourism activities are minimum in the area due to the fact that: a) during marine turtle nesting season (approximately May to November) the beach is closed from 6:00 pm to 6:00 am to the general public to allow for the marine turtle monitoring program carried out by Caño Palma Biological station; b) there was a warning of presence of sharks and crocodiles on the beach which deterred most people from bathing in the waters; and c) aesthetically the beach has been impacted by the presence of marine debris all throughout the area. Thus, it is unlikely that the high level of debris accumulation along the beach is due to the purposeful littering of locals or tourism activities in Playa Norte. We estimate that land-based litter is primarily a result of the Tortuguero river transporting debris from San Francisco, because garbage dumping in the Tortuguero river was a common practice in San Francisco (personal observation). The village doesn't have effective waste management disposal due to not being an established jurisdiction, so villagers have no choice but to resort to illegal dumping into the river or the forest, burning or burying litter. Volunteers and staff from Caño Palma Biological Station often do village cleanups, and in conjunction with the Community Association sometimes provide transportation of recyclables by boat to the nearest facility, but even these efforts are not enough to mitigate the impact of improper waste management in San Francisco. The Tortuguero River could also be transporting litter from Tortuguero (which has a high tourism activity) and other nearby villages. Lebreton et al. (2017) suggested that plastic input from central America rivers, peak usually between June and October which is consistent with our findings.

Land-based litter inputs can also depend on direct storm water runoff and wind currents. While there was no detectable effect of precipitation patterns on debris accumulation, there is evidence that suggests that extreme weather events do affect the accumulation of debris on shorelines (Ribic et al., 2011; Murray et al., 2018). The study site is part of the largest area of lowland Atlantic tropical wet forest in Central America. Annual rainfall may exceed 5,000 mm, and heavy rainfall and flooding is normal between November and January (Lewis et al., 2010; Rapp et al., 2014). Even though our seasonal variation analysis revealed that debris accumulation is higher during the drier months, regular flooding events in the area may have played an important role in the deposition of debris during the rainy season. On the other hand, 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), 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).

Conclusion

Efforts aimed at reducing plastic waste inputs to marine environments may be more efficient than focusing primarily on-site clean-ups (Eriksen et al., 2016). 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. Providing the village of San Francisco effective waste disposal methods is imperative for reducing local litter input into the Tortuguero river. The same mitigation should be made available for the small population that resides in Playa Norte. These mitigation strategies should be paired with environmental education, which is a useful way of shifting behaviour and promoting responsible citizenship (Bennet et al., 2017; Hungerford and Volk, 1990). Caño Palma Biological Station already has an environmental education program in place through the San Francisco community library, which receives San Francisco children on a weekly basis and works as an after-school program. Including content on plastic pollution and alternatives for safe waste disposal into the Station's curriculum could promote pro-environmental behaviours in children and their relatives. There is also a need to expand data collection to understand sources, trends and marine debris amounts in Playa Norte. For example, assessing monthly spatial commercial fisheries activity in the area as in Ribic et al. (2012) could provide useful information for monitoring ocean-based debris on shore. Similarly, in order to produce high-quality data, it is crucial to estipulate clear research questions prior to starting the monitoring program, so that data collection is designed to address the study objectives rather than collecting information on drivers or attempting to deduce processes after the fieldwork has ended. 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 ecotourism derived economies.

Acknowledgements

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List of Figures and Tables

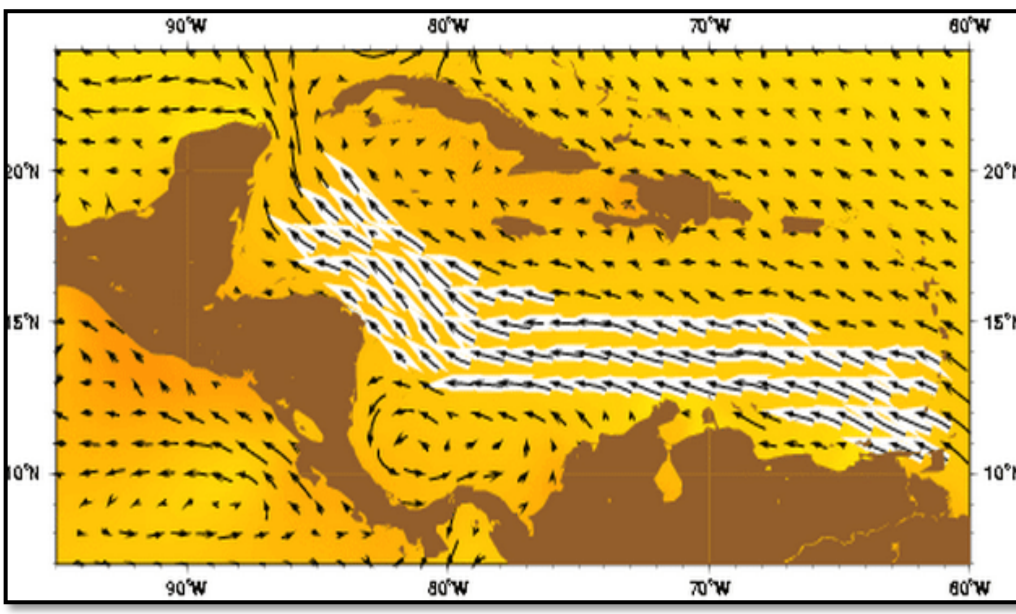

Figure 1. The Caribbean Current. The east coast of Costa Rica is adjacent to the Panama – Colombia gyre, a counter clockwise circulation that is most likely a result of the blending of waters from the Guyana Current, flowing in from South America, and the North Atlantic surface currents (Original by Gyory et al., 2008)

- Playa Norte
- Start of transect
- Caño Palma Biological Station
- San Francisco de Tortuguero
- Tortuguero River
- Tortuguero village

Figure 2. Location of the study transect (10°35'34.5"N 83°31'27.7"W), Playa Norte and other nearby relevant areas (Original Image from Google Earth).

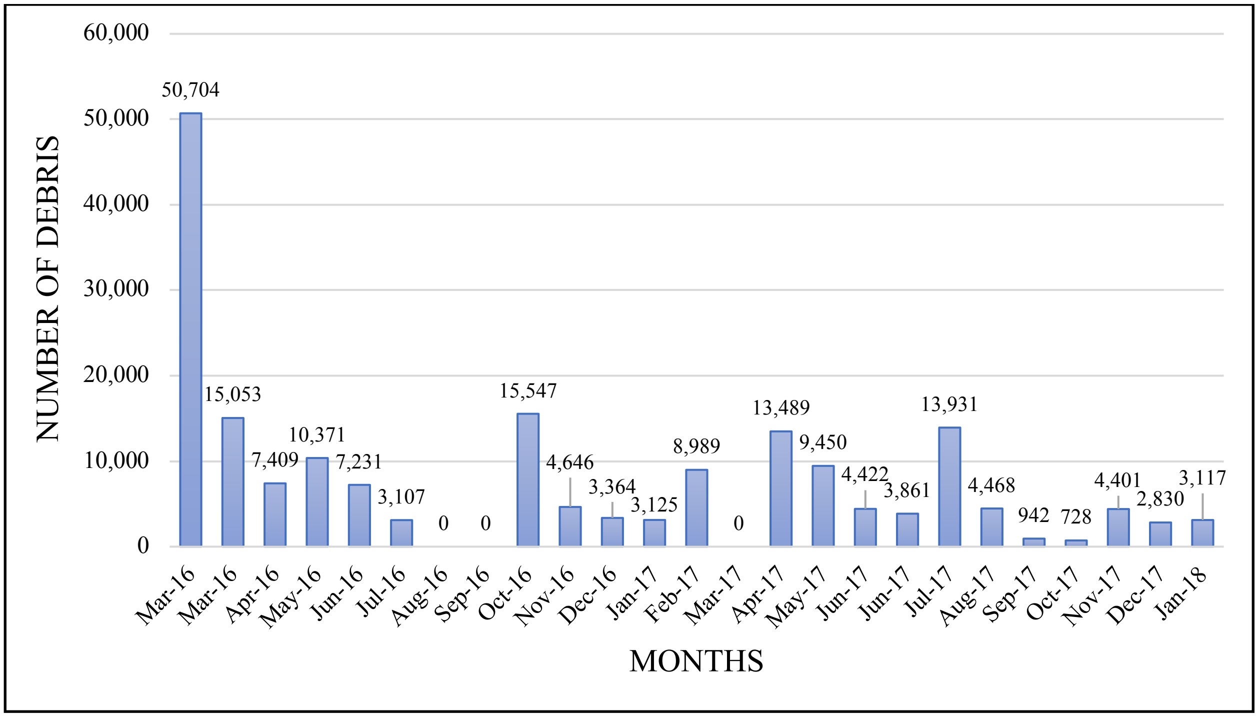

Figure 3. Total debris accumulation per month in Playa Norte, Costa Rica. The initial cleanup was done at the beginning of March 2016, during this first survey the highest amount of debris was collected and recorded. There was a lack of cleanups on August and September of 2016, therefore the peak in accumulation of debris for October 2016 reflects debris accumulation of three months (August, September and October 2016). The same scenario reflects the peak in April 2017, which represents the accumulation of debris of two months (May and April 2017).

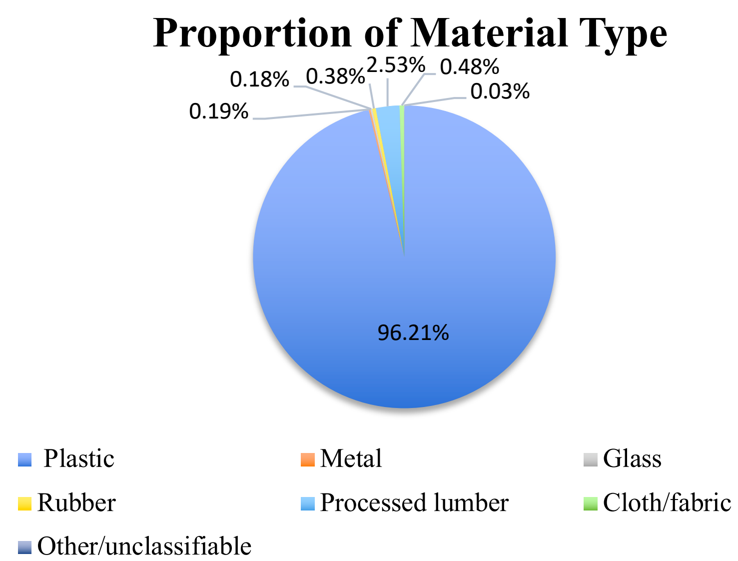

Figure 4. Amount and proportion of material type found in Playa Norte Beach, Costa Rica. Most of the debris items found on the beach were made of plastic

TOP 10 PLASTIC ITEMS	*Total Count*
Plastics fragments	114,351
Jugs or containers cap	23,397
Foamed Plastic/Sponges	10,541
Food Wrappers	6,721
Lollipop stick	6,224
Plastic rope / small net piece	3,480
Bags / various soft plastic	3,049
Bottles	2,453
Plastic utensils	1,926
Cups (including polystyrene / foamed plastic)	1,907

Table 1. Top 10 most commonly found plastic items on Playa Norte

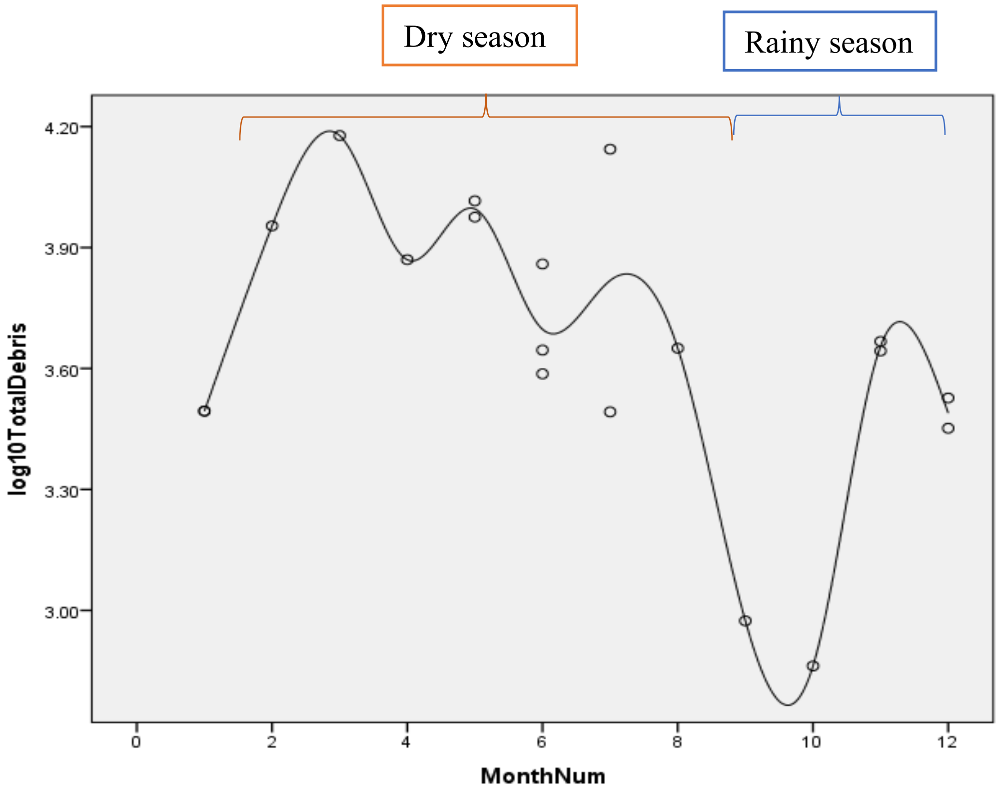

Figure 5. Seasonal variations in debris accumulation in Playa Norte. The numbers on the X axis correspond to each month of the year, January being 1 and December being 12. Debris accumulation rates were higher during the dry season (January – September), and lower during the rainy season (November – January).

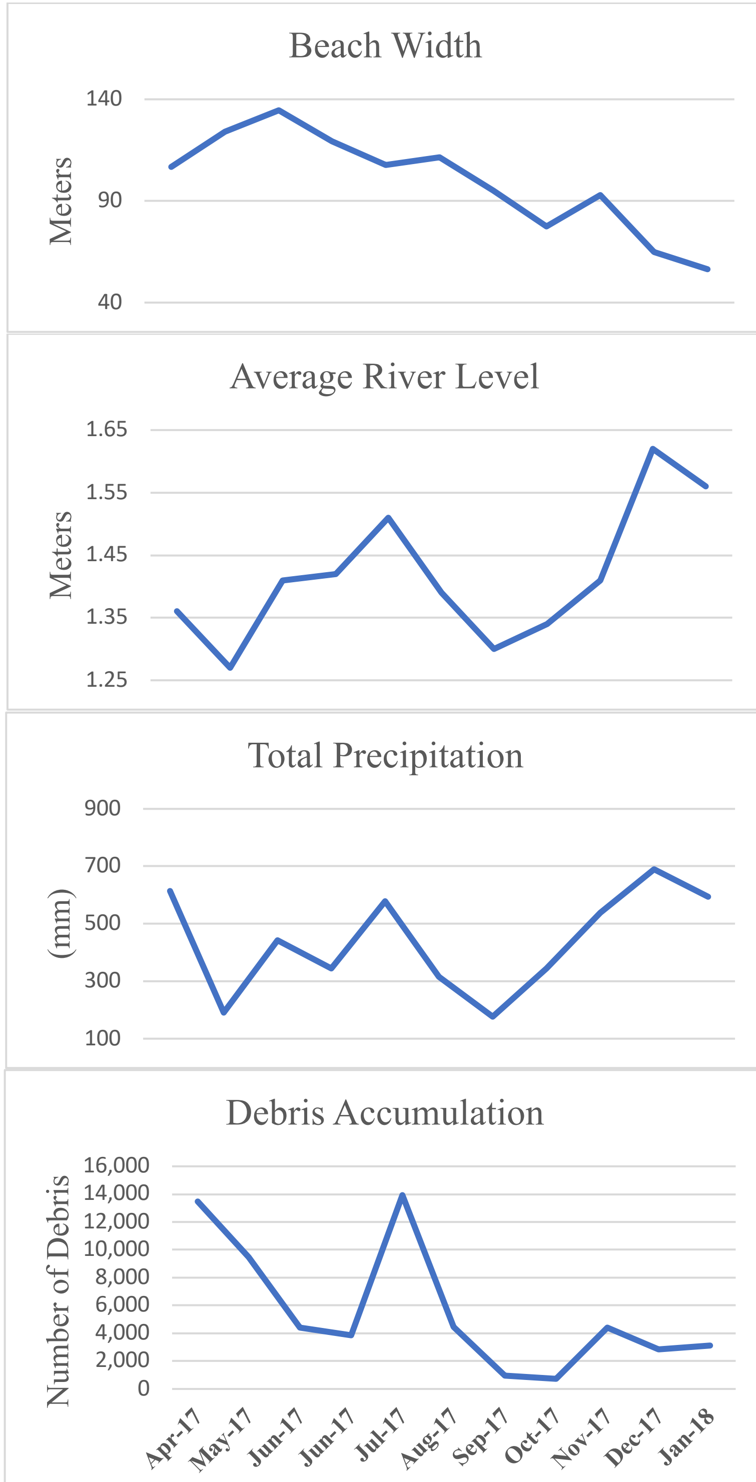

Figure 6. Debris accumulation trends compared to that of the explanatory variables used to predict debris accumulation rates from April 2017 to January 2018.

CHAPTER THREE

CASE STUDY II

Incorporation of anthropogenic debris into double-crested cormorant nests, Toronto, Ontario

Melina Damian, Gail S. Fraser

Faculty of Environmental Studies, York University, 4700 Keele St, Toronto, ON, Canada M3J 1P3

Abstract

There is a paucity of research on the extent of macro debris pollution in freshwater environments, particularly for the larger ecosystems such as the Great Lakes. Birds which use a range of materials from their environment for nest-building may be used as indicators of the characteristics of anthropogenic debris pollution in freshwater ecosystems, and over time, could be used as an index of pollution. In this study, we sampled double-crested cormorant (*Phalacrocorax auritus*) ground-nests (n = 50) for the presence and type of anthropogenic debris at a large ground-nesting colony in Canada's largest city, Toronto, Ontario. We categorized the types of debris, the colour, and proportion by weight in a subsample of nests. We also measured height of each nest because they are reused annually. To evaluate whether cormorants are a good indicator species for freshwater debris, nest content was compared to the Great Canadian Shoreline Cleanup data available for the site. All of the nests sampled had some kind of anthropogenic debris (100%). Nests contained a variety of debris items, including plastic items (bags, straws, cutlery, cups), metal bars, electric wires, fishing nets, and cloth items. Cormorants select nesting material from both terrestrial and aquatic environments, thus the results represent the anthropogenic debris available in their environment. Tracking anthropogenic debris in cormorant nests is an effective way to track changes in relative proportions in their environment but reuse of nests presents a challenge in developing an index.

Keywords: Freshwater birds • Plastic pollution • Lake Ontario • Indicator species • Great Canadian Shoreline Cleanup • Nesting material

Corresponding author: G.S. Fraser, gsfraser@yorku.ca

Introduction

Anthropogenic debris pollution is ubiquitous in the natural environment (Lippiatt et al. 2013; Gall and Thompson, 2015). Most of the anthropogenic debris that accumulates in marine and freshwater environments is plastic (Barnes et al., 2009; Nelms et al., 2015). The detrimental effects of plastic pollution in wildlife have been widely documented (Derraik, 2002; Gall and Thompson, 2005), with entanglement in plastic being of particular concern for marine and freshwater birds, especially when it is used as nesting material as it occurs at the breeding site and it puts both juveniles and adults in danger (Lavers et al., 2013; Votier et al., 2011). Most of the studies on the effects of plastic pollution on birds are marine based and there is a lack of research in the Great Lakes (Provencher et al., 2014). As of 2014, the only available data on the type and quantity of plastic pollution in Lake Ontario was produced by volunteer-led initiatives such as the Great Canadian Shoreline Cleanup and the Adopt-a-Beach Program (a U.S.-based program from the Alliance for the Great Lakes; Corcoran et al., 2015). Yet, evidence suggests that plastic pollution is similarly available to marine and freshwater birds. For example, Holland et al. (2016) found similar frequencies of anthropogenic debris ingestion in different freshwater waterfowl species compared to those found in marine common eiders (*Somateria mollissima*). Zbyszewski and Corcoran (2011) report that plastic pellets abundance in Lake Huron resembled quantities found in marine environments. The proximity to major cities and industrial sites is thought to be one of the main drivers of plastic pollution in The Great Lakes (Zbyszewski et al., 2014).

Indicator species can be used to determine impacts of anthropogenic debris pollution in aquatic environments because they are assumed to reflect exposure or response to a stressor thus providing useful information of the health condition of the ecosystem they inhabit (Canterbury et al., 2000; Kushlan, 1993; Siddig et al., 2016). Aquatic birds that are apex predators are good indicators of local environmental change because of their location in food webs (Hebert et al., 2011). Colonial birds are effective indicator species because they gather in a few locations in large numbers and can be used to detect trends on coexisting species across food webs (Piatt, 2007). Double-crested cormorants (*Phalacrocorax auritus,* hereinafter cormorants) are a colonial water bird widely distributed across North America (Dorr et al., 2014). Cormorants forage in both benthic and pelagic zones and their diet consists of almost entirely fish, although they are opportunistic feeders, which makes them prone to exposure to environmental toxins (King et al., 2017). They have been used to understand the relationship between invasive species and avian disease dynamics (Hebert et al., 2014) and the presence of contaminants and toxic persistent organochlorines in the Great Lakes (Bishop et al., 2016; Yamashita et al. 1993). Provencher et al. (2014) specifically recommended cormorants as a potential indicator species to monitor plastic pollution in the Canadian Great Lakes.

One of the most common interactions between birds and anthropogenic debris is the use of these items in nest building. Incorporation of synthetic materials in birds' nests can cause entanglement and ingestion of debris (Votier et al., 2011), negatively impact nesting and fledging success (Wang et al., 2009) and increasing the cost of nest-building and incubation by causing genotoxic damage (Suárez-Rodríguez et al., 2017). In a review on wildlife entanglement, Ryan (2018) suggests that incidence of plastic in nests correlates with local availability, yet there is evidence suggesting that birds choose anthropogenic over natural debris for nest building even when natural nesting material is available (Verlis et al., 2014; Tavares et al., 2016). The specific selection of debris colours may be associated with resemblance with organic nesting material or prey color (Lavers et al., 2013; Tavares et al., 2016) or may be used to enhance mate attraction (Verlis et al., 2014). While the study of the presence of anthropogenic debris in birds' nests is a relatively new field of study (Battisti et al., 2019), there are many examples of anthropogenic debris incorporated into marine bird nests: black-legged kittiwakes (*Rissa tridactyla*; Hartwig et al., 2005), Australasian gannets (*Morus serrator*; Norman et al., 1995), northern gannets (*Morus bassanus*; Montevecchi, 1991; Votier et al., 2011; Bond et al., 2012), kelp gulls (*Larus dominicanus*; Witteveen et al., 2017), brown bobbies (*Sula leucogaster;* Verlis et al., 2014; Tavares et al., 2016) and double-crested cormorant (Gulf of Maine; Podolsky and Kress, 1989). However, limited research exists for freshwater nesting birds (Jagiello et al., 2018).

On the Great Lakes, citizen science programs are used to monitor the abundance and distribution of anthropogenic debris. For instance, in 2012 Adopt-a-Beach and the Great Canadian Shoreline Cleanup volunteers collected nearly 20,000 kg and 9,300 kg anthropogenic debris, respectively from the Great Lakes shorelines (Driedger et al. 2015). The Great Canadian Shoreline Cleanup (GCSC), an initiative from the Vancouver Aquarium that started in 1997 in British Columbia, and is now paired with Ocean Wise and WWF-Canada, has expanded to every Canadian province and territory. This platform (shorelinecleanup.ca) allows citizen scientists to lead or join a cleanup on any shoreline across Canada, and the information collected is shared with the International Coastal Cleanup, which is coordinated by Ocean Conservancy. GCSC has conducted numerous surveys along Toronto's shorelines and volunteer-led initiatives take place regularly.

In this study, we quantified the frequency and type of debris in cormorant nests at a colony in Lake Ontario. We compared debris frequency and type in cormorants' nests to debris recorded in the GCSC to determine if cormorants should be used as an indicator species of anthropogenic debris pollution, in addition to GCSC efforts in Lake Ontario.

Methods

Study Area

Cormorant nests were sampled at Tommy Thompson Park, located in Toronto's east shoreline adjacent to Lake Ontario (43° 37' 22.2168" N, 79° 20' 30.8184" W). From 1959 to 2017 the Toronto Harbour Commission (formerly Toronto Port Authority, now Ports Toronto) used the lake front as a site for depositing waste (e.g., unreinforced concrete, broken concrete, brick, ceramic tiles and clean porcelain) from city infrastructure (Foster, 2007). In addition to construction rubble, archaeological studies show that historical deposits contained a large number of personal items and household debris (mainly electrical wire and metal) as a result of full house demolitions (Schopf and Foster, 2014) and some of this rubble is visible at plain sight, which suggests that it is also accessible to wildlife (personal observation).

Tommy Thompson Park is designated as urban wilderness and is an Important Bird Area (Taylor et al., 2011). As of 2018, it is believed to be the largest nesting colony of double-crested cormorants in North America, with 70% of the population nesting on the ground on peninsulas A and B (McDonald et al., 2018; Figure 1). Nests were sampled on Peninsula B which has had ground-nesting since 2002 (McDonald et al., 2018).

Survey design

Fifty cormorant ground-nests were sampled on Peninsula B at Tommy Thompson Park during the non-breeding season in October 2018. We ran three transects through the nesting area. Along each transect, we sampled every third nest, that was under 40 cm in height; a subsample of 15 nests were weighed. Nest height was measured to provide an assessment of nest age in the assumption that taller nests are older (Dorr et al., 2014) and may have more debris compared to more recently constructed nests (see also Montevecchi et al., 1991; Verlis et al., 2014). Each nest was scraped at ground level using a shovel, dismantled and all visible anthropogenic debris (>2.5 cm) was removed and placed in labeled bags for later assessment in the laboratory.

In the laboratory, macro-debris nesting material was washed in soapy water, and air dried. Each item was counted, weighed and measured along the longest axis and categorized according to colour and material type for a subsample of nests (n= 28). For the remaining nests (n= 22), we counted and weighed all items together for each material category. We classified anthropogenic debris using the same categories as the GCSC (Driedger et al., 2015) and added 13 additional categories to classify metal, electrical wire, different types of plastics, rubber pieces and other mixed-materials. Using the Itten Colour Wheel (Westland et al., 2012) we condensed the categories into: yellow range (yellow, yellow-orange, orange), red range (red-orange, red, red-violet), blue range (blue, blue-green, blue-violet, violet), and green range (green, yellow-green) and added black, white, transparent and an "other" category mostly for rusty metal and pink items.

To understand how debris proportion and type in cormorant nests compared with debris collected by GCSC, we used GCSC data available for Tommy Thompson Park. On GCSC surveys volunteers pick up all litter and record data for the items listed in a standardized data card (available at shorelinecleanup.ca). However, during cleanups at Tommy Thompson Park, volunteers added several other categories of items specific to the site (such as domestic appliances and building materials). We compiled GCSC data from 2011 to 2018 (seven years) for Tommy Thompson Park for comparison.

Statistical analysis

To compare GCSC data to cormorant debris data, we grouped the material types in four general categories (plastic, building material, mixed materials and miscellaneous) and examined whether the type and proportion of debris in nests differed from the debris found in GCSC surveys using a Chi-square goodness of fit analysis. Using our nest height data, we categorized nest age as "new" i.e., built in one season (< 10.5 cm in height) and "old", i.e., used over multiple seasons (>10.5 cm; Dorr et al., 2014; see also Montevecchi et al., 1991). There was no difference in the variances in these two groups ($F_{6,11} = 0.018$, $p = 0.89$) and therefore, we used a t-test, assuming equal variances, to compare the amount of debris in old versus new nests. We also treated nest height as a continuous variable and used a simple linear regression to test if nest height significantly predicted number of debris items found in the nests.

Results

All of the nests sampled contained anthropogenic debris (100%, n = 50) with a total number of 1,442 items (average ± SD = 28.84 ± 21.93 items/nest; range 5 - 91) and total weight 13.81 kg (average = 76.37 ± 301.86 g/nest). Out of 794 items measured in length the longest item was 442 cm, and the smallest was 0.02 cm (average = 29.72 ± 30.46 cm).

The most common material type found in nests was plastic (comprised primarily of plastic pieces, packaging and straws), followed by building material (comprised of metal and electrical wire), miscellaneous (comprised mainly of food wrappers, rubber pieces, and other), and mixed materials (Figure 3). The GCSC data also showed the most common material type as plastic (comprised primarily by plastic pieces, plastic bottles and bottle caps), followed by miscellaneous (comprised primarily of cigarette butts, food wrappers and beverage cans), and building material (including metal and other building materials) and mixed materials in much smaller proportions (Figure 3). There was a significant difference in the material categories for cormorant nests compared to the shoreline surveys ($X^2 = 2099.21$, *d.f.* = 3, *P* = 7.81).

The most common colour category found in nest debris was "other" (20%), followed by white (17%), black (16%), transparent (14%) and multicoloured (11%). Gray, and the blue, yellow, green and red ranges were present but in much smaller proportions (Figure 4).

There was no difference in the frequency of debris found in old versus new nests (n = 19; t= -0.529, *d.f.* = 17, p= 0.301). As a continuous variable nest height (average = 11.64 ± 3.9cm), was not a significant predictor of number of debris items in the nests ($R^2 = 0.13$, $F_{(1,17)} = 2.57$, $p < 0.12$).

Discussion

In this study, we found that all nests sampled contained some form of anthropogenic debris. Plastic was the most commonly found item, as it is the case for other studies assessing the incidence of anthropogenic debris in seabird nests (Montevecchi, 1991; Norman et al., 1995; Lavers et al., 2013; Votier et al., 2011). While plastic was also the most frequent item in GCSC surveys, using broad debris categories, the debris in cormorant nests was different from debris collected in GCSC. Nest age nor nest height was significant in predicting the number of debris found in the nests. The most commonly found colours were the "other" category, followed by white and black.

Cormorants gather nest material both in the water (e.g., aquatic plants; Podolsky and Kress, 1989) and on land (e.g., sticks), thus each environment offers an opportunity to encounter different types of human debris. Tommy Thompson Park is unusual in that the substrate itself is debris and it is not a typical waterfront city park. While much of the debris at the site is "clean" fill (Tommy Thompson Park, n.d.), there are areas where non-clean fill was dumped over the years (such as PCBs, CFCs, pesticides, heavy metals, and other toxins; Foster, 2007). Even though cormorants forage within a 30 km radius from the colony and within 2.5 km of shore (Dorr et al., 2014), it is likely that they gather nesting material near the colony due to energy expenditure of carrying nest material for long distances. This idea is supported by the amount of building material (metal, electrical wire) found in the sampled nests. Podolsky and Kress (1989) assessed 497 double-crested cormorant nests in the Gulf of Maine, and found that 37% of them contained plastic, lower than what was observed in our study. They also found there was no apparent trend for colour selection.

Driedger et al. (2015) cautions researchers when comparing litter results to those found by GCSC, given that their cleanups primarily aim to clean recreational areas which may present a site sampling bias in this study, however we used only GCSC data from Tommy Thompson Park. The designation of urban wilderness for Tommy Thompson Park means that the public cannot drive into the park and there are no large beach areas where litter could accumulate from park users. Much of the litter from GCSC (food wrappers, cigarette butts and foam pieces) may transported by air or water currents; two of the sites surveyed were adjacent to boat docks (Figure 2).

Cormorants collect nesting material throughout the breeding season and will re-use nests across nesting seasons (Dorr et al., 2014). Some nests sampled were from prior years (Fraser, personal observation) and the average nest height for our sample of nests was comparable to nest height reported by Bloome (1979). The lack of relationship between nest height and frequency of debris requires further exploration since we did not sample nests above 40 cm cm and our sample size was low. Nonetheless, the reuse of nests is an important consideration if cormorant nests will be used to monitor plastics in freshwater environments and we suggest that only nests on the edge should be sampled to account for an accumulation of debris from the previous year (see Furness and Greenwood, 2013; Norman et al., 1995).

We investigated whether cormorant nests should be used to monitor debris in freshwater environments. Provencher et al. (2014) recommended cormorant nest sampling at three-year intervals as part of a national strategy for monitoring plastic pollution in freshwater systems. While Tommy Thompson Park has the largest breeding colony of double-crested cormorants in North America (McDonald et al., 2018) we cannot recommend this site to be used in a monitoring strategy because of the history of the site.

Cormorants have coloured ornaments used in mate choice (e.g., blue mouth and yellow and yellow-orange facial features; Dorr et al. 2014) and previous studies suggest a general trend of green, blue and white debris in seabird nests (De Souza et al., 2016). Therefore, it is possible that cormorants may select human-made items for colour. The GCSC did not categorize colour of items collected, so we were unable to compare to the colour of items found in cormorant nests. In our study, the most common category was “other” which corresponded mainly to rusty metal which was often brown, thin and long, resembling natural sticks. Blue and yellow and yellow items were present in very small proportions. There may be other features that influence debris selection (see Savoca et al., 2016), but further work is required.

Even though we are unable to conclude that cormorants can be used to indicate change in plastic pollution over time, our findings are important for understanding the threat that anthropogenic debris pollution poses to cormorants. Birds can spend considerable energy trying to free themselves from entangled debris which makes them more vulnerable to predators (Sazima et al. 2016), and death by entanglement occurs mainly by nestlings (Votier et al., 2011). In South Africa Bank cormorant (*Phalacrocorax neglectus*) chicks were discovered hanging from their nests strangled by fishing line (Robinson et al., 2012). Birds that die as a result of plastic entanglement most likely experience a slow death through starvation and constriction (Votier et al., 2011), thus mitigating anthropogenic debris pollution in freshwater ecosystems is crucial for the welfare of wildlife species. One way to do so is by implementing retaining walls and breakwaters which have been proven to be effective at reducing the amount of plastic debris entering Lake St. Clair (Zbyszewski et al., 2014).

Acknowledgments

We would like to thank the Toronto and Region Conservation Authority for their support of cormorant research at Tommy Thompson Park and to C. Swanson for discussions on the topic of cormorants and plastic. We also thank the Great Canadian Shoreline Cleanup initiative and for the use of their data in this study. We are also grateful with our laboratory assistants Andrew Gavloski, and Miranda Baksh, and with the Colla lab for sharing their working space with us.

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List of figures

Figure 1. Double-crested cormorant on a nest at Tommy Thompson Park, Toronto, ON (photo credit: G. S. Fraser)

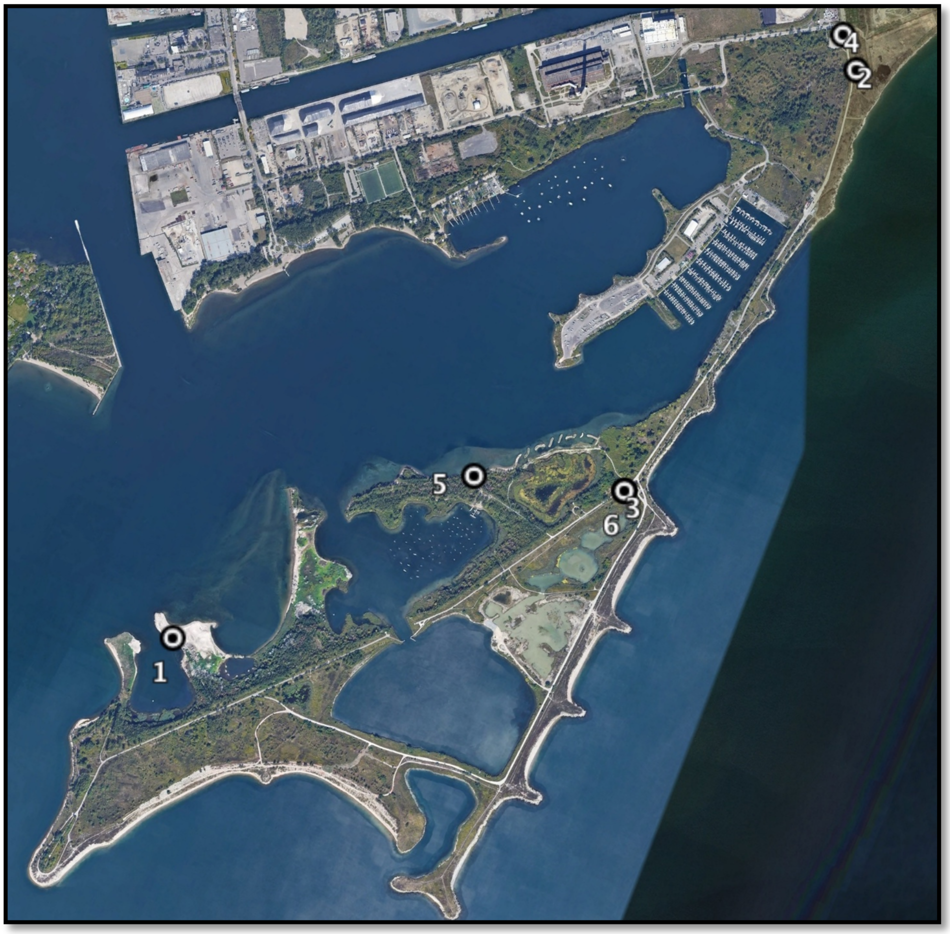

Figure 2. Tommy Thompson Park, Toronto, ON. Site 1 is Peninsula B where cormorant nests were sampled in the Fall of 2018. Sites 2-6 are where GCSC surveys took place between 2011 and 2018.

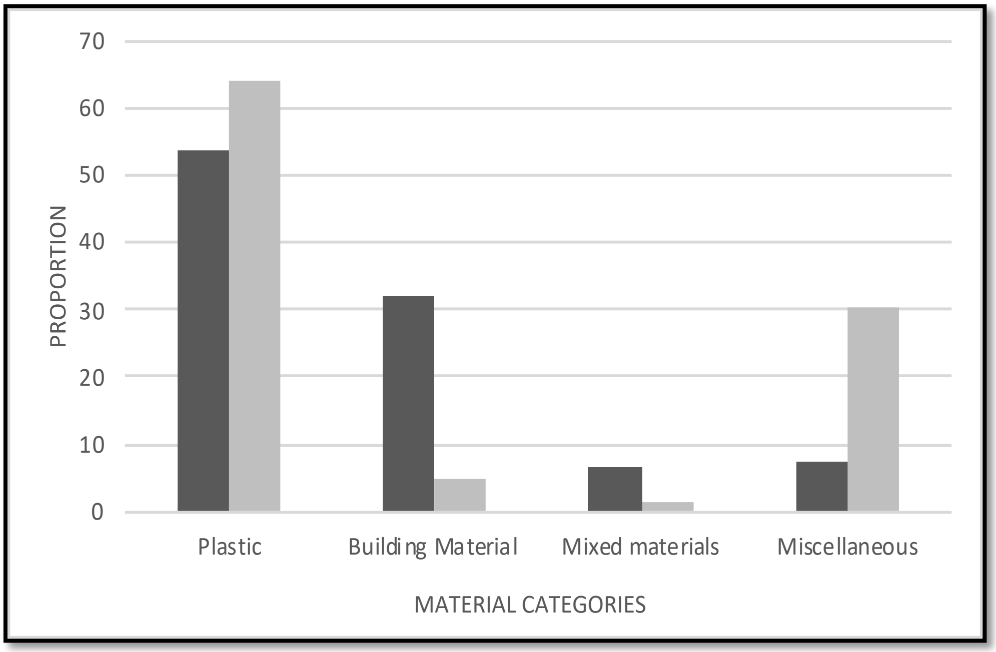

Figure 3. Material categories comparison between debris found in nests (dark bars) and debris found in GCSC surveys (light bars). Most of the anthropogenic debris found in cormorants' nests was plastic (comprised primarily of plastic pieces, packaging and straws), followed by building material (comprised of metal and electrical wire), miscellaneous (comprised mainly of food wrappers, rubber pieces, and other), and mixed materials. GCSC surveys also found the most abundant debris to be plastic (comprised primarily by plastic pieces, plastic bottles and bottle caps), followed by miscellaneous (comprised primarily of cigarette butts, food wrappers and beverage cans), and building material (including metal and other building materials) and mixed materials in much smaller proportions.

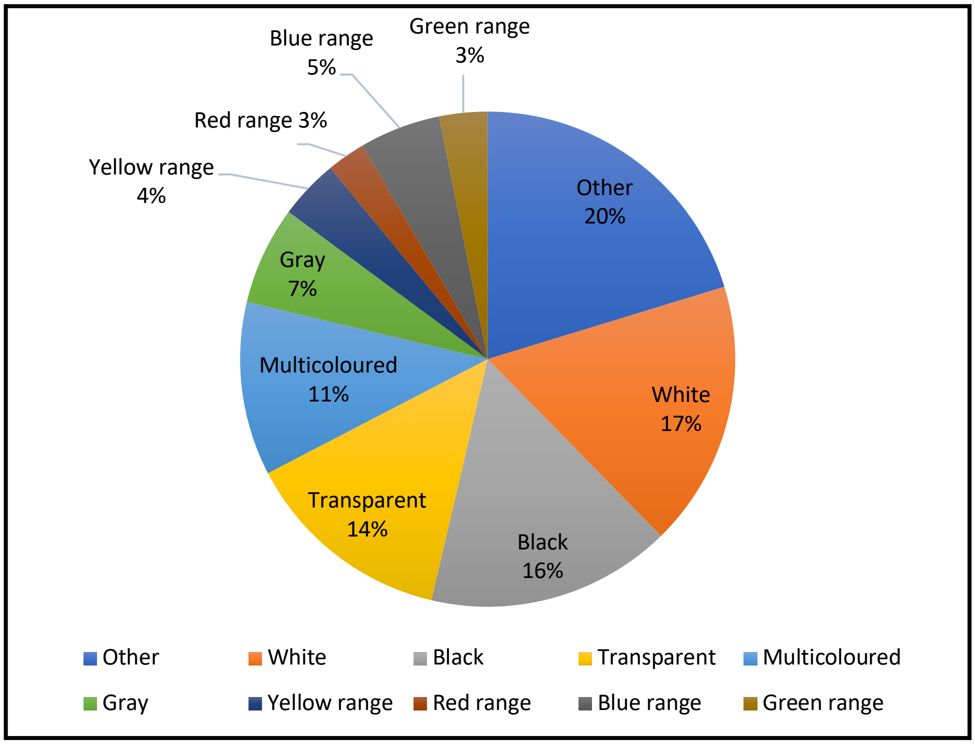

Figure 4. The colour of the debris items found in double-crested cormorant nests (794 pieces in 28 nests).

Length: 174.5

Width: 72.7 cm

Figure 5. Example of debris (n= 80 pieces) found in a single nest (photo credit M. Damian).

CHAPTER FOUR

REFLECTION ON ENVIRONMENTAL EDUCATION

My journey as a formal educator started not too long ago. In September 2018, I was given the opportunity to be the Teaching Assistant for the course ENVS 1500- Introduction to Environmental Science. I have, however, felt the responsibility to educate others (i.e.: my family and friends) about environmental issues since I was young. When I was 14 my dad came to me one day and said “Meli, did you know straws take 500 years to biodegrade? They often end up in the ocean hurting animals. Let’s make a promise and not use straws anymore”. Not too long after learning about that terrible revelation, I came across a picture of a marine turtle whose body was deformed by a plastic piece wrapped around its stomach. I was only 14, nobody in my immediate social circle was an environmentalist, yet my dad’s pledge coupled with the shocking image was enough for me to start a personal commitment to fight plastic pollution – and convince others to do the same. In high school, I became the annoying friend who wouldn’t let others use straws when going out, and up to this day my aunt (who I haven’t seen since 2012) says that every time she gets a plastic bag in the supermarket she remembers that if I saw it, I wouldn’t be happy about it. Who would have known that years later, I would be doing graduate research on the impacts of plastic (and other anthropogenic debris) pollution on marine turtles and on double-crested cormorants? …

I often wonder: what worked for me? As I look back into my childhood I try to decipher what was that turned on the switch in me to care about Mother Earth. Until I was 17 when I moved to Canada I grew up in Caracas, Venezuela, a big, crowded city – similar to Toronto. My home city is more like a valley, surrounded by “El Ávila”, a mountain part of the Andes mountain range that can be seen from anywhere in the city. Every day felt like waking up to a green noble giant whose shade turned pink and orange when the sun set, and whose background sky was adorned with noisy yet beautiful yellow and blue macaws. But truly, other than that, my memories of spending time in or feeling connected to nature are scarce. My school’s playground was a large parking lot with only three small trees and no other green spaces, my neighborhood wasn’t surrounded by natural areas, my first time camping was when I was 15. The more I try to put the puzzle together to understand “what makes people care?”, the more I realize how complex the puzzle is.

In an attempt to promote a systemic change within the Faculty of Environmental Studies (FES), I produced an infographic as my contribution piece and final assignment for the course Environmental Education with professor Traci Warkentin (Appendix B). The infographic provides basic information on the dangers of plastic pollution, and what FES can do about it. Events that take place within the faculty that cater food almost without exception also provide single-use cutlery, plates, stirring sticks, and other disposable utensils. The amount of waste produced at faculty events doesn’t align with sustainable values, and most importantly: it could be prevented. My objective with producing an infographic is to catch the reader’s attention by presenting the problem and the opportunities they have to create change in concise and easy terms. The infographic was displayed in FES’ 50th Anniversary Celebration. Just like the picture of the turtle wrapped in plastic had a profound effect in me when I was young, my hope is that the infographic provided a strong visual component capable of at least inciting conversation and inquiry, by raising awareness and educating to subsequently provoke behaviour modification.

I am aware that an infographic is just a drop in the bucket, in comparison to the work we have ahead as environmental educators, yet I can say that my experience throughout competing the Diploma in Environmental/Sustainability Education provided me excellent tools to implement in the classroom with my tutorial students. There was not a single week that I wouldn’t reflect on the way my tutorials went and what could I have done better. I realized that environmental education should be geared not only towards students, but also to educators! I was faced with the challenge of figuring out how to enrich the learning objectives I had to deliver while promoting meaningful (and fun!) discussions. There were a number of weeks in the semester that my lack of creativity was the biggest barrier: how could I teach my students about cell respiration, if even I found that topic too abstract because I couldn’t perceive a cell with any of my senses? How could I present such information in a story setting to make it relatable or link it to day to day events? The short answer was: I couldn’t. There were weeks when I relied on power point slides and an activity sheet and student’s enthusiasm was lower than usual. Yet I didn’t give up. The week following cell respiration I handed out post-it notes and asked the prompt question Robin Wall Kimmerer (from Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teaching of Plants) once asked her students: do you think humans and nature are a bad mix? I asked them to reflect on it, and vote who agreed and who didn't agree with the statement (Figure 1). The subsequent week, after completing the scheduled exercise, I asked them to do a zine with the prompt question: What does environmental science mean to you? (Figure 2). I then scanned all the zines they had produced and attached a motivation letter that I hand-wrote to the class, encouraging to never give up on their dreams and on their willingness to learn about the environment and work towards protecting it. So, we did have weeks in which my creativity as an educator translated into fun learning activities, yet I would often leave tutorials feeling like I failed my students. Not every week was as engaging, and I knew I was at fault – but on the other hand, it was beautiful to realize how the process of teaching also made me become a student myself during every class. Some weeks the content was dense, and the classroom space wasn't the most appropriate (the classrooms didn't have windows). First year students are the entry point (or not) to an entire new level of awareness, they are the future leaders of society! Resources should be better on them. Why are big spacious rooms at FES reserved for graduate courses and not for first-year tutorials? When I requested to switch rooms, the faculty allotted me the basement of the HNES building – which my students disliked even more when I asked them.

Educating is a beautiful responsibility that I definitely want to pursue in the future. My first time as a formal educator was full of flaws, but I know that I did my best at trying to overcome the shortcomings of my teaching strategies. In spite of always feeling like I could have done a better job in tutorials, I received positive feedback from my students. When I asked them to tell me what they liked and didn't like about tutorials so that I knew how to make them better, they provided some thoughtful, positive comments (Figure 3). Also, after our last tutorial, I received two emails from students who told me how much they enjoyed our time together (Appendix A). Completing the Diploma in Environmental/Sustainability Education opened my horizons as a student and educator, I learned meaningful content that I was able to reflect on and put in practice and realizing that I was able to have a positive impact on some of my students gives me strength and motivates me to keep trying to inspire others in learning about the importance of protecting Mother Earth.

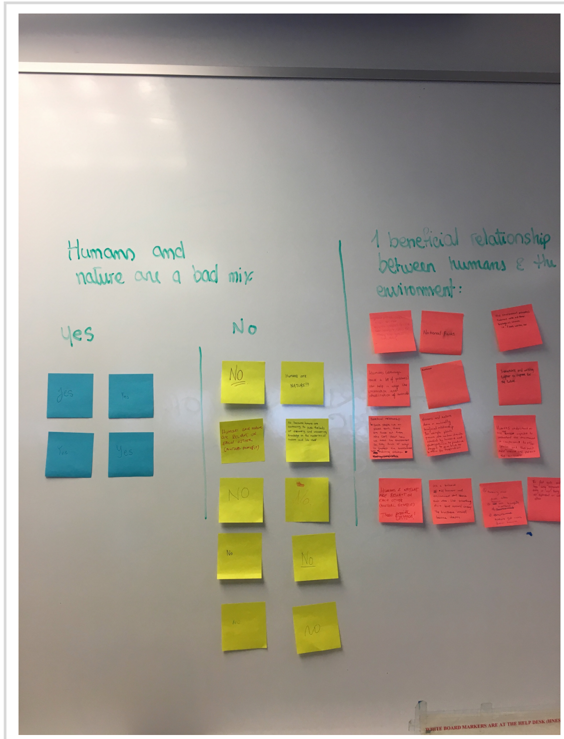

Figure 1 – Class activity. Questions for students: do you think humans and nature are a bad mix? Why?

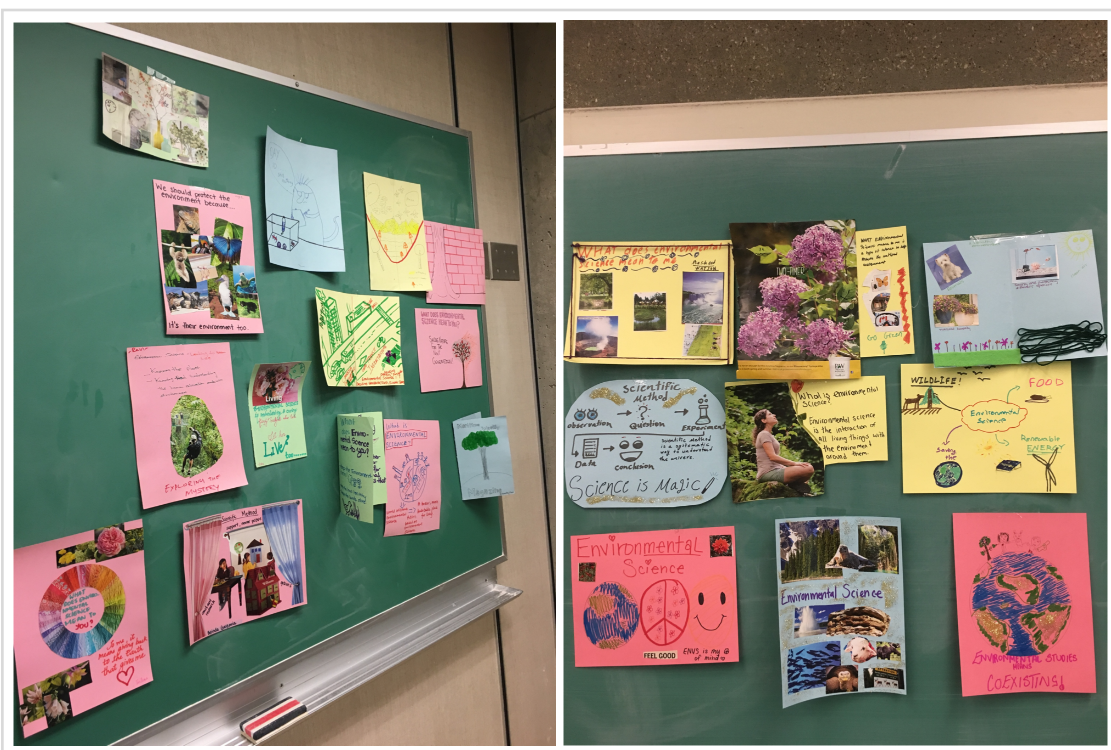

Figure 2 – Class activity. Zine making with the prompt question: what does environmental science mean to you?

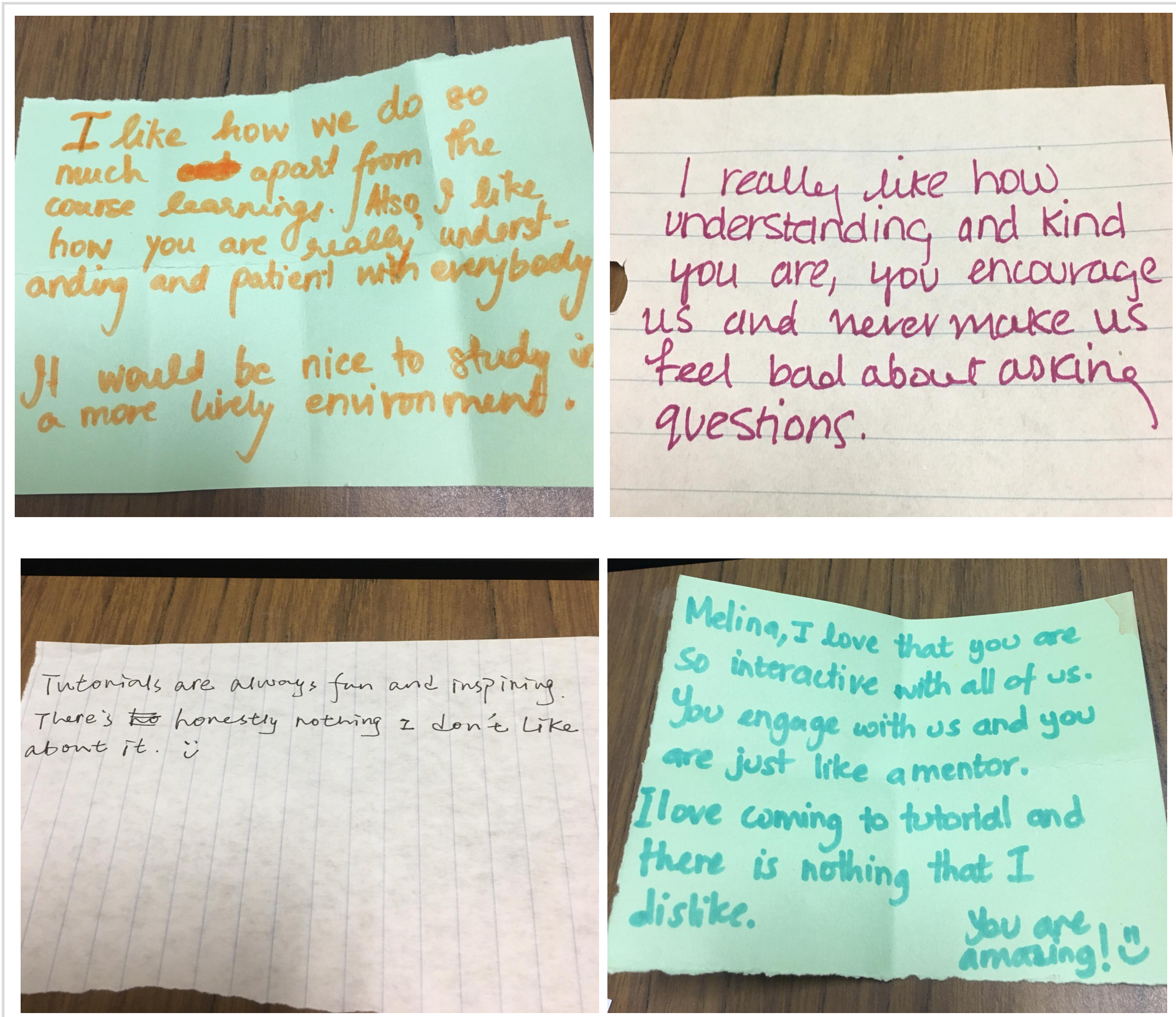

Figure 3 – Class activity. Questionnaire for students: tell me one thing you like and one thing you don't like (and how to make it better) about tutorials?

Appendix A

Dear Melina,

I would like to thank you for the thoughtful letter and the beautiful view of Mother Earth, it really changed my perception of our planet! It made me realize how much you've inspired us all in just a matter of a few months! You are so kind and have encouraged us to be better students as well as humans. I really found ENVS 1500 to be my favourite course because of two such inspiring professors as well as such an inspiring TA! It actually saddened me when I realized that our first year was coming to end and that it was our last tutorial and will be our last class soon! Thank you for being someone we all look up to and aspire to be like one day! I really look forward to seeing you and discussing future endeavours.

With sincere thanks,

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Hi Melina!

This is Zian from your ENVS 1500 tutorial.

I just want to say thank you for the amazing tutorials we had and you've been a wonderful TA. You are honestly the best TA I had so far. I will continue studying in ENVS next year and hope will see you around!

Again, Thank you very much for the journey!

PlasticPollution

WHAT'S THE PROBLEM AND WHAT CAN FES DO ABOUT IT?

Commonly manufactured from fossil fuels, plastic pollution is a threat for ecosystems worldwide. Depending on the type of polymer, it has been estimated that plastics take between 100-1000 years to degrade.

It has been estimated that of all plastic ever produced, only **9%** have been recycled

60% have become trash and are currently accumulating in landfills or in the natural environment

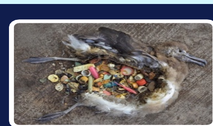
Of the anthropogenic debris that accumulates in the natural environment, plastic accounts for approx. **80%**

17% of the species reported to have ingested or become entangled in plastics are also listed on the IUCN Red List

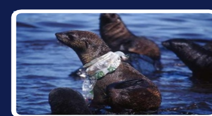
Some of the consequences...

Bio-accumulation

Transport of pollutants



Leaching of chemicals



Entanglement and ingestion

Transport of alien species

IF YOU REPRESENT THE FACULTY OF ENVIRONMENTAL STUDIES

THIS IS HOW *you can* MAKE A CHANGE

- **AVOID USING SINGLE-USE PLASTICS**

Unless you have a disability or other condition that physically requires you to use a straw, do you really need it? Do you really need that coffee lid or stirring stick? Regardless of whether you dispose of plastics correctly, there is always a high chance they will end up in a water body endangering wildlife!

- **DRINK TAP WATER**

In Toronto, tap water is tested every 6 hours to meet safety standards from Toronto Public Health

- **QUESTION COMMON SENSE**

Ontario is facing a waste disposal shortage. Residents from the town of Ingersoll are currently fighting a landfill proposal that jeopardizes their groundwater resources, their air quality and local endangered species

Are you hosting an event at FES that includes catering food?

If you are a faculty or staff member

FES has a set of non disposable utensils available for your use Contact OSAS!

If you are a student and/or part of a student group

You can borrow a dish cupboard. Contact prof. Lisa Myers!