UNIVERSIDADE FEDERAL DO PARÁ

NÚCLEO DE ECOLOGIA AQUÁTICA E PESCA DA AMAZÔNIA

PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA AQUÁTICA E PESCA

LUCIO DAVI MORAES BRABO

CONTAMINAÇÃO POR RESÍDUOS SÓLIDOS E MICROPLÁSTICOS NOS ECOSSISTEMAS MARINHOS DO NORDESTE DO BRASIL

BELÉM – PA

2021

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Dissertação apresentada ao Programa de Pós-Graduação em Ecologia Aquática e Pesca da Universidade Federal do Pará, como requisito para obtenção do título de Mestre em Ecologia Aquática e Pesca.

Orientador: Prof. Dr. Tommaso Giarrizzo.
Co-orientador: Prof. Dr. Marcelo Andrade.
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Área de Concentração: Ecologia Aquática e Pesca.

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Dedico essa dissertação a todas as vítimas da pandemia de COVID-19.

"A ciência é muito mais que um corpo de conhecimentos. É uma maneira de pensar"

Carl Sagan

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APOIO

RESUMO

A gestão de resíduos sólidos é um dos desafios mais importantes da sociedade moderna. O seu manejo inadequado de resíduos causa alterações nos ecossistemas incluindo a poluição do ar, água e solo, representando uma ameaça real a fauna e a saúde humana. Entender as características dos resíduos nos diferentes ambientes marinhos e terrestres é fundamental para dar suporte aos gestores na tomada de decisão. Esta dissertação é composta por dois artigos científicos (i.e., capítulos) sendo um publicado em revista cientifica e outro em processo de submissão. O primeiro capítulo avalia a abundância, composição e distribuição dos resíduos sólidos nas praias do Parque Nacional de Jericoacoara (Ceará). Sendo que, um total de 7.549 itens de resíduos sólidos foram coletados em quatro setores do parque. Os plásticos foram os itens mais abundantes e através da aplicação de modelos aditivos generalizados (GAMs) foi possível prever pontos críticos de maior concentração de resíduos sólidos nas praias do parque. O segundo capítulo apresenta o primeiro registro de ingestão de microplásticos pela raia-lixo (*Hypanus guttatus*) no oceano atlântico ocidental. Os microplásticos mais frequentes foram as fibras (82%), os de cor azul (47%) e os compostos por tereftalato de polietileno (PET) (35%). Estes resultados fornecem informações importantes para estudos futuros de ingestão de microplásticos por raias e contribuem para o entendimento mais amplo das dimensões espaciais e temporais da poluição por resíduos plásticos nos ecossistemas marinhos.

Palavras-chave: Poluição, Resíduos sólidos, Microplásticos, Ingestão, Hypannus guttatus.

ABSTRACT

Solid waste management is one of the most important challengers to modern society. Inadequate waste management causes injuries on the environment including air, water and soil pollution, representing a threat to animals and human life. Understanding characteristics of solid wastes in different marine and terrestrial ecosystems is important to support managers to make decisions. This dissertation is composed of two papers (i.e., chapters), one of that published in a scientific magazine and another one in the submission process. First chapter evaluates abundance, composition, and distribution of solid waste on Jericoacoara National Park beaches. A total of 7549 items of residues were collected in four park sectors. Plastics were items more abundant and through application of generalized additive models (GAM) was able to predict critical points of solid wastes on beaches. Second chapter shows the first record of microplastics ingestion by longnose stingray (Hypannus guttatus) on western Atlantic Ocean. The most frequent microplastics were fibers (28%), blue color (47%) and polyethylene terephthalate compounds (PET) (35%). These results provide important information to future studies about microplastic ingestion by longnose stingray and contribute to broad understanding of spatial and temporal dimensions of plastic pollution on marine ecosystems.

Keywords: Pollution, Solid wastes, Microplastics, Ingestion, Hypannus guttatus

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Sumário

ESTRUTURA DA DISSERTAÇÃO

A dissertação intitulada — Contaminação por resíduos sólidos e microplásticos nos ecossistemas marinhos do Nordeste do Brasil, foi elaborada em formato de artigo, de acordo com a resolução N. 4.782 do Programa de Pós-Graduação em Ecologia Aquática e Pesca da Universidade Federal do Pará, sendo composta por uma introdução geral, objetivos, capítulos 1 e 2 e considerações finais. O produto da dissertação são 2 artigos científico, sendo o primeiro artigo: "Disentangling beach litter pollution patterns to provide better guidelines for decision-making by coastal managers" a ser submetido à revista internacional Marine Pollution Bulletin, qualis A1, fator de impacto 4.049; e o segundo: "Ingestion of microplastics by *Hypanus guttatus* stingrays in the Western Atlantic Ocean (Brazilian Amazon Coast)" publicado na mesma revista, volume 162, (Pt A): 111799, DOI: https://doi.org/10.1016/j.marpolbul.2020.111799

INTRODUÇÃO GERAL

A gestão dos resíduos sólidos é um dos maiores desafios para a sociedade mundial. Isso se deve principalmente ao aumento da geração, consumo e descarte desses resíduos e ao seu alto custo de gerenciamento (Abdel-Shafy & Mansour, 2018). Nas últimas décadas observou-se uma tendência global crescente na geração de resíduos sólidos, com a atual geração mundial de resíduos de 2,01 bilhões de toneladas por ano projetada para aumentar 70% até 2050 (Deus et al., 2020). Resíduos mal gerenciados têm um enorme impacto na saúde, no meio ambiente e na economia, resultando em custos posteriores mais elevados do que custaria para gerenciar os resíduos de forma adequada (Worldbank, 2012). Assim sendo, o volume e a complexidade dos resíduos associados ao modo de vida moderna representam sérios riscos aos ecossistemas, a fauna, e à saúde humana. (Luttenberger, 2020).

Resíduos Sólidos

Resíduos sólidos são todos os materiais de origem antropogênica descartados de maneira direta e indireta no ambiente, tais como utensílios de vidros, plásticos, metais, equipamentos eletrônicos, hospitalares e manufaturados (BRASIL, 2010). Fatores como urbanização, pesca, turismo, atividades industriais e doméstica são as principais fontes para a deposição desses resíduos no ambiente uma vez que não são destinados de forma adequada quando não mais encontram utilidade ao uso humano (Rangel-Buitrago et al., 2020). A permanência de resíduos sólidos, a longo prazo, no ambiente tem sido atribuída a práticas inadequadas de gerenciamento, falta de infraestruturas, atividades e comportamentos humanos indiscriminados e uma compreensão inadequada por parte do público sobre as consequências potenciais de suas ações no ambiente quando descartados inapropriadamente (Nubi et al., 2019).

O descarte inadequado dos resíduos sólidos pode provocar diversos impactos socioambientais. O acúmulo e apodrecimento de lixo em proximidade de centros urbanos, afetam as populações humanas, podendo causar danos na saúde com o potencial aparecimento de vetores de doenças (Thompson et al., 2009). Adicionalmente, danos econômicos ocorrem na forma de operações de limpeza dispendiosas, perda de receita do turismo devido à baixa atratividade de locais com muito lixo (Schuhmann, 2012). Além disso, a persistência desses resíduos no ambiente gera efeitos negativos sobre a fauna, provocando problemas gastrointestinais quando ingeridos, estrangulamento em répteis e mamíferos e até a morte pelo emaranhamento em redes de pesca descartadas ou perdidas em alto-mar (Beaumont et al., 2019).

A produção de resíduos sólidos está intrinsecamente ligada a poluição do ar, do solo e da água, assim o gerenciamento de resíduos sólidos torna-se um dos serviços mais importantes que uma cidade oferece, tanto em sua zona urbana como rural (Coban et al., 2018). A gestão eficiente de resíduos sólidos depende muito da composição dos resíduos produzidos pela população, sendo essa composição influenciada pela condição socioeconômica, o tamanho da população, estações do ano e fatores ambientais. Para conduzir um processo de tomada de decisão bem-sucedido que conduza a estratégias viáveis e sustentáveis de gestão de resíduos, é aconselhável começar com um bom levantamento de informações acerca do problema.

Resíduos Plásticos e Microplásticos

O plástico é o material mais produzido do mundo. Sua fabricação cresceu rapidamente no mundo desde a metade do século XX, atingindo cerca de 359 milhões de toneladas em 2018 (Europe, 2019). O plástico é um dos maiores contribuintes para os resíduos sólidos urbanos e devido ao seu intenso consumo, pode alcançar uma ampla gama de ambientes (praias, rios, oceanos, montanhas), tonando-se assim, um grave problema ambiental para a sociedade (Geyer et al., 2017).

Os plásticos são materiais sólidos à temperatura ambiente, sintéticos, leves, fortes, duráveis e resistentes à corrosão, sendo constituídos de uma grande variedade de polímeros, entre os quais os mais usados e abundantes são polietileno tereftelato (PET), polietileno (PE), cloreto de polivinila (PVC), poliamida (PA), poliestireno (PS), polipropileno (PP) e a acrilonitrila butadieno estireno (ABS) (Thompson et al., 2009).

Os resíduos plásticos têm impactos negativos em uma ampla variedade de organismos como aves, peixes, répteis e mamíferos aquáticos, sendo que o emaranhamento em resíduos de plásticos (Jepsen & de Bruyn, 2019; Ryan, 2018) e sua ingestão (Basto et al., 2019; Markic et al., 2019), são os principais impactos observados. Por outro lado, é comprovado também que os plásticos aumentam a suscetibilidade de recife de corais a doenças, podendo causar lesões físicas em seus tecidos e permitindo a invasão de patógenos (Lamb et al., 2018). Além disso, resíduos plásticos podem afetar diretamente os meios de subsistência humana com o aumento de inundações em áreas urbanas, acúmulo nas praias, margens de rios e corpos d'água, afetando potencialmente o turismo local e a saúde humana (Andrady, 2011). No ambiente, os plásticos são materiais de difícil biodegradação e possuem como principal característica a fragmentação, persistindo no meio ambiente devido à sua longa vida útil e resistência à corrosão (Windsor et al., 2019).

Os plásticos podem ser classificados quanto ao seu tamanho. Embora existam diferenças nessa classificação na literatura, em geral os plásticos são classificados como: Microplásticos, partículas menores que 5 milímetros de diâmetro. Mesoplásticos, por sua vez, são partículas iguais ou maiores que 5 milímetros e menores que 25 milímetros de diâmetro. Finalmente, os Macroplásticos são os resíduos maiores que 25 mm de diâmetro (Andrady, 2011; Barrows et al., 2018). Os microplásticos (MPs) são classificados como primários, se forem produzidos e adicionados intencionalmente a produtos como cosméticos e tintas (ex: pellets, microbeds). Já os MPs secundários são aqueles que se formam da fragmentação de resíduos plásticos maiores (Godoy et al., 2019).

Em contraste com outros poluentes, os MPs não são degradados no meio ambiente, persistindo na coluna d'água e nos sedimentos de fundo, adsorvendo contaminantes químicos em sua superfície, incluindo metais pesados e poluentes orgânicos persistentes (POPs) de fontes próximas. Assim sendo, os microplásticos são potenciais vetores de contaminação, impondo um alto risco à fauna marinha e, possivelmente, à saúde humana por meios da cadeia alimentar (Brennecke et al., 2016; Godoy et al., 2019).

Devido a permanência dos MPs no ambiente, há um grande potencial de ingestão de microplástico pela fauna marinha em seus habitats naturais. Vários estudos em ambiente natural indicam que uma ampla gama de organismos marinhos tem a capacidade de ingerir partículas microplásticas, tais como peixes, tubarões, raias, baleias, o zooplâcton e anêmonas (Andrade et al., 2019; Cole et al., 2013; Germanov et al., 2018, 2019; Morais et al., 2020; Pegado et al., 2018; Valente et al., 2019). A posição dos MPs na coluna d'água depende basicamente da forma, tamanho e da densidade das partículas. MPs mais densos como o PVC irão depositar no fundo junto aos sedimentos, e MPs menos densos irão ficar suspensos na coluna d’água favorecendo a ingestão pelos animais marinhos (Brownie et al., 2007). Em geral a ingestão de MPs pela fauna ocorre sem intensão, não fazendo parte de dieta habitual, mas uma vez ingerido, o MP fica retido no trato digestivo do animal ou absorvido no revestimento epitelial do intestino por fagocitose, podendo ser transportadas para outros tecidos do corpo (Burns & Boxall, 2018).

O gerenciamento de resíduos sólidos e a problemática do plástico são temas amplamente discutidos em várias áreas do conhecimento. As soluções de gestão não devem ser apenas ambientalmente sustentáveis, mas também econômicas e socialmente aceitáveis (Malinauskaite et al., 2017). O registro e levantamento de dados sobre a contaminação dos resíduos no ambiente, seus impactos sobre a fauna e a saúde humana, é o primeiro passo em um conjunto de fatores que influenciam o processo complexo de tomada de decisão eficiente.

OBJETIVOS

Objetivo Geral

Avaliar a presença dos resíduos sólidos no ambiente e sua ingestão pela fauna nos ecossistemas marinhos do nordeste do Brasil.

Objetivos Específicos

Analisar a abundância, composição e distribuição dos resíduos sólidos nas praias do Parque Nacional de Jericoacoara (Ceará) **(Capítulo 1)**.

Classificar os tipos, cores e analisar composição polimérica do primeiro registro de ingestão de microplásticos encontrados na espécie de raia-lixo (*Hypannus guttatus)* no oceano atlântico ocidental **(Capítulo 2)**.

Bibliografia

Abdel-Shafy, H. I., & Mansour, M. S. M. (2018). Solid waste issue: Sources, composition, disposal, recycling, and valorization. Egyptian Journal of Petroleum, 27(4), 1275–1290. https://doi.org/10.1016/j.ejpe.2018.07.003

Andrade, M. C., Winemiller, K. O., Barbosa, P. S., Fortunati, A., Chelazzi, D., Cincinelli, A., & Giarrizzo, T. (2019). First account of plastic pollution impacting freshwater fishes in the Amazon: Ingestion of plastic debris by piranhas and other serrasalmids with diverse feeding habits. Environmental Pollution, 244, 766–773. https://doi.org/10.1016/j.envpol.2018.10.088

Andrady, A. L. (2011). Microplastics in the marine environment. Marine Pollution Bulletin, 62(8), 1596–1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Barrows, A. P. W., Cathey, S. E., & Petersen, C. W. (2018). Marine environment microfiber contamination: Global patterns and the diversity of microparticle origins. Environmental Pollution, 237, 275–284. https://doi.org/10.1016/j.envpol.2018.02.062

Basto, M. N., Nicastro, K. R., Tavares, A. I., McQuaid, C. D., Casero, M., Azevedo, F., & Zardi, G. I. (2019). Plastic ingestion in aquatic birds in Portugal. Marine Pollution Bulletin, 138(May 2018), 19–24. https://doi.org/10.1016/j.marpolbul.2018.11.024

Beaumont, N. J., Aanesen, M., Austen, M. C., Börger, T., Clark, J. R., Cole, M., Hooper, T., Lindeque, P. K., Pascoe, C., & Wyles, K. J. (2019). Global ecological, social and economic impacts of marine plastic. Marine Pollution Bulletin, 142(March), 189–195. https://doi.org/10.1016/j.marpolbul.2019.03.022

BRASIL. (2010). Política Nacional de Resíduos Sólidos. http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm

Brennecke, D., Duarte, B., Paiva, F., Caçador, I., & Canning-Clode, J. (2016). Microplastics as vector for heavy metal contamination from the marine environment. Estuarine, Coastal and Shelf Science, 178, 189–195. https://doi.org/10.1016/j.ecss.2015.12.003

Brownie, M. A., Galloway, T., & Thompson, R. (2007). Microplastic - An Emerging Contaminant of Potential Concern? Integrated Environmental Assessment and Management, 98(3), 219–229. https://doi.org/10.1001/archderm.98.3.219

Burns, E. E., & Boxall, A. B. A. (2018). Microplastics in the aquatic environment: Evidence for or against adverse impacts and major knowledge gaps. Environmental Toxicology and Chemistry, 37(11), 2776–2796. https://doi.org/10.1002/etc.4268

Coban, A., Ertis, I. F., & Cavdaroglu, N. A. (2018). Municipal solid waste management via multi-criteria decision making methods: A case study in Istanbul, Turkey. Journal of Cleaner Production, 180, 159–167. https://doi.org/10.1016/j.jclepro.2018.01.130

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., & Galloway, T. S. (2013). Microplastic ingestion by zooplankton. Environmental Science and

Technology, 47(12), 6646–6655. https://doi.org/10.1021/es400663f
Deus, R. M., Mele, F. D., Bezerra, B. S., & Battistelle, R. A. G. (2020). A municipal solid waste indicator for environmental impact: Assessment and identification of best management practices. Journal of Cleaner Production, 242, 118433. https://doi.org/10.1016/j.jclepro.2019.118433
Europe, P. (2019). Plastics - the Facts 2019 An analysis of European plastics production, demand and waste data. 14, 35. https://www.plasticseurope.org/en/resources/market-data
Germanov, E. S., Marshall, A. D., Bejder, L., Fossi, M. C., & Loneragan, N. R. (2018). Microplastics: No Small Problem for Filter-Feeding Megafauna. Trends in Ecology and Evolution, 33(4), 227–232. https://doi.org/10.1016/j.tree.2018.01.005
Germanov, E. S., Marshall, A. D., Hendrawan, I. G., Admiraal, R., Rohner, C. A., Argeswara, J., Wulandari, R., Himawan, M. R., & Loneragan, N. R. (2019). Microplastics on the Menu: Plastics Pollute Indonesian Manta Ray and Whale Shark Feeding Grounds. Frontiers in Marine Science, 6. https://doi.org/10.3389/fmars.2019.00679
Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use , and fate of all plastics ever made. July, 25–29.
Godoy, V., Blázquez, G., Calero, M., Quesada, L., & Martín-Lara, M. A. (2019). The potential of microplastics as carriers of metals. Environmental Pollution, 255. https://doi.org/10.1016/j.envpol.2019.113363
Jepsen, E. M., & de Bruyn, P. J. N. (2019). Pinniped entanglement in oceanic plastic pollution: A global review. Marine Pollution Bulletin, 145(June), 295–305. https://doi.org/10.1016/j.marpolbul.2019.05.042
Lamb, J. B., Willis, B. L., Fiorenza, E. A., Couch, C. S., Howard, R., Rader, D. N., True, J. D., & Kelly, L. A. (2018). Plastic waste associated with disease on coral reefs. 2010(January), 26–29.
Luttenberger, L. R. (2020). Waste management challenges in transition to circular economy – Case of Croatia. Journal of Cleaner Production, 256, 120495. https://doi.org/10.1016/j.jclepro.2020.120495
Malinauskaite, J., Jouhara, H., Czajczyńska, D., Stanchev, P., Katsou, E., Rostkowski, P.,

Thorne, R. J., Colón, J., Ponsá, S., Al-Mansour, F., Anguilano, L., Krzyżyńska, R., López, I. C., A.Vlasopoulos, & Spencer, N. (2017). Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. Energy, 141, 2013–2044. https://doi.org/10.1016/j.energy.2017.11.128

Markic, A., Gaertner, J., Gaertner-mazouni, N., & Albert, A. (2019). Technology Plastic ingestion by marine fish in the wild. Critical Reviews in Environmental Science and Technology, 0(0), 1–41. https://doi.org/10.1080/10643389.2019.1631990

Morais, L. M. S., Sarti, F., Chelazzi, D., Cincinelli, A., Giarrizzo, T., & Martinelli Filho, J. E. (2020). The sea anemone Bunodosoma cangicum as a potential biomonitor for microplastics contamination on the Brazilian Amazon coast. Environmental Pollution, 265, 114817. https://doi.org/10.1016/j.envpol.2020.114817

Nubi, A. T., Nubi, O. A., Franco-garcia, L., Oyediran, L., & Laoye, O. (2019). Effective solid waste management: A solution to the menace of marine litter in coastal communities of Lagos State, Nigeria. 13(March), 104–116. https://doi.org/10.5897/AJEST2018.2588

Pegado, T. de S. e. S., Schmid, K., Winemiller, K. O., Chelazzi, D., Cincinelli, A., Dei, L., & Giarrizzo, T. (2018). First evidence of microplastic ingestion by fishes from the Amazon River estuary. Marine Pollution Bulletin, 133(March), 814–821. https://doi.org/10.1016/j.marpolbul.2018.06.035

Rangel-Buitrago, N., Williams, A., Costa, M. F., & de Jonge, V. (2020). Curbing the inexorable rising in marine litter: An overview. Ocean and Coastal Management, 188(February), 105133. https://doi.org/10.1016/j.ocecoaman.2020.105133

Ryan, P. G. (2018). Entanglement of birds in plastics and other synthetic materials. Marine Pollution Bulletin, 135(July), 159–164. https://doi.org/10.1016/j.marpolbul.2018.06.057

Schuhmann, P. W. (2012). Tourist Perceptions of Beach Cleanliness in Barbados: Implications for Return VisitationPerceptions de la propreté de la plage par les touristes à la Barbade: implications sur le retour des visiteurs. Études Caribéennes, 19, 0–13. https://doi.org/10.4000/etudescaribeennes.5251

Thompson, R. C., Moore, C. J., Saal, F. S. V., & Swan, S. H. (2009). Plastics, the environment and human health: Current consensus and future trends. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 2153–2166. https://doi.org/10.1098/rstb.2009.0053

Valente, T., Sbrana, A., Scacco, U., Jacomini, C., Bianchi, J., Palazzo, L., Andrea, G., Lucia, D., Silvestri, C., & Matiddi, M. (2019). Exploring microplastic ingestion by three deep-water elasmobranch species : A case study from the Tyrrhenian Sea *. Environmental Pollution, 253, 342–350. https://doi.org/10.1016/j.envpol.2019.07.001

Windsor, F. M., Durance, I., Horton, A. A., Thompson, R. C., Tyler, C. R., & Ormerod, S. J. (2019). A catchment-scale perspective of plastic pollution. Global Change Biology, 25(4), 1207–1221. https://doi.org/10.1111/gcb.14572

Capítulo 1 - Disentangling beach litter pollution patterns to provide better guidelines for decision-making by coastal managers

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Abstract

Litter pollution is now an ubiquitous feature of the world's terrestrial and aquatic ecosystems, of which, beaches at the land-ocean interface have been studied since past century in which the first warnings on this type of pollution have arose. In the present study, we assessed the litter pollution patterns in a prominent touristic and environmental site in Brazil, the Jericoacoara National Park (Ceará state) to provide a baseline of litter types and abundance, as well as a delta-generalized additive modeling (GAM) approach to its distribution. Thus, the predicted pollution hotspots provided from this may better guide for coastal managers on the most effective strategies for the prevention of beach pollution. Beach litter surveys were conducted during the rainy and dry seasons (2019) at 16 beaches divided in four sectors according to their exposure to wind (onshore or offshore). A total of 7,549 items of litter (mean = 0.23 items/m^2) were collected from the 16 study beaches, with the highest litter densities being recorded on onshore beaches (sectors 1 and 2, with a mean of 0.47 and 0.27 items/m^2, respectively). Hard and flexible plastics were the most abundant type of litter, followed by fragments of rope, primarily blue nylon filaments. Our GAM analysis revealed that the distribution of each type of litter had distinct drivers in the study area, with the extension of the beach, tourist attractions, the angle of the wind, and the distance to bodies of water and villages being the most significant. Our model was also suitable for the prediction of the presence of specific litter pollution hotspots on the beaches of this national park, which is a valuable input for the development of guidelines for the development of effective management strategies according to the type of litter.

Keywords: Beach debris, Waste management, Anthropogenic litter, Aquatic pollution, Tourism.

Anthropogenic marine litter can be defined as “any persistent, manufactured, or processed solid material discarded, disposed, or abandoned into the environment” (Bergmann et al., 2019; UNEP, 2009). Originating from both marine and land-based activities, the sources of this pollution, and its pathways to the marine environment are numerous, including commercial and artisanal fisheries, shipping, industrial installations, and densely-populated urban centers (Brownie, 2015; Li et al., 2016). Beaches are one of the best-known marine habitats on which litter often accumulates and have been investigated ever since the first studies of plastic pollution were conducted in the 1970s (Cundell, 1973; Merrell, 1980). Beaches occupy approximately 40% of the world's coastlines and are among its most dynamic physical systems, being characterized by their instability and propensity for erosion (Babić et al., 2019; Radziejewska et al., 2017). Beach litter is a major environmental problem, which impacts economic activities (e.g., tourism and recreation), the provision of ecosystem services, goods to society, and local wildlife (Asensio-Montesinos et al., 2019; Garcés-ordóñez et al., 2020).

Although litter pollution has been monitored widely on beaches in the past few years, and these are one of the most well-studied marine environments in terms of their litter pollution, many studies lack reliable information on the data collected or have been based on methods that are not easily replicated, which hampers a systematic review of the problem (Serra-Gonçalves et al., 2019). Sandy beaches are also highly dynamic environments, in which local weather conditions, in particular winds and waves, can influence the abundance and distribution of litter significantly (Andrades et al., 2018; Rangel-Buitrago et al., 2018). The identification of the local factors that influence beach litter pollution is crucial to better inform coastal managers and the wider society, as well as to provide adequate guidelines for the effective monitoring and mitigation of the potential loss of economic goods and ecological services. In fact, the presence or absence of litter is a key parameter for the definition of the scenic score of a beach, that is, its attractiveness to tourists (Anfuso et al., 2017; Williams et al., 2016) with polluted beaches often being avoided by beachgoers (Krelling et al., 2017).

Brazil has the longest shoreline in the South Atlantic, which covers approximately 8000 km of equatorial, tropical, subtropical, and warm temperate latitudes (Araujo et al., 2019). Beach tourism is an important economic activity for the local and regional economies of many Brazilian coastal environments (Sousa et al., 2014). The principal commercial activity is the sale of food and beverages, which is a prominent source of litter (Araújo et al., 2018; Sousa et al., 2014). In recent years, the northeastern coast of Brazil has become a popular destination for mass tourism, which has exerting increasing anthropogenic pressure on it beaches (Sacramento, 2018).

In the present study, we assessed the influence of local variables on the abundance and distribution of litter on the beaches of the Jericoacoara National Park in Ceará state, northern Brazil, which is a popular tourist destination. We used a modelling approach to track litter pollution hotspots according to the type of the litter and the use of the beaches, as well as the prediction of litter distribution patterns.

The Jericoacoara National Park, in northeastern Brazil (Figure 1), was created in 2002 to protect coastal ecosystems and ensure the compatibility of local tourism with the preservation of natural resources (ICMBio, 2011). Jericoacoara is currently Brazil's fourth most frequently-visited national park with an annual average of approximately 1 million of tourist per year (Castro, 2020). This park comprises 8,416 hectares, covering a mosaic of coastal landscapes, formed by sandy beaches, dunes, mangroves, and rocky shores. The variation in local wind patterns is associated with seasonal shifts in the location of the Intertropical Convergence Zone (ITCZ), which is an area of intense cloudiness and low atmospheric pressure, marked by confluence of the northeasterly and southeasterly trade winds (Medeiros et al., 2020). In general, the southeasterly trade winds are most intense when the ITCZ is in its northern extreme, between August and October, decreasing progressively as the zone migrates southward toward the equator, until reaching their lowest annual values in March and April (Meireles, 2011). The rainfall regime of the area is tropical with rainy season concentrated in the first half of the year (90% of the annual rainfall), generally beginning in February, peaking typically in March and April. From July onward, precipitation decreases until November (Meireles, 2011).

Beach litter surveys were conducted in June (rainy season) and November (dry season) 2019 on 16 beaches, which were divided into four sectors. Each sector included four beaches and has it own specific characteristics in terms of access (by vehicle or on foot), the principal recreational activities (fishing, surfing, bathing), tourist attractions (e.g., "Árvore da preguiça" – the lazy tree, "Pedra furada" – the hole in the rock, and "Duna do por do sol" – the sunset dune), and the presence of villages and other infrastructure. The sectors were also classified in relation to their exposure to wind (onshore or offshore), with sectors 3 and 4 being classified as "offshore" (Figure 1), with prevailing winds from the land to the sea and thus a much lower wind load than sectors 1 and 2, which were classified as "onshore", and are under the influence of sea-driven winds (Galloway et al., 1989).

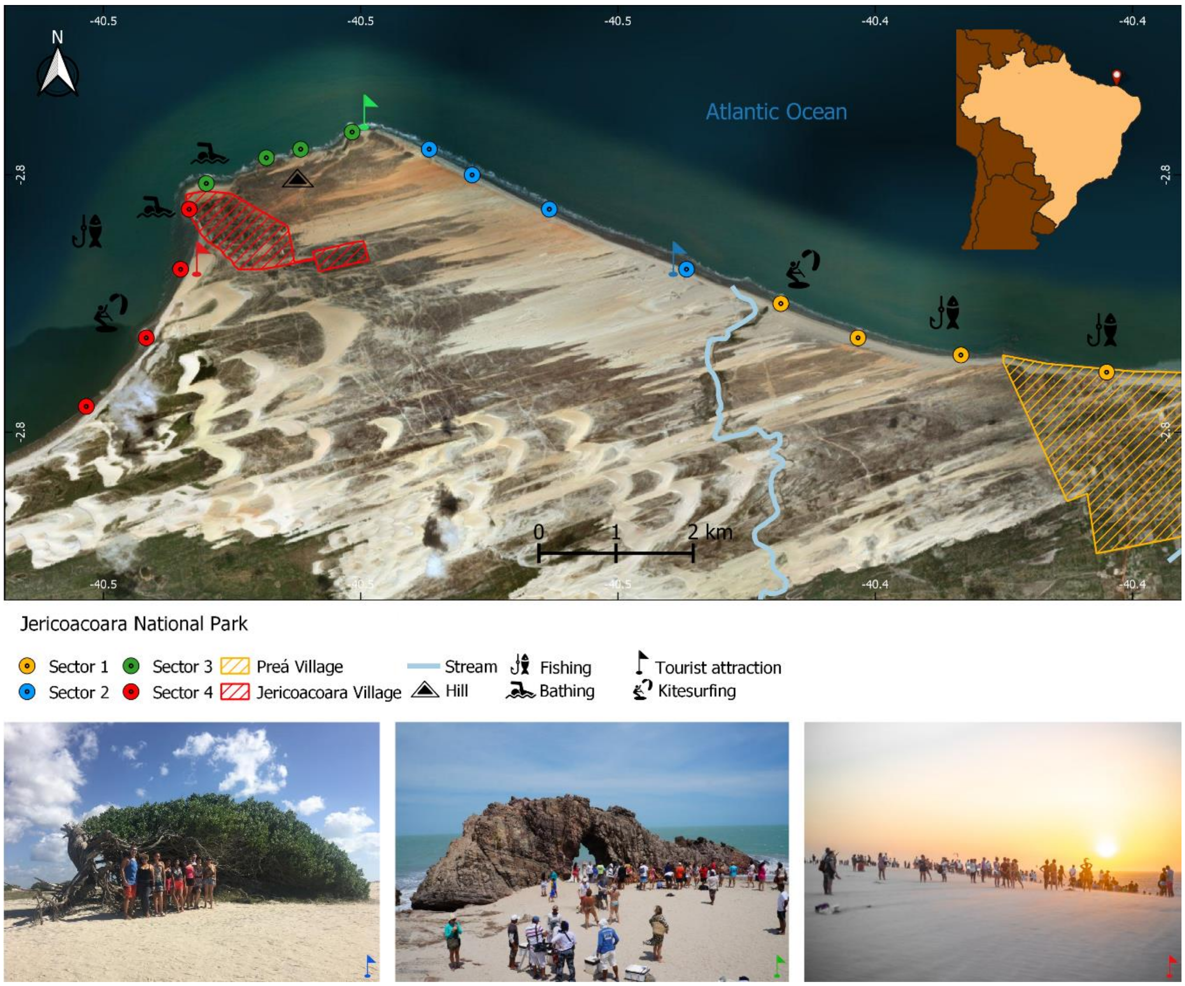

Figure 1. Jericoacoara National Park. Villages, study sectors (color-coded), with the principal human activities and the tourist attractions highlighted by the icons.

Litter surveys were conducted along five 4-meter wide perpendicular transects on each beach, which were walked during low tide. The transect was initiated at the tide line and continued up to the limit of the supralittoral (i.e., beginning of "restinga" coastal vegetation, the base of a dune or a sidewalk). The length of each transect was measured during the sampling and the litter encountered along the transect was collected manually and stored in bags for further identification. The litter items were subsequently quantified and classified according to their type (plastic and other materials) and color.

We also measured the environmental parameters of each beach, such as its extension (meters), wind angle (degrees), distance from the villages (i.e. Preá and Jericoacoara), and the distance from coastal bodies of water and tourist spots. To determine the influence of these variables on the distribution and abundance of litter, a delta-generalized additive modeling (GAM) approach was applied to account for the zero inflation of the count data (Rubec et al., 2016). In this approach, the positive values were fitted by the GAM using a Gaussian distribution, while the presence-absence data were fitted by a GAM with a binomial distribution, using the *mgcv* package (Wood, 2012). A penalized cubic regression spline was applied as the smoothing function for reach. This procedure selects the degree of smoothing automatically based on the Generalized Cross-Validation (GCV) score. The best model was then selected through the application of the criterion of explained deviance, the GCV score and the Akaike Information Criterion, AIC (Akaike, 1973), which provides a balance between the model fit and the parameters used. We investigated all possible combinations of the variables, selecting the best models according to the criteria described above, and the package functions.

A total of 7,549 items (mean = 0.23 items/m^2) were found along all study sectors in the Jericoacoara National Park. Previous studies have reported similar densities of litter on Brazilian beaches (0.42 items/m^2; Andrades et al., 2020). The litter density recorded in the present study is also similar to those recorded on other beaches worldwide, in studies based on similar survey methods (Table 1). Unfortunately, further comparisons of beach litter densities in these regions are limited due to inconsistencies among the survey methods used by different researchers (Serra-Gonçalves et al., 2019).

Table 1. Data on beach litter densities from studies in brazil and worldwide based on survey methods equivalent to those used in the present study.

Study área	Number of baches surveyed	Density of litter (items/m²)	Reference
Taiwan	6	0.15	Kuo & Huang (2014)
Italy	5	0.2	Munari et al. (2016)

China	1	0.5	Han et al. (2018)
Brazil (Southeast)	8	0.1	Corraini et al. (2018)
Colombia	27	0.5	Rangel-Buitrago et al. (2020)
Brazil	44	0.42	Andrades et al. (2020)
Albania	5	0.14	Gjyli et al. (2020)
Jericoacoara National Park	16	0.23	Present study

The beaches in sectors 1 and 2 (onshore side) returned the highest densities of litter in both seasons, that is, the rainy and dry seasons, with 0.13 and 0.11 items/m², respectively (Fig. 2). The highest mean density (0.47 item/m²) was recorded in sector 2, followed by sector 1, with 0.27 items/m². The values are much higher than those recorded in sectors 3 (0.14 items/m²) and 4 (0.04 items/m²). These differences reflect the role of the type of wind exposure (onshore *vs.* offshore) on the accumulation of litter in our study area. In general, the primary factor influencing litter deposition on Brazilian beaches is their proximity to the run-off of large estuaries (Andrades et al., 2020), but in the absence of this feature, as observed in the present study and on some Brazilian islands, exposure to winds and waves appears to be the principal factor determining the distribution and accumulation of beach debris (Andrades et al., 2018).

The highest density was recorded for plastic litter, including flexible plastic, at 0.02 item/m², and hard plastic at 0.01 items/m², densities similar to those recorded in other studies (Abreo, 2018; Aytan et al., 2020; Munari et al., 2016). Small plastic litter (< 5 cm in length) was more abundant than larger pieces (Fig. S1). In general, small plastic pieces are the most prevalent items on beaches, worldwide (Andrades et al., 2020; Galgani et al., 2015; Topçu et al., 2013). In our study, most small-sized litter was made up of fragments of larger pieces, rather than virgin plastic, such as pellets, which hampers the implementation of specific strategies for the prevention or removal of this type of beach litter. Considering all types of litter (total litter), the factor that best explained the distribution of the litter was tourist attractions, while the distance from bodies of water was marginally significant (Table 2). The extension of the beach was also a significant factor for all the different types of litter evaluated (Tab. 2), which is as expected, given that, the larger the foreshore and backshore areas, the greater the amount of litter that is likely to accumulate on the beach. More ample beaches with a more gently-sloping foreshore also tend to have more litter than less ample and more steeply-sloping beaches (Ghaffari et al., 2019).

One other prominent type of litter was rope (mean density = 0.01 items/m^2), in particular blue nylon fibers, which are derived from a type of rope commonly used by fisheries in the study area and in many other parts of the world (Orasutthikul et al., 2017). The extension of the beach and its proximity to a village were the principal drivers of pollution by rope on the study beaches (Tab. 2), which can be linked to local fishery activities or due to oceanic mass-water derive. Small blue polyester and polyamide (nylon) fibers were also the most abundant types of litter ingested by many coastal fish species in the study region (Dantas et al., 2020; Dantas et al., 2012; Possatto et al., 2011).

It is important to note that the density of cigarette butts, while low overall (< 0.003 items/m^2), was clearly associated with tourist attractions. Our GAM analysis (Tab. 2) confirmed that pollution by cigarette butts was influenced strongly by tourist attractions and the angle of the wind, and, to a lesser extent, the proximity of bodies of water. Garcés-Ordóñez et al. (2020) recorded high levels of pollution by cigarette butts on touristic beaches in Colombia, which is similar to the pattern observed on touristic beaches in Argentina (Becherucci et al., 2017) and Chile (Honorato-Zimmer et al., 2019). In addition to plastics, cigarette butts are the principal type of litter found on most Brazilian beaches (Andrades et al., 2020), which raises a number of concerns given that many studies have shown that bodies of water may be contaminated by toxic compounds, such as nicotine, leaching from cigarette butts, which may also be ingested by wildlife.

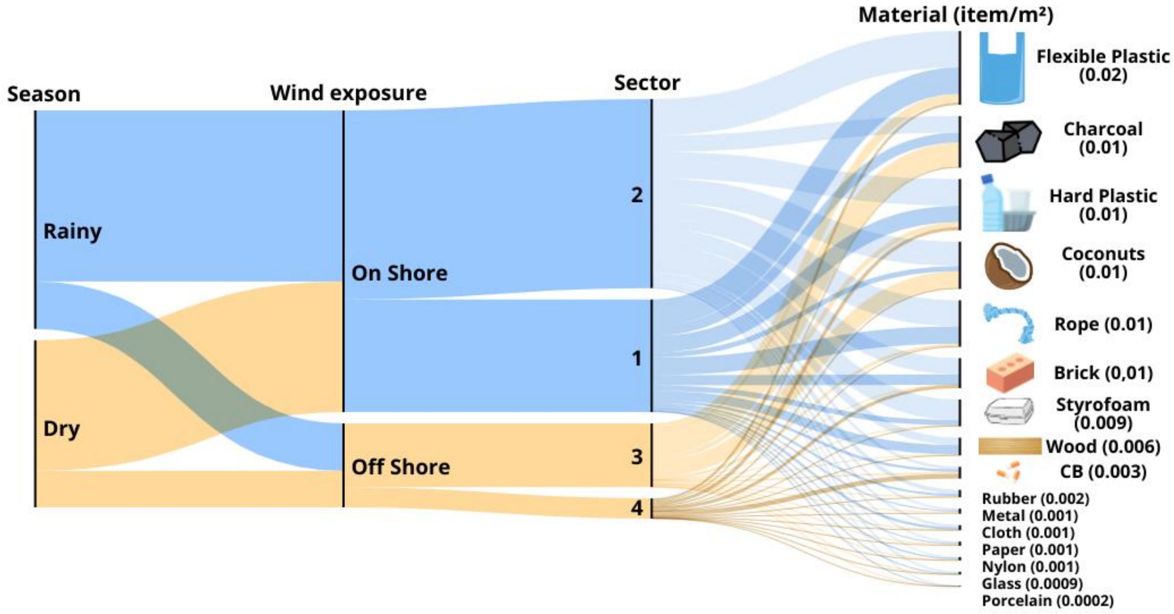

Figure 2. Alluvial diagram showing the distribution of different types of litter (items/m^2) between seasons and among the sectors surveyed in Jericoacoara National Park.

Overall, the extension of the beach and the presence of tourist attractions influenced the distribution of almost all the types of litter recorded in our study (Tab. 2). Other factors, such as the distance to bodies of water and the villages (Jericoacoara and Preá), were also important. Once the best model for each litter category was selected, we ran a predictive GAM to estimate the potential number of items according to the variables selected (Fig. 3), with the independent (input) variables being estimated for 168 equidistant points located along the shoreline at intervals of 100 meters. The output variables (the number of litter items) were predicted for each point on the basis of the most suitable model. The most interesting finding of this analysis is that the certain types of litter, in particular cigarette butts and styrofoam, accumulate in different patterns along the study areas (Fig. 3), whereas plastics (both hard and flexible) and rope presented a pattern similar to that of the total litter (Fig. 3). These results are important for the delineation of management strategies, such as beach cleaning, the positioning of trash cans, and the implementation of campaigns of awareness focusing on specific items, such as cigarette butts. However, it is important to note that the predictive GAM was not able to estimate precisely the amount of litter, but rather only the probable location of litter hotspots, based on the color gradient in Fig. 3. In the present case, the GAM approach permitted the identification of areas where waste management or removal is a priority, to prevent their transfer to the marine environment, where removal is much more difficult and costly.

Litter-specific guidelines can improve the effectiveness of beach pollution management, given that different types of litter can be generated and deposited in distinct patterns, with varying implications for the environment and its biodiversity. Jericoacora National Park is currently the fourth most-visited national park in Brazil (Castro, 2020), and is an important source of income for the local economy. We would recommend in particular an increase in specific efforts, including awareness campaigns on the onshore beaches, as well as specific approaches, such as the installation of trash cans and ashtrays or butt collectors at the tourist attractions, given the prevalence of cigarette butts in these areas. These efforts should help guarantee the preservation of the natural beauty of the national park, ensuring the satisfaction of tourists and the sustainable use of local beaches.

Table 2. Results of the generalized additive models (GAM) of the environmental variables.

Item	EXT	WA	D_riacho	D_Jeri	D_Prea	Tourist	Intercept	R-sq.(adj)	Deviance explained
Total litter	**(+) <0.01**	(+) 0.12	(-) **0.04**	-	(+) 0.28	**(+) <0.01**	1.25e07	0.508	53.9%
Cigarette	**(+) <0.01**	**(-) <0.01**		-	(-) **0.02**	**(+) <0.01**	0.93452	0.224	26.1%
Rope	**(+) <0.01**	-	(+) 0.29	**(±) <0.01**	(-) 0.23	(+) 0.94	0.00331	0.615	66.3%
Hard Plastic	**(+) <0.01**	-	(+) 0.28	-	(-) 0.42	(+) 0.33	0.000135	0.497	52.9%
Flexible Plastic	**(+) <0.01**	**(+) <0.01**	(-) 0.01	-	(+) 0.28	**(+) <0.01**	5.73e-06	0.504	54.4%
Styrofoam	-	**(-) <0.01**	-	**(+) <0.01**	-	(+) 0.85	0.63	0.453	50.3%

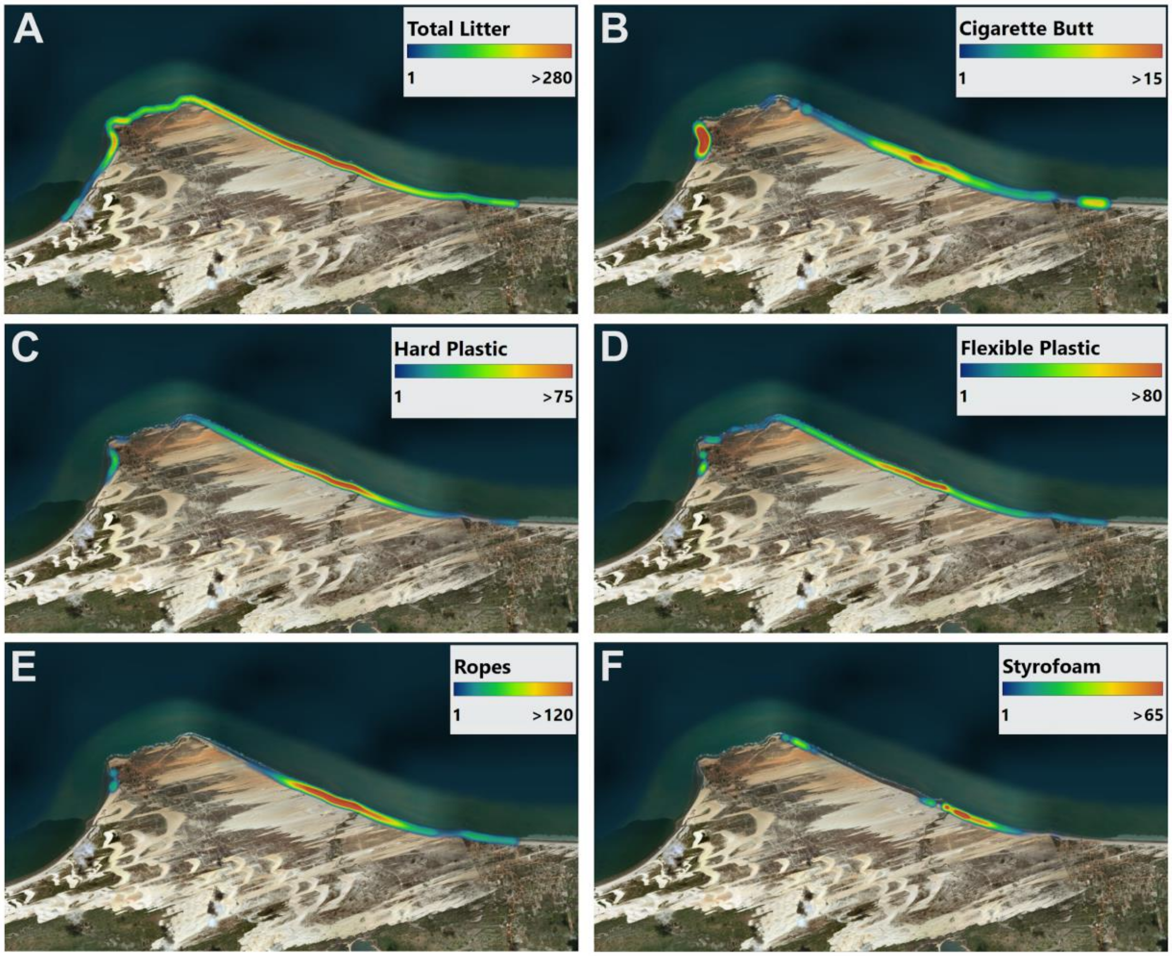

Figure 3. Distribution (items/m^2) of (A) all litter and (B-F) the most abundant types of litter observed in the Jericoacoara National Park, Brazil.

References

Abreo, N. A. S. (2018). Marine plastics in the Philippines: a call for research. Philippine Science Letters, 11(01), 18–19.

Akaike, H., 1973. Maximum likelihood identification of Gaussian autoregressive moving average models. Biometrika 60, 255–265. https://doi.org/10.1093/biomet/60.2.255

Andrades, R., Pegado, T., Godoy, B. S., Reis-Filho, J. A., Nunes, J. L. S., Grillo, A. C., Machado, R. C., Santos, R. G., Dalcin, R. H., Freitas, M. O., Kuhnen, V. V., Barbosa, N. D., Adelir-Alves, J., Albuquerque, T., Bentes, B., & Giarrizzo, T. (2020). Anthropogenic litter on Brazilian beaches: Baseline, trends and recommendations for future approaches. Marine Pollution Bulletin, 151(October 2019), 110842. https://doi.org/10.1016/j.marpolbul.2019.110842

Andrades, R., Santos, R. G., Joyeux, J., Chelazzi, D., Cincinelli, A., & Giarrizzo, T. (2018). Marine debris in Trindade Island, a remote island of the South Atlantic. Marine Pollution Bulletin, 137(October), 180–184. https://doi.org/10.1016/j.marpolbul.2018.10.003

Anfuso, G., Williams, A. T., Casas Martínez, G., Botero, C. M., Cabrera Hernández, J. A., & Pranzini, E. (2017). Evaluation of the scenic value of 100 beaches in Cuba: Implications for coastal tourism management. Ocean and Coastal Management, 142, 173–185. https://doi.org/10.1016/j.ocecoaman.2017.03.029

Araújo, M. C. B., Silva-Cavalcanti, J. S., & Costa, M. F. (2018). Anthropogenic litter on beaches with different levels of development and use: A Snapshot of a coast in Pernambuco (Brazil). Frontiers in Marine Science, 5(JUL), 1–10. https://doi.org/10.3389/fmars.2018.00233

Asensio-Montesinos, F., Anfuso, G., & Williams, A. T. (2019). Beach litter distribution along the western Mediterranean coast of Spain. Marine Pollution Bulletin, 141(November 2018), 119–126. https://doi.org/10.1016/j.marpolbul.2019.02.031

Aytan, U., Sahin, F. B. E., & Karacan, F. (2020). Beach litter on sarayköy beach (Se black sea): Density, composition, possible sources and associated organisms. Turkish Journal of Fisheries and Aquatic Sciences, 20(2), 137–145. https://doi.org/10.4194/1303-2712-v20_2_06

Babić, L., Razum, I., Lužar-Oberiter, B., & Zupanič, J. (2019). Sand beaches on highly indented karstic coasts: Where the sands come from and what should be protected (SE Adriatic, Croatia). Estuarine, Coastal and Shelf Science, 226(August 2018), 106294. https://doi.org/10.1016/j.ecss.2019.106294

Becherucci, M. E., Rosenthal, A. F., & Seco Pon, J. P. (2017). Marine debris in beaches of the Southwestern Atlantic: An assessment of their abundance and mass at different spatial scales in northern coastal Argentina. Marine Pollution Bulletin, 119(1), 299–306. https://doi.org/10.1016/j.marpolbul.2017.04.030

Bergmann, M., Gutow, L., & Klages, M. (2019). Marine Anthropogenic Litter. In Environmental Science and Technology (Vol. 53, Issue 9). https://doi.org/10.1021/acs.est.9b01360

Brownie, M. A. (2015). Sources and pathways of microplastics to habitats. In Marine

Anthropogenic Litter (pp. 229–244). https://doi.org/10.1007/978-3-319-16510-3
Castro, V. (2020). Número de visitantes em unidades de conservação aumenta 20%. https://www.gov.br/turismo/pt-br/assuntos/noticias/numero-de-visitantes-em-unidades-de-conservacao-aumenta-20
Corraini, N. R., Lima, A. de S., Bonetti, J., & Rangel-buitrago, N. (2018). Troubles in the paradise: Litter and its scenic impact on the North Santa Catarina Island beaches, Brazil. Marine Pollution Bulletin, 131(March), 572–579. https://doi.org/10.1016/j.marpolbul.2018.04.061
Cundell, A. M. (1973). Plastic materials accumulating in Narragansett Bay. Marine Pollution Bulletin, 4(12), 187–188. https://doi.org/10.1016/0025-326X(73)90226-9
Dantas, N. C. F. M., Duarte, O. S., Ferreira, W. C., Ayala, A. P., Rezende, C. F., & Feitosa, C. V. (2020). Plastic intake does not depend on fish eating habits: Identification of microplastics in the stomach contents of fish on an urban beach in Brazil. Marine Pollution Bulletin, 153(October 2019), 110959. https://doi.org/10.1016/j.marpolbul.2020.110959
Dantas, D. V., Barletta, M., & da Costa, M. F. (2012). The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (Sciaenidae). Environmental Science and Pollution Research, 19(2), 600–606. https://doi.org/10.1007/s11356-011-0579-0
de Medeiros, F. J., de Oliveira, C. P., & Torres, R. R. (2020). Climatic aspects and vertical structure circulation associated with the severe drought in Northeast Brazil (2012–2016). Climate Dynamics, 55(9–10), 2327–2341. https://doi.org/10.1007/s00382-020-05385-1
De Sousa, R. C., Pereira, L. C. C., Da Costa, R. M., & Jiménez, J. A. (2014). Tourism carrying capacity on estuarine beaches in the Brazilian Amazon region. Journal of Coastal Research, 70(70), 545–550. https://doi.org/10.2112/SI70-092.1
Galgani, F., Hanke, G., & Maes, T. (2015). Marine anthropogenic litter. In Marine Anthropogenic Litter (pp. 1–447). https://doi.org/10.1007/978-3-319-16510-3
Galloway, J. S., Collins, M. B., & Moran, A. D. (1989). Onshore / Offshore Wind Influence on B r e a k i n g Waves : An Empirical Study. Coastal Engineering, 13(4), 305–323. https://doi.org/https://doi.org/10.1016/0378-3839(89)90039-2

Garcés-ordóñez, O., Espinosa, L. F., Pereira, R., & Costa, M. (2020). The impact of tourism on marine litter pollution on Santa Marta beaches, Colombian Caribbean. Marine Pollution Bulletin, 160(2), 111558. https://doi.org/10.1016/j.marpolbul.2020.111558

Gjyli, L., Vlachogianni, T., Kolitari, J., Matta, G., Metalla, O., & Gjyli, S. (2020). Marine litter on the Albanian coastline: Baseline information for improved management. Ocean and Coastal Management, 187(December 2019), 105108. https://doi.org/10.1016/j.ocecoaman.2020.105108

Han, M., Zhao, K., Zhang, Y., & Sui, C. (2018). Investigation and comprehensive evaluation of the litter pollution on the Heishijiao beach in Dalian. IOP Conference Series: Earth and Environmental Science, 121(3). https://doi.org/10.1088/1755-1315/121/3/032014

Honorato-Zimmer, D., Kruse, K., Knickmeier, K., Weinmann, A., Hinojosa, I. A., & Thiel, M. (2019). Inter-hemispherical shoreline surveys of anthropogenic marine debris – A binational citizen science project with schoolchildren. Marine Pollution Bulletin, 138(November 2018), 464–473. https://doi.org/10.1016/j.marpolbul.2018.11.048

ICMBio. (2011). Plano de Manejo do Parque Nacional de Jericoacoara. https://www.icmbio.gov.br/portal/unidadesdeconservacao/biomas-brasileiros/marinho/unidades-de-conservacao-marinho/2261-parna-de-jericoacoara

Krelling, A. P., Willian, A. T., & Turra, A. (2017). Differences in perception and reaction of tourist groups to beach marine debris that can influence a loss of tourism revenue in coastal areas. Marine Policy, 85(August), 87–99. https://doi.org/10.1016/j.marpol.2017.08.021

Kuo, F. J., & Huang, H. W. (2014). Strategy for mitigation of marine debris: Analysis of sources and composition of marine debris in northern Taiwan. Marine Pollution Bulletin, 83(1), 70–78. https://doi.org/10.1016/j.marpolbul.2014.04.019

Li, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. 567, 333–349. https://doi.org/10.1016/j.scitotenv.2016.05.084

Meireles, A. J. A. de. (2011). GEODINÂMICA DOS CAMPOS DE DUNAS MÓVEIS DE JERICOACOARA / CE-BR. Mercator, 10(22), 169–190.

https://doi.org/10.4215/RM2011.1022. 0011

Merrell, T. R. (1980). Accumulation of plastic litter on beaches of Amchitka Island, Alaska. Marine Environmental Research, 3(3), 171–184. https://doi.org/10.1016/0141-1136(80)90025-2

Munari, C., Corbau, C., Simeoni, U., & Mistri, M. (2016). Marine litter on Mediterranean shores: Analysis of composition, spatial distribution and sources in north-western Adriatic beaches. Waste Management, 49, 483–490. https://doi.org/10.1016/j.wasman.2015.12.010

Orasutthikul, S., Unno, D., & Yokota, H. (2017). Effectiveness of recycled nylon fiber from waste fishing net with respect to fiber reinforced mortar. Construction and Building Materials, 146, 594–602. https://doi.org/10.1016/j.conbuildmat.2017.04.134

Possatto, F. E., Barletta, M., Costa, M. F., Ivar do Sul, J. A., & Dantas, D. V. (2011). Plastic debris ingestion by marine catfish: An unexpected fisheries impact. Marine Pollution Bulletin, 62(5), 1098–1102. https://doi.org/10.1016/j.marpolbul.2011.01.036

Radziejewska, T., Kotta, J., & Kotwicki, L. (2017). Sandy coasts. Biological Oceanography of the Baltic Sea, 1–683. https://doi.org/10.1007/978-94-007-0668-2

Rangel-buitrago, N., Velez-mendoza, A., C, A. G., & Neal, W. J. (2020). The impact of anthropogenic litter on Colombia’s central Caribbean beaches. Marine Pollution Bulletin, 152(January), 110909. https://doi.org/10.1016/j.marpolbul.2020.110909

Rangel-Buitrago, N., Williams, A., & Anfuso, G. (2018). Killing the goose with the golden eggs: Litter effects on scenic quality of the Caribbean coast of Colombia. Marine Pollution Bulletin, 127(October 2017), 22–38. https://doi.org/10.1016/j.marpolbul.2017.11.023

Rubec, P.J., Kiltie, R., Leone, E., Flamm, R.O., McEachron, L., Santi, C., 2016. Using Delta-Generalized Additive Models to Predict Spatial Distributions and Population Abundance of Juvenile Pink Shrimp in Tampa Bay, Florida. Mar. Coast. Fish. 8, 232–243. https://doi.org/10.1080/19425120.2015.1084408

Sacramento, O. (2018). The production of tourism in Ponta Negra, Northeast Brazil: policies, representations and logics of desire. Journal of Tourism and Cultural Change, 16(2), 191–207. https://doi.org/10.1080/14766825.2017.1324862

Serra-Gonçalves, C., Lavers, J. L., & Bond, A. L. (2019). Global Review of Beach Debris

Monitoring and Future Recommendations. Environmental Science and Technology, 53(21), 12158–12167. https://doi.org/10.1021/acs.est.9b01424

Topçu, E. N., Tonay, A. M., Dede, A., Öztürk, A. A., & Öztürk, B. (2013). Origin and abundance of marine litter along sandy beaches of the Turkish Western Black Sea Coast. Marine Environmental Research, 85, 21–28. https://doi.org/10.1016/j.marenvres.2012.12.006

UNEP. (2009). Marine Litter : A Global Challenge. In Unep 2009.

Williams, A. T., Rangel-Buitrago, N. G., Anfuso, G., Cervantes, O., & Botero, C. M. (2016). Litter impacts on scenery and tourism on the Colombian north Caribbean coast. Tourism Management, 55, 209–224. https://doi.org/10.1016/j.tourman.2016.02.008

Wood, S., 2012. mgcv: Mixed GAM Computation Vehicle with GCV/AIC/REML smoothness estimation.

Worldbank. (2012). A global review of solid waste management. 1-115.

Capítulo 2 - Ingestion of microplastics by *Hypanus guttatus* stingrays in the Western Atlantic Ocean (Brazilian Amazon Coast)

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Abstract

The present study documents, for the first time, the ingestion of microplastics (MPs) by Longnose stingrays in the Western Atlantic Ocean. We examined 23 specimens of *Hypanus guttatus* from the Brazilian Amazon coast and found microplastic particles in the stomach contents of almost a third of the individuals. Fibers were the most frequent item (82%), blue was the most frequent color (47%) and Polyethylene terephthalate (PET) was the most frequent polymer recorded (35%), as identified by 2D imaging - Fourier Transform Infrared (FTIR). The ingestion of microplastics by Longnose stingray has not been previously recorded. The findings of the present study thus provide an important baseline for future studies of microplastic ingestion by dasyatidae rays and other batoid species in the Atlantic Ocean and contribute to the broader understanding of the spatial and temporal dimensions of the growing problem of plastic pollution in aquatic ecosystems and organisms.

Keywords: Plastic pollution, Elasmobranchii; Longnose stingray; 2D FTIR Imaging.

Microplastics (MPs) are now widely distributed in the environment, reaching even the remotest areas of the oceans, and infiltrating food webs worldwide (Germanov et al., 2019). These particles are potential carriers of persistent organic pollutants (POPs) and metals (Yu et al., 2019). Microplastics are normally defined as plastic particles with a maximum dimension of less than 5 mm (Arthur et al., 2009). These particles can be classified according to their origin as either primary or secondary MPs. Primary MPs are produced intentionally as micro-sized particles for use in cosmetics and a range of other industrial applications (Ogata et al., 2009), while secondary MPs are produced by the physical or chemical degradation of larger plastic waste by the environment (Cole et al., 2011; Godoy et al., 2019). Given their small size and abundance, MPs can be actively ingested by a wide range of organisms (Eriksen et al., 2014; Herrera et al., 2019), when the MPs are mistaken for prey, or passively, through the unintentional ingestion of the particles during normal feeding activities (Campbell et al., 2017; Desforges et al., 2015).

Despite the large number of studies that have focused on the ingestion of MPs by marine teleost fishes (e.g. Markic et al., 2018; Murphy et al., 2017; Pegado et al., 2018), few data are available on elasmobranchs, and most of which refer to sharks or pelagic rays (Alomar and Deudero, 2017; Anastasopoulou et al., 2013; Germanov et al., 2019; Valente et al., 2019). Up to now, only two reports have apparently been published on the ingestion of MPs by benthonic rays in marine environments; Neves et al. (2015) recorded MPs in specimens of *Raja asterias*, off the coast of Portugal and Pegado et al. (2018) that found MPs in an individual of *Narcine brasiliensis* from Amazon river estuary. However, both studies analyzed less than 10 individuals, which Markic et al. (2020) considered to be a suboptimal sample size for a reliable estimate of plastic ingestion rates.

Elasmobranchs are commercially important fishes, being consumed widely by some Latin American populations, from the Caribbean coast to northeastern Brazil (Feitosa et al., 2018; Rodrigues Filho et al., 2020; Schmid et al., 2019). This suggests that the ingestion of microplastics by stingrays and sharks may eventually also affect human food safety and health (Van Cauwenberghe and Janssen, 2014). The Longnose stingray, *Hypanus guttatus* (Bloch and Schneider, 1801), a species of the family Dasyatidae, is an opportunistic, benthonic predator (Gianeti et al., 2019; Last et al., 2016), distributed from the southern Gulf of Mexico to southeastern Brazil (Bigelow and Schroeder, 1953; Rosa and Furtado, 2016). This species may reach up to 2 meters in disc width and is very common as by-catch in the artisanal and industrial fisheries along the northern and northeastern coasts of Brazil (Rodrigues Filho et al., 2020; Tagliafico et al., 2013). The present study investigated the presence of MPs in *H. guttatus* from the southern extreme of the Brazilian Amazonian coast. The study also provides an important baseline for future comparisons of the abundance, shape, and color of the microplastics found in the stomach contents of elasmobranch species.

The Maranhão Gulf is located at the southern extreme of the Brazilian Amazonian coast (Figure 1) and is formed by the bay of São Marcos and São José, on either side of São Luís Island (Castro et al., 2018; Teixeira and Souza Filho, 2009). São Luís, the capital of Maranhão state, with its population of more than one million inhabitants, is located on this island (IBGE, 2010). This whole area forms an estuarine complex that covers an area of 5,414 km² (Souza Filho, 2005) and has an extreme semidiurnal macrotidal regime, with mean tidal amplitude of 3–7 m (Castro et al., 2018; Teixeira and Souza Filho, 2009). The local climate is tropical humid, with an annual precipitation of approximately 2,300 mm (Fisch et al., 1998) and a mean temperature of 26 ºC (Castro et al., 2018;Teixeira and Souza Filho, 2009).

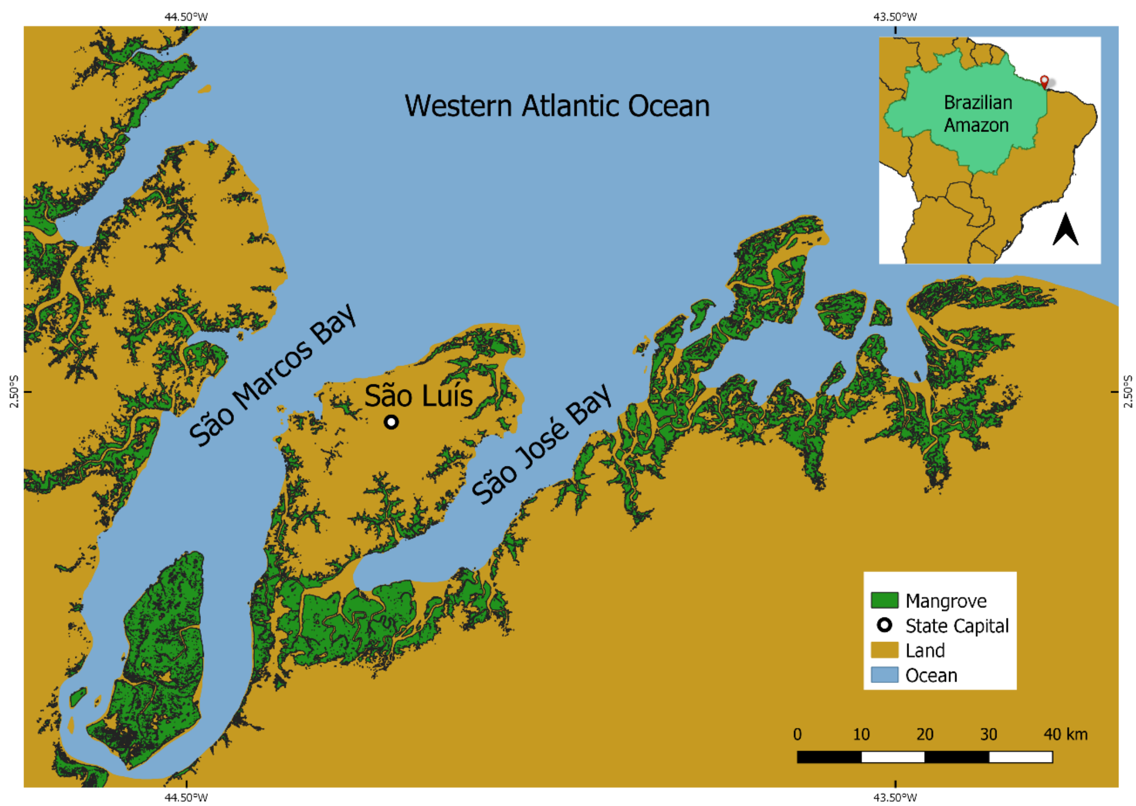

Figure 1: Map of the Maranhão Gulf estuarine complex, located on southern extreme of the Brazilian Amazon coast in the Western Atlantic Ocean, where the longnose stingray (*Hypanus guttatus*) individuals analyzed in this study were captured.

The 23 Longnose stingray specimens analyzed in the present study were obtained from local fishers and were captured by longlines and gillnets between August 2018 and March 2019. All individuals were immediately transported to the laboratory on ice in portable coolers. The length and width of the disc of each specimen were measured, and they were then eviscerated through a longitudinal incision in the abdominal area, using surgical forceps and a scalpel. The stomachs were removed carefully, and their contents placed in Petri dishes for analysis under a stereomicroscope (ZEISS Stemi DV4) at a magnification of 8x to 32x. All the MPs identified during this analysis were placed in Petri dishes containing distilled water, dried at 35ºC for 48 hours, and then separated according to shape and color. All the material and equipment used during the laboratory processing were cleaned constantly and protected from possible external contamination. Therefore, sample processing (extraction and stomachs contents analysis) was executed under a laboratory fume hood, by personnel using natural fiber clothing and maintaining doors and windows closed. To guarantee the accuracy of the readings, a clean Petri dish was placed beside the stereomicroscope during the analysis of the stomach contents and inspected after the processing of the sample, to identify possible external contamination by MPs existing in the laboratory environment.

The findings of this analysis are presented here through descriptive statistics, including the mean, minimum, and maximum numbers of microplastic items, the percentages of the different categories of shape and color, as well as the polymeric composition of the particles, and the frequency of occurrence (FO%) of the microplastics found in the stomach contents. The FO% was calculated by: $FO\% = (Ni / N) \times 100$, where Ni = the number of stomachs that contained microplastic particles, and N = total number of stomachs examined.

Samples of each category of microplastic particle found in the gastrointestinal tracts of the stingrays were separated for 2D imaging-Fourier transform infrared (FTIR) analysis. The FTIR analysis was conducted directly on the dry filters (with no further processing), using a Cary 620-670 FTIR microscope, equipped with a 128x128 FPA detector (Agilent Technologies). The spectra were recorded directly on the surface of the samples (or of the Au background) in reflectance mode, with an open aperture and a spectral resolution of 8 cm^{-1}, with 128 scans being acquired for each spectrum. A “single-tile” analysis resulted in a map of 700 x 700 μm^2 (128 x 128 pixels), with each imaging map having a spatial resolution of 5.5 μm (i.e., each pixel has an area of 5.5 x 5.5 μm^2).

The discs of the stingray specimens had a mean length of 52.3 (SD ± 8.68) cm, with a minimum of 32.4 cm and maximum of 72.0 cm, and a mean width of 54.6 (SD ± 10.0) cm, ranging from 34 cm to 83 cm (Table 1). Almost a third (FO% = 30.43%) of the samples contained microplastics, a value similar to that recorded in benthonic rays (43%) from the Portuguese coast (Neves et al., 2015). This relatively high incidence of MP ingestion may be related to the foraging strategy of the species (Romeo et al., 2015). The stingray *H. guttatus* is an important predator of benthic and benthopelagic coastal organisms, feeding on a wide range of prey. As a generalist top predator when adult, it seems likely that these individuals were susceptible to bioaccumulated microplastic contamination through the food chain, by passive ingestion (Gianeti et al., 2019).

Table 1: Biometrics of the Longnose stingray (*Hypanus guttatus*) specimens and the characteristics (shape, color, and type of polymer) of the microplastic particles (MPs) found in their stomach contents. The presence of MPs is expressed as the presence (1) or absence (0). The polymers are: ABS = Acrylonitrile Butadiene Styrene; PA = Polyamide; PE = Polyethylene; PET = Polyethylene Terephthalate; PP = Polypropylene; SBR = Styrene-Butadiene Rubber.

Stingray	**Disc length (cm)**	**Disc width (cm)**	**Presence of MPs**	**Shape of the MPs**	**Color of the MPs**	**Number of MPs**	**Polymer**
1	55	58	0	-	-	0	-
2	55	59	0	-	-	0	-
3	56.5	60	1	Fiber	Transparent	6	PET, PP, PA
4	56	57.5	1	Fragment	Blue	2	ABS
5	51	54	0	-	-	0	-
6	56.5	54.5	0	-	-	0	-
7	51	56	0	-	-	0	-
8	57	61	0	-	-	0	-
9	57.5	58.5	1	Fiber	Red	1	Blend (PET+SBR)

10	72	73.5	0	-	-	0	-
11	41.5	41	1	Fiber	Blue	3	PET, PE
12	51.5	55	0	-	-	0	-
13	72	83	1	Fiber	Black	2	PA
14	52	55.5	0	-	-	0	-
15	52.5	56	0	-	-	0	-
16	45.5	48	1	Fragment	Blue	1	ABS
17	48.3	52	0	-	-	0	-
18	43.3	45.5	0	-	-	0	-
19	44.8	48.5	0	-	-	0	-
20	49	53	0	-	-	0	-
21	43	45	0	-	-	0	-
22	46	49	1	Fiber	Blue	2	PE
23	32.4	34	0	-	-	0	-

A total of 17 microplastic particles were found in the stomach contents of seven stingrays, with a mean of 2.4 (SD ± 1.7) particles per individual (N = 7 individuals), ranging from one to six particles in a given individual. The majority (82%) of the particles found in our study were classified as fibers and the other 18% as fragments, which were primarily blue (47%) or transparent (35.3%), with some black (11.8%) and red (5.9%) particles (Figure 2).

Neves et al. (2015) recorded a mean of only 0.5 (SD ± 0.8) particles per individual in *Raja asterias*, and found only fibers in the stomach content of this ray. Many authors have found that fibers are the most abundant microplastic particles in marine environments (Alomar and Deudero, 2017; de Lucia et al., 2018, 2014; Neves et al., 2015; Rochman et al., 2015). Our findings further support that the marine biota, including benthic stingrays like *H. guttatus*, may be most exposed to microplastic fibers. The distribution of microplastics in the oceans may be influenced directly by anthropogenic processes (Barnes et al., 2009) and large amounts are found in aquatic environments near areas of urban development (Garcia et al., 2020). In Sao Luis, like many other largest cities in the Amazonian region, such as Manaus and Belém, due to the lack of environmental awareness and efficient waste management, more than 19% of the urban solid waste, including plastics, is not collected by municipalities and an unknown fraction of this mismanaged waste is washed into the Gulf of Maranhão (Giarrizzo et al. 2019).

Further, Maranhão is recognized as one of the most important states for artisanal fisheries in Brazil’s northern and northeastern regions (Almeida et al., 2015). This potentially contributes to the high presence of filaments in the coastal and estuarine ecosystems, originated by the fragmentation of fishing gear (Soares et al., 2017). These particles are introduced into marine environments through ports and fisheries activity, wastewater treatment plants, urban runoff (Peters and Bratton, 2016), and river discharge (Woodall et al., 2014). Strong macro-tidal currents and other oceanographic phenomena (e.g. the permanent east-to-west prevailing winds) found in this region may contribute to the ample dispersal of microplastics through the known accumulating effects of enclosed or semi-enclosed bays within metropolitan urban areas (Auta et al., 2017).

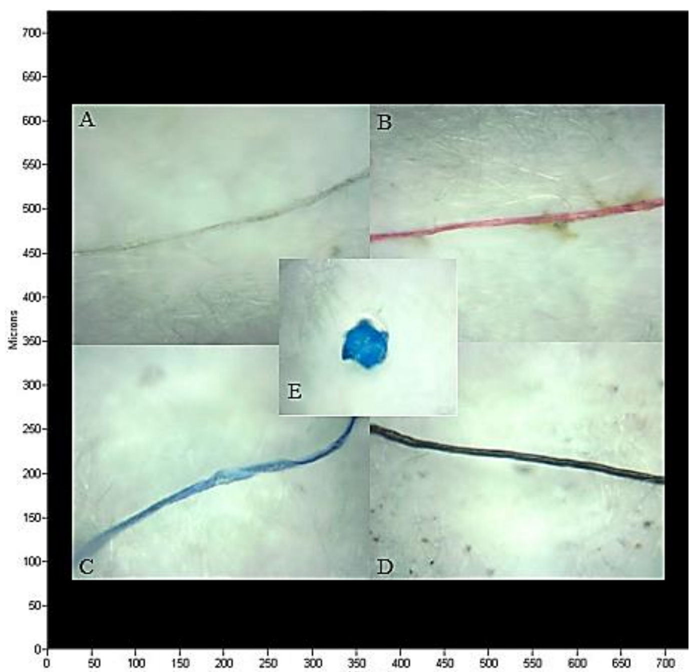

Figure 2: Examples of the different categories of microplastic found in the stomach content of the Longnose stingray *Hypanus guttatus* specimens collected from the Gulf of Maranhão. A) Transparent Fiber; B) Red Fiber; C) Blue Fiber; D) Black Fiber; E) Blue Fragment.

Six types of polymer were identified in the microplastic particles analyzed by 2D FTIR Imaging in the present study (Figure 3). The most frequent polymer was Polyethylene Terephthalate (PET; 35.3%), followed by Polyamide (PA), Acrylonitrile butadiene styrene (ABS), and Polyethylene (PE), each with a frequency of occurrence of 17.6%, and then Polypropylene (PP) and PET + SBR (Styrene Butadiene Rubber), both with a frequency of 5.9%. The predominance of PET is consistent with the fact that it is one of the polymers most produced by industries, worldwide, and thus more likely than others to be present in the marine environment (Andrady, 2011). This polymer is used in the production of textiles, including clothes, blankets, and fleeces, as well as bottles (Wang et al., 2017). Therefore, PET fibers are common in domestic wastewater, in particular from washing machines, which contaminates river basins and, eventually, oceans (Browne et al., 2011; Napper and Thompson, 2016). As a relatively dense polymer, PET is also more likely to sink to the bottom of aquatic environments, where it can be ingested by benthic organisms (GESAMP, 2015), including the Longnose stingray. The second most common polymers were PE and PA, which could come from the fishing gears, like nets and floats that are often have these polymers in their composition (GESAMP, 2016). Over time, however, lower-density polymers, such as PP and PE, may decompose and sink, and thus become available to a variety of benthic organisms (Long et al., 2015; Morét-Ferguson et al., 2010).

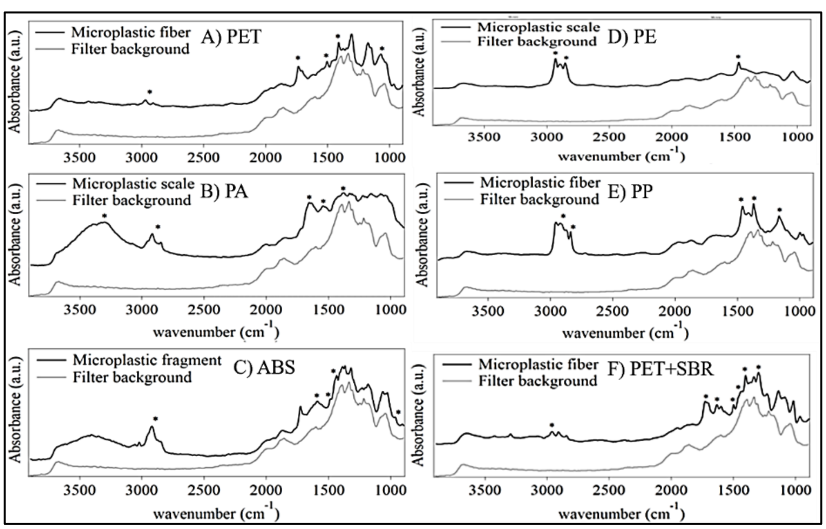

Figure 3: Representative FTIR reflectance spectra acquired different microplastic polymers, collected from the stomach contents of the Longnose stingray *Hypanus guttatus* from the Maranhão Gulf, Brazil. A) PET: Polyethylene Terephthalate; B) PA: Polyamide; C) ABS: Acrylonitrile Butadiene Styrene; D) PE: Polyethylene; E) PP: Polypropylene; F) Blend of PET (Polyethylene Terephthalate), and SBR (Styrene-butadiene rubber).

In the present study, microplastic particles were found in the stomach contents of almost one third of the analyzed *H. guttatus* specimens. This stingray species is an important target of the artisanal fisheries of Maranhão State, at the Latin America and in southern extreme of the Brazilian Amazon coast. Most of the particles were fibers, and the most frequent polymer was PET. With 23 specimens analyzed, the present study provides a more reliable estimate than the previous reports of microplastic ingestion by benthonic rays. Our study provides the first record of ingestion of MPs by *Hypanus guttatus* from the Western Atlantic Ocean, as well as an important database for further comparisons of the exposure of this elasmobranch group to plastic contaminants in the marine environment. Such investigations, specifically for understudied areas and species, are important contributions towards the understanding of spatial and temporal patterns of plastic pollution in aquatic ecosystems and organisms, as well as to support effective prevention and conservation efforts in response to this global problem.

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References

Almeida, Z. S.; Isaac-Nahum, V. J. 2015. Os Recursos Pesqueiros Marinhos e Estuarinos do Maranhão: Biologia, Tecnologia, Socioeconomia da Arte e Manejo. 1. ed. Novas Edições Acadêmicas, v. 1. 293p

Alomar, C., Deudero, S., 2017. Evidence of microplastic ingestion in the shark Galeus melastomus Rafinesque, 1810 in the continental shelf off the western Mediterranean

Sea. Environ. Pollut. 223, 223–229. https://doi.org/10.1016/j.envpol.2017.01.015

Anastasopoulou, A., Mytilineou, C., Smith, C.J., Papadopoulou, K.N., 2013. Plastic debris ingested by deep-water fish of the Ionian Sea (Eastern Mediterranean). Deep. Res. Part I Oceanogr. Res. Pap. 74, 11–13. https://doi.org/10.1016/j.dsr.2012.12.008

Andrady, A.L., 2011. Microplastics in the marine environment. Mar. Pollut. Bull. 62, 1596–1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Arthur, C., Baker, J., Bamford, H., 2009. Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris. Group 530.

Auta, H.S., Emenike, C.U., Fauziah, S.H., 2017. Distribution and importance of microplastics in the marine environment. A review of the sources, fate, effects, and potential solutions. Environ. Int. 102, 165–176. https://doi.org/10.1016/j.envint.2017.02.013

Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. B Biol. Sci. 364, 1985–1998. https://doi.org/10.1098/rstb.2008.0205

Bigelow HB and Schroeder WC (1953) Fishes of the Western North Atlantic. Sawfishes, Guitarfishes, Skates and Rays, vol. 1. New Haven, CT: Memoirs Sears Foundation for Marine Research, pp. 1–514.

Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., Thompson, R., 2011. Accumulation of microplastic on shorelines woldwide: Sources and sinks. Environ. Sci. Technol. 45, 9175–9179. https://doi.org/10.1021/es201811s

Campbell, S.H., Williamson, P.R., Hall, B.D., 2017. Microplastics in the gastrointestinal tracts of fish and the water from an urban prairie creek. Facets 2, 395–409. https://doi.org/10.1139/facets-2017-0008

Castro, A. C. L., Eschirque, S. A., Silveira, P. C. A., Azevedo, J. W. J., Ferreira, H. R. S., Soares, L. S., Monteles, J. S., Araujo, M. C., Nunes, J., Silva, M. H. L. 2018. Physicochemical properties and distribution of nutrients on the inner continental shelf adjacent to the Gulf of Maranhão (Brazil) in the Equatorial Atlantic. Appl. Ecol. Env. Res. 16, 4829-4847.

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: A review. Mar. Pollut. Bull. 62, 2588–2597. https://doi.org/10.1016/j.marpolbul.2011.09.025

de Lucia, G.A., Caliani, I., Marra, S., Camedda, A., Coppa, S., Alcaro, L., Campani, T., Giannetti, M., Coppola, D., Cicero, A.M., Panti, C., Baini, M., Guerranti, C., Marsili, L., Massaro, G., Fossi, M.C., Matiddi, M., 2014. Amount and distribution of neustonic micro-plastic off the western Sardinian coast (Central-Western Mediterranean Sea). Mar. Environ. Res. 100, 10–16. https://doi.org/10.1016/j.marenvres.2014.03.017

de Lucia, G.A., Vianello, A., Camedda, A., Vani, D., Tomassetti, P., Coppa, S., Palazzo, L., Amici, M., Romanelli, G., Zampetti, G., Cicero, A.M., Carpentieri, S., Di Vito, S., Matiddi, M., 2018. Sea water contamination in the Vicinity of the Italian minor islands caused by microplastic pollution. Water (Switzerland) 10. https://doi.org/10.3390/w10081108

Desforges, J.P.W., Galbraith, M., Ross, P.S., 2015. Ingestion of Microplastics by Zooplankton in the Northeast Pacific Ocean. Arch. Environ. Contam. Toxicol. 69, 320–330. https://doi.org/10.1007/s00244-015-0172-5

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea. PLoS One 9, 1–15. https://doi.org/10.1371/journal.pone.0111913

Feitosa, L.M., Martins, A.P.B., Giarrizzo, T., MacEdo, W., Monteiro, I.L., Gemaque, R., Nunes, J.L.S., Gomes, F., Schneider, H., Sampaio, I., Souza, R., Sales, J.B., Rodrigues-Filho, L.F., Tchaicka, L., Carvalho-Costa, L.F., 2018. DNA-based identification reveals illegal trade of threatened shark species in a global elasmobranch conservation hotspot. Sci. Rep. 8, 1–11. https://doi.org/10.1038/s41598-018-21683-5

Fisch, G., Marengo, J.A., Nobre, C.A., 1998. The climate of Amazonia - a review. Acta Amaz. 28, 101–126.

Garcia, T.M., Campos, C.C., Mota, E.M.T., Santos, N.M.O., Campelo, R.P. de S., Prado, L.C.G., Melo Junior, M., Soares, M. de O., 2020. Microplastics in subsurface waters of the western equatorial Atlantic (Brazil). Mar. Pollut. Bull. 150. https://doi.org/10.1016/j.marpolbul.2019.110705

Germanov, E.S., Marshall, A.D., Hendrawan, I.G., Admiraal, R., Rohner, C.A., Argeswara, J., Wulandari, R., Himawan, M.R., Loneragan, N.R., 2019. Microplastics on the Menu: Plastics Pollute Indonesian Manta Ray and Whale Shark Feeding Grounds. Front. Mar. Sci. 6. https://doi.org/10.3389/fmars.2019.00679

GESAMP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, 2015. Sources, fate and effects of microplastics in the marine environment: a global assessment". Reports Stud. GESAMP 90, 96. https://doi.org/10.13140/RG.2.1.3803.7925

GESAMP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, 2016. Sources, fate and effects of microplastics in the marine environment: part 2 of a global assessment". Reports Stud. GESAMP 93, 220.

Gianeti, M.D., Yokota, L., Lessa, R.P.T., Dias, J.F., 2019. Diet of longnose stingray Hypanus guttatus (Myliobatiformes: Dasyatidae) in tropical coastal waters of Brazil. J. Mar. Biol. Assoc. United Kingdom 99, 1869–1877. https://doi.org/10.1017/S0025315419000912

Giarrizzo, T., Andrade, M.C., Schmid, K., Winemiller, K.O., Ferreira, M., Pegado, T., Chelazzi, D., Cincinelli, A., Fearnside, P.M., 2019. Amazonia: the new frontier for plastic pollution. Front. Ecol. Environ. 17, 309–310. https://doi.org/10.1002/fee.2071

Godoy, V., Martín-Lara, M.A., Calero, M., Blázquez, G., 2019. Physical-chemical characterization of microplastics present in some exfoliating products from Spain. Mar. Pollut. Bull. 139, 91–99. https://doi.org/10.1016/j.marpolbul.2018.12.026

Herrera, A., Ŝtindlová, A., Martínez, I., Rapp, J., Romero-Kutzner, V., Samper, M.D., Montoto, T., Aguiar-González, B., Packard, T., Gómez, M., 2019. Microplastic ingestion by Atlantic chub mackerel (Scomber colias) in the Canary Islands coast. Mar. Pollut. Bull. 139, 127–135. https://doi.org/10.1016/j.marpolbul.2018.12.022

IBGE (Instituto Brasileiro de Geografia e Estatística), 2010. Portal do Governo Brasileiro. https://cidades.ibge.gov.br/brasil/ma/sao-luis/panorama. Accessed 28 Jan 2020.

Last, P.R., Naylor, G.J.P., Manjaji-Matsumoto, B.M., 2016. A revised classification of the family Dasyatidae (Chondrichthyes: Myliobatiformes) based on new morphological and molecular insights. Zootaxa 4139, 345–368. https://doi.org/10.11646/zootaxa.4139.3.2

Long, M., Moriceau, B., Gallinari, M., Lambert, C., Huvet, A., Raffray, J., Soudant, P.,

2015. Interactions between microplastics and phytoplankton aggregates: Impact on their respective fates. Mar. Chem. 175, 39–46. https://doi.org/10.1016/j.marchem.2015.04.003

Markic, A., Gaertner, J.C., Gaertner-Mazouni, N., Koelmans, A.A., 2020. Plastic ingestion by marine fish in the wild. Crit. Rev. Environ. Sci. Technol. 50, 657–697. https://doi.org/10.1080/10643389.2019.1631990

Markic, A., Niemand, C., Bridson, J.H., Mazouni-Gaertner, N., Gaertner, J.C., Eriksen, M., Bowen, M., 2018. Double trouble in the South Pacific subtropical gyre: Increased plastic ingestion by fish in the oceanic accumulation zone. Mar. Pollut. Bull. 136, 547–564. https://doi.org/10.1016/j.marpolbul.2018.09.031

Ministério da Pesca e Aquicultura. 2010. Boletim Estatístico da Pesca e Aquicultura: Brasil 2008 – 2009. Brasília, 99p.

Morét-Ferguson, S., Law, K.L., Proskurowski, G., Murphy, E.K., Peacock, E.E., Reddy, C.M., 2010. The size, mass, and composition of plastic debris in the western North Atlantic Ocean. Mar. Pollut. Bull. 60, 1873–1878. https://doi.org/10.1016/j.marpolbul.2010.07.020

Murphy, F., Russell, M., Ewins, C., Quinn, B., 2017. The uptake of macroplastic & microplastic by demersal & pelagic fish in the Northeast Atlantic around Scotland. Mar. Pollut. Bull. 122, 353–359. https://doi.org/10.1016/j.marpolbul.2017.06.073

Napper, I.E., Thompson, R.C., 2016. Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. Mar. Pollut. Bull. 112, 39–45. https://doi.org/10.1016/j.marpolbul.2016.09.025

Neves, D., Sobral, P., Ferreira, J.L., Pereira, T., 2015. Ingestion of microplastics by commercial fish off the Portuguese coast. Mar. Pollut. Bull. 101, 119–126. https://doi.org/10.1016/j.marpolbul.2015.11.008

Ogata, Y., Takada, H., Mizukawa, K., Hirai, H., Iwasa, S., Endo, S., Mato, Y., Saha, M., Okuda, K., Nakashima, A., Murakami, M., Zurcher, N., Booyatumanondo, R., Zakaria, M.P., Dung, L.Q., Gordon, M., Miguez, C., Suzuki, S., Moore, C., Karapanagioti, H.K., Weerts, S., McClurg, T., Burres, E., Smith, W., Velkenburg, M. Van, Lang, J.S., Lang, R.C., Laursen, D., Danner, B., Stewardson, N., Thompson, R.C., 2009. International Pellet Watch: Global monitoring of persistent organic pollutants (POPs) in coastal waters. 1. Initial phase data on PCBs, DDTs, and HCHs. Mar. Pollut. Bull. https://doi.org/10.1016/j.marpolbul.2009.06.014

Pegado, T. de S. e. S., Schmid, K., Winemiller, K.O., Chelazzi, D., Cincinelli, A., Dei, L., Giarrizzo, T., 2018. First evidence of microplastic ingestion by fishes from the Amazon River estuary. Mar. Pollut. Bull. 133, 814–821. https://doi.org/10.1016/j.marpolbul.2018.06.035

Peters, C.A., Bratton, S.P., 2016. Urbanization is a major influence on microplastic ingestion by sunfish in the Brazos River Basin, Central Texas, USA. Environ. Pollut. 210, 380–387. https://doi.org/10.1016/j.envpol.2016.01.018

Rochman, C.M., Tahir, A., Williams, S.L., Baxa, D. V., Lam, R., Miller, J.T., Teh, F.C., Werorilangi, S., Teh, S.J., 2015. Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Sci. Rep. 5. https://doi.org/10.1038/srep14340

Rodrigues Filho, L.F. da S., Feitosa, L.M., Silva Nunes, J.L., Onodera Palmeira, A.R., Martins, A.P.B., Giarrizzo, T., Carvalho-Costa, L.F., Monteiro, I.L.P., Gemaque, R., Gomes, F., Souza, R.F.C., Sampaio, I., Sales, J.B. de L., 2020. Molecular identification of ray species traded along the Brazilian Amazon coast. Fish. Res. 223, 105407. https://doi.org/10.1016/j.fishres.2019.105407

Romeo, T., Pietro, B., Pedà, C., Consoli, P., Andaloro, F., Fossi, M.C., 2015. First evidence of presence of plastic debris in stomach of large pelagic fish in the Mediterranean Sea. Mar. Pollut. Bull. 95, 358–361. https://doi.org/10.1016/j.marpolbul.2015.04.048

Rosa, R. and Furtado, M., 2016. The IUCN Red List of Threatened Species. Version 2017-3 (2018). Available at http://www.iucnredlist.org.

Schmid, K., Andrade. M., Machado, F., Araujo, J. Corrêa, e., Giarrizzo, T. Morphological abnormality in a Longnose Stingray Hypanus guttatus (Bloch & Schneider, 1801) (Myliobatiformes: Dasyatidae). Biota Neotropica. 19(4): e20190792. http://dx.doi.org/10.1590/1676-0611-BN-2019-0792

Soares, M.D.O., Monteiro, T., Vieira, M., Salani, S., Hadju, E., Matthews-, H., Margarida, Z., Nery, D.A., Kenji, R., 2017. Marine Animal Forests, Marine Animal Forests. https://doi.org/10.1007/978-3-319-17001-5

Souza Filho, P.W.M., 2005. Costa de manguezais de macromaré da amazônia: cenários morfológicos, mapeamento e quantificação de áreas usando dados de sensores remotos. Rev. Bras. Geofis. 23, 427–435. https://doi.org/10.1590/s0102-261x2005000400006

Tagliafico, A., Rago, N., Salomé Rangel, M., 2013. Aspectos biológicos de las rayas Dasyatis guttata y Dasyatis americana (Myliobatiformes: Dasyatidae) capturadas por la pesquería artesanal de la isla de Margarita, Venezuela. Rev. Biol. Mar. Oceanogr. 48, 365–373. https://doi.org/10.4067/S0718-19572013000200015

Teixeira, S.G., Souza Filho, P.W.M., 2009. Mapeamento de ambientes costeiros tropicais (Golfão Maranhense, Brasil) utilizando imagens de sensores remotos orbitais. Rev. Bras. Geofis. 27, 69–82. https://doi.org/10.1590/s0102-261x2009000500006

Valente, T., Sbrana, A., Scacco, U., Jacomini, C., Bianchi, J., Palazzo, L., de Lucia, G.A., Silvestri, C., Matiddi, M., 2019. Exploring microplastic ingestion by three deep-water elasmobranch species: A case study from the Tyrrhenian Sea. Environ. Pollut. 253, 342–350. https://doi.org/10.1016/j.envpol.2019.07.001

Van Cauwenberghe, L., Janssen, C.R., 2014. Microplastics in bivalves cultured for human consumption. Environ. Pollut. 193, 65–70. https://doi.org/10.1016/j.envpol.2014.06.010

Wang, W., Ndungu, A.W., Li, Z., Wang, J., 2017. Microplastics pollution in inland freshwaters of China: A case study in urban surface waters of Wuhan, China. Sci. Total Environ. 575, 1369–1374. https://doi.org/10.1016/j.scitotenv.2016.09.213

Woodall, L.C., Sanchez-Vidal, A., Canals, M., Paterson, G.L.J., Coppock, R., Sleight, V., Calafat, A., Rogers, A.D., Narayanaswamy, B.E., Thompson, R.C., 2014. The deep sea is a major sink for microplastic debris. R. Soc. Open Sci. 1. https://doi.org/10.1098/rsos.140317

Yu, F., Yang, C., Zhu, Z., Bai, X., Ma, J., 2019. Adsorption behavior of organic pollutants and metals on micro/nanoplastics in the aquatic environment. Sci. Total Environ. 694, 133643. https://doi.org/10.1016/j.scitotenv.2019.133643

CONSIDERAÇÕES FINAIS

Atualmente, o descarte de resíduos sólidos causa uma série de problemas ambientais, econômicos e sociais. Encontrar soluções que melhor informem os gestores no gerenciamento destes resíduos é fundamental para minimizar os seus impactos no ambiente e na sociedade.

Em ambientes costeiros, conhecer os principais fatores ambientais que alteram a abundância dos resíduos, bem como suas principais fontes de descarte, se mostraram bons parâmetros para indicar em quais lugares há maior probabilidade de se encontrar esses resíduos, bem como possibilita criar estratégias específicas para cada tipo de resíduo.

O plástico é o maior contribuinte dos resíduos sólidos encontrados no ambiente, sendo que, sua ingestão pela fauna marinha é um dos grandes problemas ambientais no mundo. Por tanto, registrar as ocorrências de ingestão são extremamente importantes para se criar uma base de dados comparativa para as espécies e entender melhor a distribuição espacial dos resíduos plásticos nos ecossistemas.