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Socio-economic impact of marine litter for remote oceanic islands: The Azores archipelago

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DECLARAÇÃO DE AUTORIA DE TRABALHO

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Declaro ser a autora de este trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

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(Yasmina Mª Rodríguez González)

ABSTRACT

Marine litter is present throughout the world's oceans, representing a significant threat to marine ecosystems. While most efforts have focused on assessing ecological impacts, information on the socio-economic dimension of marine litter is scarce. Here we provide a detailed assessment of the direct economic costs of marine litter for a remote region of the North-East Atlantic, the Azores archipelago. Face-to-face interviews were performed to quantify and characterise the costs of marine litter-related incidents and coastal clean-ups to259 sea-users (fishermen, tourist operators and transport companies) and the costs of coastal clean-ups to 21 local authorities (parish councils, municipalities and harbours). We provide a detail characterisation of the frequency, type and costs of marine litter-related incidents and clean-ups along with an evaluation of the perceptions and opinions of different stakeholders on this issue. The average cost of a marine litter-related incident was €1618 (±401, SE), while the average cost associated with cleaning a coastal site was €10233 (±3597, SE) per local authority and year. Overall, marine litter pollution was estimated to cost a total of €710,698 (±195,181; SD) per year, which is the equivalent to 0.02% of the Gross Domestic Product of the Azores archipelago. Our results demonstrate that marine litter can significantly impact the activity of sea-users and represent an important economic burden for local authorities, thus, marine litter creates costs and inconveniences for a range of stakeholders engaged in marine activities and also increases the waste clean-up budgets of small communities living on remote islands. Quantifying the socio-economic implication of marine litter is crucial to further raise public awareness on this issue and demonstrate that the impacts are wide-ranging.

Keywords: Plastic pollution, economic assessment, stakeholders, outermost regions, Atlantic Ocean.

RESUMO

O lixo marinho é qualquer material duradouro, fabricado ou processado que é descartado, eliminado ou abandonado na costa ou no mar. Dos diferentes tipos de lixo marinho, os plásticos são sem dúvida, os mais abundantes e que causam mais impactos. É por isto que atualmente a poluição do meio marinho por este material é reconhecida como um problema que afeta ecossistemas e espécies globalmente, apesar de que a produção de plásticos em grande escala só começou na década dos anos 50. Cada ano, as deficiências no sistema de tratamento de resíduos e na reciclagem provocam grandes descargas de plásticos no meio marinho, tanto acidentais como intencionais. Uma vez no oceano, estes plásticos concentram-se à volta das grandes cidades e nos cinco Giros Subtropicais de correntes oceânicas, acabando por afetar regiões remotas localizadas longe das zonas principais de poluição.

A poluição por plásticos é uma questão social séria para a qual os impactos estão apenas a começar a ser avaliados. Apesar de que nas últimas duas décadas houve um aumento dos estudos focados na quantificação dos impactos ecológicos desta problemática no ambiente marinho, ainda existe muito desconhecimento em várias áreas. Assim por exemplo, até agora dedicou-se pouca atenção às implicações económicas que o lixo marinho causa em diferentes sectores. Neste sentido, poucos investigadores têem aprofundado este tema apesar de evidências que demostram que uma ampla gama de setores económicos pode estar potencialmente afetados pelo lixo marinho, o qual atua como um fardo económico significativo para as comunidades costeiras e ataca diretamente as indústrias de turismo, pesca e transporte marítimo.

Por exemplo, um estudo que usou dados das estatísticas de seguros do Sistema Nacional das Pescas no Japão mostrou que os custos associados a incidentes relacionados com lixo marinho, incluindo colisões, emaranhamentos das hélices em lixo e entupimentos nas bombas de água, correspondia a um custo para a indústria pesqueira de US $18,450 milhões anuais em 1985. Da mesma forma, em 21 economias da região da Ásia-Pacífico, os custos de danos causados por lixo marinho nas hélices de barcos e sistemas de refrigeração de pequenos navios foram estimados em US $1.26 bilhões por ano.

Mas, além destes problemas causados aos utilizadores do mar, a limpeza da orla costeira pode representar outros custos significativos para comunidades costeiras. Um estudo realizado na UE em 1998 mostrou que as limpezas de praias representavam um total de

2.9 milhões de libras por ano, incluindo a recolha e o transporte de lixo marinho, taxas de descarte, força de trabalho e equipamentos. Na Holanda, o município turístico de Den Haag estimou gastar aproximadamente 0.5 milhões de euros por ano para remover lixo marinho das áreas costeiras. Portanto, os gastos relacionados com o lixo marinho podem ser significativos, mesmo quando consideramos pequenas comunidades.

O arquipélago dos Açores, um grupo remoto de ilhas vulcânicas localizadas no extremo Nordeste do Oceano Atlântico, é particularmente afetado pelo lixo marinho. Mais especificamente, um estudo realizado nesta região reportou que 83% das tartarugas marinhas analisadas tinham ingerido itens de plástico. Além disso, outros estudos nos Açores demostraram que grandes quantidades de itens da pesca, especialmente equipamentos de pesca perdidos ou descartados intencionalmente, estão presentes no fundo do mar perto de áreas costeiras, nas montanhas submarinas, mas também a flutuar na superfície da água.

O objetivo deste trabalho de tese foi quantificar o impacto económico direto e os custos associados ao lixo marinho para a economia do arquipélago dos Açores. Os Açores têm um grande território marinho, onde atividades como a pesca e o turismo são alguns dos setores mais importantes para a economia do arquipélago. Através do uso de entrevistas pessoais, este estudo fornece uma caracterização detalhada da frequência e do tipo de incidentes causados pelo lixo marinho aos principais usuários do mar. Com o objetivo de ter uma avaliação económica abrangente para esta questão, também foram entrevistadas autoridades locais que permitissem estimar o custo das limpezas costeiras. Por fim, foram exploradas as perceções e opiniões das partes interessadas em relação a esta problemática. Esta avaliação socioeconómica contribui para um maior esforço de investigação nesta área com o objetivo de estabelecer uma base que quantifique e caracterize toda a gama de impactos causados pela poluição por plásticos na região dos Açores.

Neste estudo foram entrevistados 259 utilizadores do mar (pescadores profissionais e recreativos, empresas marítimas turísticas e empresas de transportes de mercadorias) e 21 autoridades locais gestoras de zonas costeiras (Câmaras Municipais, Juntas de Freguesia, Portos e Marinas). Dos 327 barcos avaliados, um total de 95 barcos reportou incidentes, o que dá uma frequência percentual de ocorrência (%FO) de incidentes relacionados a lixo marinho de 29%. O emaranhado de lixo marinho foi o incidente mais comumente relatado (92%), geralmente associado à hélice do barco (68%; n = 76), mas também as artes de pesca ativas (24%; n = 27) de ambos, tanto pescadores profissionais como

pescadores recreativos. Outros tipos de incidentes incluem aqueles onde itens de lixo entopem a bomba de água (4%; n = 5), um problema que afetou a todos os usuários do mar a exceção dos pescadores recreativos. Também foram reportadas colisões com lixo marinho (4%; n = 4), mas apenas por pescadores profissionais e operadores marítimo turísticos.

Os resultados obtidos demostram que o custo médio que os utilizadores do mar devem suportar após um incidente relacionado com o lixo marinho é de €1617 (±400, SE), enquanto que o custo médio associado à limpeza de um local costeiro é de €10,233 (± 3597, SE) por ano. Finalmente, a extrapolação destes resultados a todo o Arquipélago dos Açores demostra que o lixo marinho tem um impacto económico estimado de €710,698 (±195,181, SD) por ano. Este valor corresponde a 0.02% do Produto Interno Bruto (PIB) total para os Açores no mesmo ano (PIB: €3,962,000,000, SREA).

Em todo o mundo ainda existe um entendimento limitado das implicações económicas do lixo marinho para as comunidades costeiras, principalmente para as regiões remotas. O fato de este estudo mostrar como este problema também está presente num arquipélago oceânico, pode-se incentivar outros investigadores a realizar avaliações económicas semelhantes sobre os impactos económicos do lixo marinho em novos locais. Sendo que nossa sociedade é predominantemente impulsionada por interesses económicos, essas avaliações económicas podem aumentar a conscientização e ajudar a direcionar esforços futuros para controlar a entrada de lixo no meio marinho, e paralelamente, disparar o alarme sobre as consequências de nosso consumo crescente de plásticos.

Palavras chave: lixo marinho, plásticos marinhos, custos económicos, regiões remotas, Oceano Atlântico

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CHAPTER 1

1. INTRODUCTION

1.1 Marine litter pollution

Marine litter was defined by the UNEP (2009) as 'any persistent, manufactured or processed solid material discarded, disposed or abandoned in the marine and coastal environment. Marine litter consists of items that have been made or used by people and deliberately discarded into the sea, rivers or beaches; brought indirectly to the sea with rivers, sewage, storm water or winds; or accidentally lost, including material lost at sea in bad weather'.

1.1.1. Sources and global distribution of marine litter

Marine litter is worldwide distributed and its presence has been confirmed even in the most remote areas, such as the Arctic and the Antarctic (Halsband et al., 2019; Lacerda et al., 2019). The release of marine litter into the ocean occurs through a diversity of pathways, from land or directly from sea activities. In general, litter items make their way into the ocean from land typically carried by canals or rivers (e.g., Rech et al., 2014; Sadri and Thompson, 2014). It was estimated that the top 20 polluting rivers account for 67% of the global total input of marine litter, which it is between 1.15 and 2.41 million tons of plastic waste entering the ocean every year from rivers (Lebreton et al., 2017). In addition, waste can be blown away from landfills, making their way into the ocean (Newman et al., 2015), but also due to beach littering and storm drains. Recently, it was suggested that the air mass can also transport through the atmosphere, microplastics particles over a distance of up to 95 km (Allen et al., 2019). The remaining percentage of marine litter that ends up in the oceans and seas come directly from sea activities related mainly with the fishing, aquaculture and shipping sectors (GESAMP, 2016.).

Once in the ocean, marine litter can spread due to the oceanic current systems and can later wash up on coastal areas, be ingested by marine organisms and deposited on the seafloor. Oceanic currents play a central role in the transport and release of marine litter in convergence zones of the open ocean (Maximenko et al., 2012). Specifically, mathematical models confirmed that plastic items cluster in the five subtropical convergence zones in addition to near human population centers (e.g., Thompson et al., 2004; Law et al., 2010; Cózar et al., 2014). For example, Eriksen et al. (2014) suggested

that subtropical gyres may accumulate the staggering amount of 5.25 trillion of floating plastic particles.

1.1.2. Typologies of marine litter

The different typologies that make up marine litter are plastics, glass, metal, paper, cloth, rubber, and wood (UNEP, 2005). Nevertheless, plastic items are, by far, the most abundant material present in the marine environment, known to significantly affect marine organisms, for example, a recent review revealed that marine litter affected 914 species through entanglement and/or ingestion (Kühn and Van Franeker, 2020), but also coastal economies worldwide (UNEP, 2016). Plastics are used by many sectors of our economy; thus, the different types of products include a wide range of food and water packaging and innumerable of consumer products like textiles and clothing, electrical and electronic devices, life-saving advanced medical equipment and reliable and durable construction materials (Andrady and Neal, 2009; Thompson et al., 2009).

The most common plastic polymers found in the oceans are low density polyethylene (PE-LD), linear low-density polyethylene (PE-LLD), high-density polyethylene (PE-HD), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS) and polyvinyl chloride (PVC) (Gallo et al., 2018). The higher density polymers such as polyvinyl chloride (PVC) and polyethylene terephthalate (PET) will more easily sink to the seafloor in marine systems (Woodall et al., 2014).

Plastic is a popular material due to its durability, low production cost and efficiency in its uses (Ryan et al., 2009). However, since the large scale of plastic production began in the early 1960s, the inefficiency to manage the end-of-life of such material resulted in important amounts of plastic waste entering the oceans. Jambeck et al. (2015) estimated for 2010 that among 4.8 to 12.7 million tons of plastic items are entering the ocean per year, and due to the low regulation to control plastic production and consumption worldwide, it is expected that litter items continue leaching into sea during the following decades.

1.1.3. Sizes of marine litter

Litter items of all sizes are omnipresent in seas and oceans worldwide. Large litter items are readily visible and adversely affects wildlife species (Kühn et al., 2015), while the smaller particles have recently started to be studied. Plastic items can be fragmented when exposed to UV radiation, a reaction known as photo-oxidation (Gregory and Andrady,

2003). This fragmentation can be also initiated by mechanical factors such as wave action or abrasion, or even by a biological degradation when microorganisms or other animals weaken their surface (Browne et al., 2007). Therefore, these items are classified into macro (visible items bigger than 25mm), meso (items from 5 mm up to 25 mm) and micro particles (items with 5mm or less sizes) (Gregory and Andrady, 2003; Arthur et al., 2009).

Specifically, microplastics particles has been sub-classified into two main categories: (1) primary microplastics, resulted from mass-produced processes that include raw-materials known as pellets, microbeads added to cosmetics (Lassen et al., 2015) or fibers that leach into the environment when synthetic cloths are manufactured or washed (Browne et al., 2011); and (2) secondary microplastics, small plastic fragments caused from the degradation of bigger items (e.g., Ryan et al., 2009). Further degradation may produce nanoplastics, particles comprised between 1 to 100 nm that still have unidentified impacts and unknown toxicological properties (Wagner et al., 2019).

1.1.4. Threats of marine litter

Environmental and ecological impacts

The research on the field of litter pollution in the marine environment have increased in the last decade. However, the total amounts of marine plastics litter, temporal trends in these amounts under exponentially increasing production, as well as degradation processes, vertical fluxes, and time scales are largely unknown (Maximenko et al., 2019). Many impacts caused by marine litter pollution are hard to assess despite it is well established that marine litter and, in particular plastics, affect marine organisms and habitats; the threats are diverse, characterized by many open questions, knowledge gaps, and uncertainties. Moreover, the impacts of the small microplastics (<1mm) on marine wildlife and food chains remains unknown (e.g., Volker et al., 2018). Microplastics have been discovered in ecosystems, whether deep-sea sediments or freshwater environments, but the traditional approach to environmental risk assessment of chemical sub-stances cannot evaluate the multitude of microplastic particles and intervening variables (Brennholt, et al., 2018).

The main threats known to affect marine biodiversity are the entanglement (Galgani et al., 2018) and the ingestion (Provencher et al., 2017). Recently, over 900 species were identified to be affected by marine litter pollution, being plastic ingestion one of the major risks (Kühn and Van Franeker, 2020). Furthermore, the ingestion of plastics may release

negative effects on the wellbeing status of the organisms. Some of the deleterious effects that have been detected are the reduction of the space that is available for food, which may cause satiation, starvation, weakness, or in even perforations and ulcerations of the digestive tract (e.g., Gregory, 2009; Cole et al., 2011). Additionally, plastics might have indirect effects when their toxic substances leach to the organisms that ingested them, with likely negative consequences in the healthiness causing endocrine disruptions (Rochman et al., 2013) or vulnerability of preys to detect and avoid predators (Seuront, 2018). In particular, plastic is a chemically inert material, however when it enters in the ocean, high concentration of additives (e.g., phthalates, brominated flame retardants, benzophenones, etc.) combined with high adsorption rates of chemical contaminants such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and polibromodifenil eteres (PBDEs) are potentially toxic when ingested by marine species (Rochman et al., 2013).

Socio-economic impacts

Besides these pressures that affect marine ecosystems worldwide, marine litter pollution can also cause socio-economic impacts to our societies. These impacts are further divided between (1) directs damages to sea-users and cleaning costs of stranded plastics around recreational coastal areas, and (2) indirect damages to the ecosystem's services.

1.2 Socio-economic impacts/implications of marine litter

Marine litter pollution has been reported to have economic and social impacts that can affect several economic sectors including fisheries and aquaculture, commercial shipping, recreational boating, local coastal governments, coastal tourism, and emergency response services (UNEP, 2016).

The costs associated with marine litter are divided between direct and indirect costs (Newman et al., 2015). Direct costs include expenses related with beach cleanups and/or damages to marine equipment (e.g., aquaculture) and boats (e.g., Hall, 2000; Mouat et al., 2010; McIlgorm et al., 2011). On the contrary, the indirect costs are related with impacts to biodiversity and habitats, and costs resulted from damages to the ecosystem services, such as problems with water and food supply, tourism and recreational activities, among others (Beaumont et al., 2019). For example, indirect costs to fishermen happen when commercial species are reported to ingest plastics or accumulate pollutants which devalue the resource and profit. These impacts have been considered as indirect costs since they

may take some time to reveal, but even when revealed, may not be very accessible to study (Newman et al., 2015).

From evidence available it becomes clear that marine litter has negative social and economic impacts. However, so far, the economic costs did not receive so much attention. In addition, differences in terms of geography and demography of coastal populations may also affect comparisons of these costs between communities (McIlgorm et al., 2020). Due to these data gaps, this thesis work was focused to study the direct economic cost of marine litter to a remote region of the North Atlantic.

1.2.1. Direct costs to sea-users

Repairs or even replacement of elements are some of the consequences that sea-user face after interactions with marine litter. Fishermen may be affected directly by marine litter by damaging their vessel and their fishing equipment. Within the problems resulted from interactions with marine litter, the most frequent are litter items that are pressed or entangled on the vessels propellers, litter items that enters into the water pump or damages to the fishing equipment (Takehama, 1989).

The aquaculture sector can also be affected by problems of entanglements on boat propellers and by pipe´s blockages. Furthermore, in highly polluted locations, the need to regularly remove litter items clustering in the vicinity of aquaculture facilities results in significant extra costs. In Scotland, every producer has been estimated to spend around €580 per year on repairs and litter removal (Mouat, et al., 2010).

1.2.2. Direct costs for local authorities

Governments are directly influenced by the amount of marine litter that strand on coastal areas worldwide, either beaches visited by residents and tourists, or less accessible areas where recreational activities are carried out, such as coastal fishing sites. These costs might be higher in regions where the shoreline is used for activities that generate important economic contributions for the local population.

Not only beaches are affected by marine litter pollution. Harbors and marinas are also facing important accumulations of litter items in their surroundings, which forces the responsible authorities to find and implement methods to remove and control this type of pollution in such areas. For example, it is estimated that UK is spending an average of €2.4 million per year in cleaning events for harbors and ports (Mouat et at., 2010).

Moreover, in many places local and international organizations are joining local authorities in volunteer campaigns aimed at remove marine litter from coastal areas (Hidalgo-Ruz and Thiel, 2015). This type of work has also direct costs associated, for example in terms of insurance, materials and operations management. But, even when the workforce is free, the time of volunteers has an associated value. A study in the U.K analyzed the value of the volunteers' time in two cleaning operations estimating a total cost of €131,000 (Mouat et al., 2010), an economic value that can be underestimated since the authors did not include the direct costs mentioned above.

1.2.3. Policies

As previously mentioned, marine litter is a transboundary pressure (Lebreton et al., 2017). This anthropogenic stressor results from an unsustainable production and consumption patterns, deprived solid waste management and lack of organization, adequate legal policy frameworks and poor administration (Vitorino de Souza Melaré et al., 2017).

At the global level, the 2030 Agenda for Sustainable Development calls for action to 'Conserve and sustainably use the oceans, seas and marine resources' in its Goal 14, and 'By 2025, prevent and significantly reduce marine pollution of all kinds, particularly from land-based activities, including marine debris and nutrient pollution' assumption that is established in the target 14.1. In parallel, the European Union, as part of its "Integrated Maritime Policy" has developed the "Marine Strategy Framework Directive" (MSFD, 2008/56/EC), that is aiming for clean, healthy and productive marine ecosystems within all EU Member States by 2020. With the ultimate objective of achieving Good Environmental Status (GES) by 2020, the MSFD requires member states to implement monitoring programs for regular assessment of all the descriptors that are shaping the MSFD. Among the 11 descriptors, incorporating 56 indicators of GES, Descriptor 10 focuses specifically on marine litter. In addition, national policies started to be implemented by various Governments such as the plastic ban of certain products, consumption reduction targets, obligations for producers and awareness-raising measures, among others (UNEP, 2018).

Even with these national and international strategies, the costs of impacts arising from marine litter pollution have been poorly studied (Mouat et al., 2010) and policies regarding this issue are minimal. Marine litter is an avoidable cost and prevention is cheaper than treating the environmental and ecological impacts thus, the countries that

need to prevent marine litter from entering the ocean require improved governance regimes and an investment framework (McIlgorm et al., 2020).

1.3 The Azores Archipelago

The Azores is an Archipelago of nine islands located remotely in the North East Atlantic Ocean. Straddling the WNW-ESE Atlantic middle ridge (37ºN to 40ºN and 25ºN to 31ºW) (Fig. 1), their origin is a result of volcanic activity. The land surface is about 2333 km^2, with 780 km of rocky shoreline and cliffs up to 100-300 m in height. The Archipelago is divided in three main groups; western (Corvo and Flores), central (Faial, Pico, São Jorge, Graciosa and Terceira) and eastern (São Miguel and Santa Maria).

1.3.1. Blue economy

The Exclusive Economic Zone (EEZ) of the Azores has an area of about 1,000,000 km^2 (https://www.marineregions.org/). The large scale of the Azorean seafloor represents 55% of the Portuguese EEZ and approximately 6% of the European EEZ. This region is characterized by a low productivity, typical of oceanic environments (Amorim et al. 2017). Local upwelling and areas rich in nutrients are located around emergent shoals and seamounts along this territory. These features together with specific oceanic currents strongly influenced by the Gulf Stream and its southern multi branched systems, with many unstable meanders and eddies at the Azores front, attract the presence of a high diversity of migratory animals including different seabird species (Morato et al., 2008b).

Fisheries and tourism are some of the main economic sectors in the Azores. The fishery industry is sector that provides many employments for fishermen, haulers and support staff on land, operating with different fishing techniques, characterized by their selective nature and, consequently, their contribution towards the sustainability of marine resources and habitats. Furthermore, tourism is one of the sectors of the regional economy which has the greatest potential for growth, with an impact on income generation and employment. The development of tourism in the Autonomous Region of the Azores is especially worthy of note due to its connection and political and commercial agreements, with diverse other sectors and aspects including maritime activities to environmental and demographic issues.

1.3.2. Previous studies on marine litter pollution in the Azores

The Azores archipelago, with around 250,000 inhabitants, is geographically isolated from large population centres and big industrial areas of the mainland north America and

Europe with populations over 1,000,000 inhabitants. However, recent studies have shown significant abundance of marine litter in various environmental compartments of the Azores, such as on the seafloor (Pham et al., 2013; Rodríguez and Pham 2017), the water surface (Chambault et al., 2018; Herrera et al., 2020) and coastal areas around the islands (Ríos et al., 2018; Pham et al., 2020).

In addition, high occurrence and high levels of plastics are being ingested by loggerhead sea turtles (*Caretta caretta*; Pham et al., 2017) that uses the Azores as a feeding area during juvenile oceanic stages. In addition, in the Azores, at least five commercial fish species belonging to contrasting habitats, from the open ocean and the deep sea, ingest plastics, however with still with low incidence of occurrence (9.43%; Pereira et al., 2020).

2. OBJECTIVE

The objective of my thesis was to assess the direct economic cost of marine litter impacts to remote locations using the Azores archipelago as a case study. To reach this objective, face-to-face interviews were performed in four different islands of the archipelago covering both, sea-users (fishermen, tourist operators and shipping companies) and local authorities (the ones responsible for coastal cleanings). Finally, the results were extrapolated to the entire region using data of the total fleet working in the Azores in 2016 and the potential coastal areas that are cleaned.

The results obtained by this research aim to create the first baseline assessment of impacts and costs associated to marine litter in the region, contributing in the design of preventive cost-effective measures and to raise public awareness about the impact of marine litter.

3. RESEARCH QUESTIONS

1.- Does marine litter pollution cause economic costs to sea-users or local authorities in the Azores archipelago? If so, which are the most frequent problems face by sea-user when impacted by marine litter items?

2.- Does the same typology of items affect sea-users and local authorities responsible for clean-ups of coastal areas?

3.- What is the total direct cost of marine litter for the Azores archipelago?

4.- Are the various stakeholders aware about the problems related with marine litter pollution for the marine environment of the Azores islands?

4. SUMMARY

Despite the size of the Portuguese territorial sea area is about 50,957 Km^2 (third bigger sea territory in Europe and the 11º in the world ranking), Portugal has not yet implemented a monitoring program to understand the costs of marine litter pollution to the economic sectors that are related with sea activities. Indeed, Monteiro et al. (2018) highlighted the scarcity of knowledge on marine litter in isolated oceanic islands, although these places are usually hotspots of biodiversity. Remote islands may be acting as sinks or reservoirs of marine litter, arising the necessity to increase our knowledge about this issue.

Given that marine litter is already affecting various ecosystems and organisms in the Azores archipelago, the general aim of my thesis is to assess whether marine litter in the Azores is also affecting this region economically.

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CHAPTER 2

Socio-economic impacts of marine litter for remote oceanic islands: The case of the Azores

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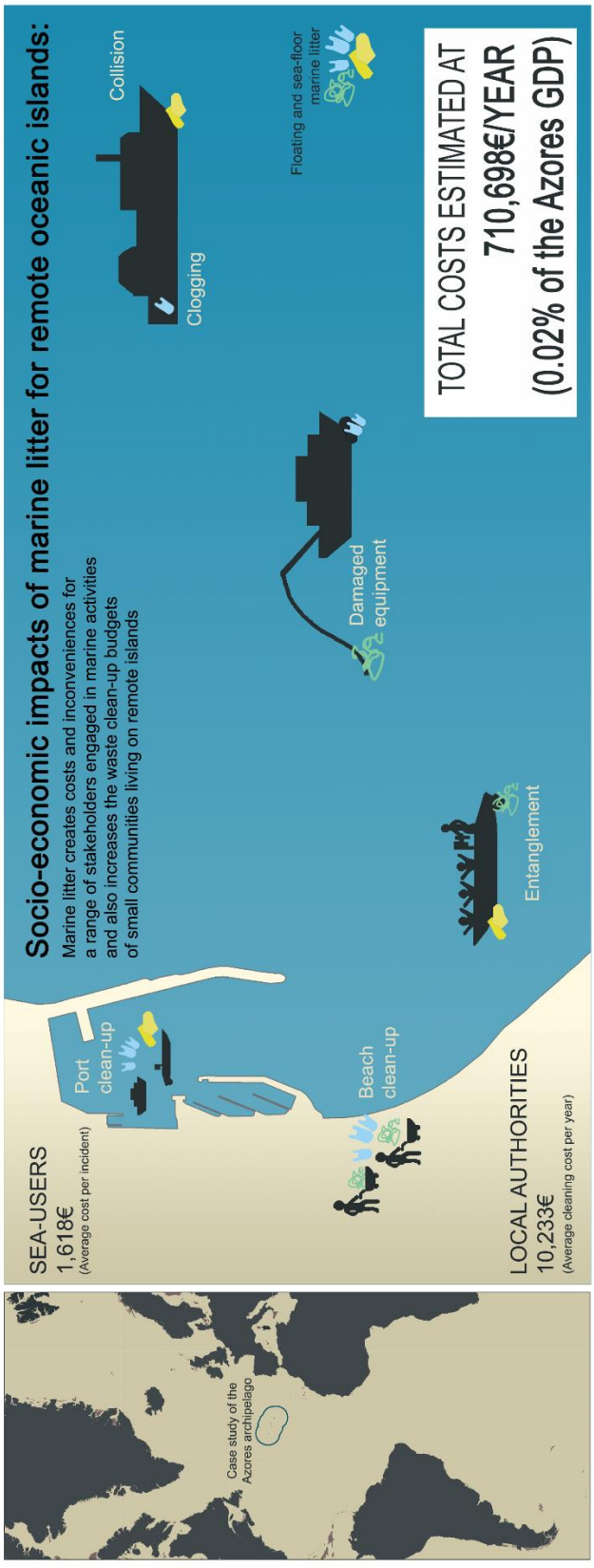
Highlights

- Direct economic costs of marine litter are quantified for a remote archipelago.
- A sea-user spends an average of €1618 (±401, SE) per incident with marine litter.
- Cleaning coastal sites costs on average €10,233 (±3597, SE) per authority/year.
- Marine litter is costing the stakeholders a total of €710,698 (±195,181) per year.
- Marine litter creates costs and inconveniences for a range of stakeholders.

Abstract

Marine litter is present throughout the world's oceans, representing a significant threat to marine ecosystems. While most efforts have focused on assessing ecological impacts, information on the socio-economic dimension of marine litter is scarce. Here we provide a detailed assessment of the direct economic costs of marine litter for a remote region of the North-East Atlantic, the Azores archipelago. Face-to-face interviews were performed to quantify and characterise the costs of marine litter-related incidents and coastal clean-ups to 259 sea-users and 21 local authorities, respectively. Overall, marine litter pollution was estimated to cost a total of €710,698 (±195,181; SD) per year, which is the equivalent to 0.02% of the Gross Domestic Product of the Azores archipelago. Our results demonstrate that marine litter creates costs and inconveniences for a range of stakeholders engaged in marine activities and also increases the waste clean-up budgets of small communities living on remote islands.

Graphical abstract



1. Introduction

Plastic pollution is a serious societal issue for which the impacts are only starting to emerge. Over the past two decades, there have been a virtual explosion of research focussed on quantifying the ecological impacts of plastics in the marine environment with far less attention dedicated to its economic implications (Ryan, 2015; Newman, 2015). However, there is evidence that a wide range of economic sectors are being affected, acting as a significant economic burden for coastal communities, directly impacting tourism, fishing and shipping industries (Hall, 2000; Mouat et al., 2010). For example, in Japan, a study using data from the insurance statistics of the National Fishery Revenue showed that costs associated with marine litter-related incidents, including collisions, entanglements and clogging of water intakes, corresponded to $18.45 million for the fishing industry in 1985 (Takehama, 1989). Similarly, throughout 21 economies of the Asia-Pacific rim, the costs of damages by marine litter on boat propellers and cooling systems of small ships were estimated at $1.26 billion per year (McIlgorm et al., 2011).

Beach clean-ups represent another significant cost for coastal communities. A cross-country study conducted across the EU in 1998 showed that coastal clean-ups accounted for a total of £2.9 million per year, including the collection and transport of marine litter, disposal charges, workforce and equipment (Hall, 2000). In the Netherlands, the tourist Municipality of Den Haag estimated to spend approximately €0.5 million per year to remove marine litter from coastal areas (OSPAR, 2009). Therefore, even for small communities, the expenditures related to marine litter can be significant. Integrating information from various stakeholders (local authorities responsible for clean-ups, fishing industry, aquaculture), Hall (2000) estimated that the economic costs associated to marine litter for the small Shetland island community, north of the U.K, was approximately £5.6 million per year.

Oceanographic models and empirical observations indicate that litter floating at the ocean surface tends to accumulate in the centre of oceanic gyres in so-called garbage patches (Hall, 2000; Mouat et al., 2010; Kühn et al., 2015). As a result, the shores of oceanic islands close to these zones often suffer exceptionally high levels of plastic pollution, despite being located far from major source-areas of plastic waste (Lavers and Bond, 2018; Monteiro et al., 2018; Pham et al., 2020). Such islands are under the influence of large-scale currents that are transporting considerable amounts of marine litter from far away sources (Ryan et al., 2019) and thus are acting as sentinels of global ocean pollution (Barnes et al., 2018).

The Azores archipelago is a remote group of islands of the North-East Atlantic Ocean that is particularly affected by marine litter (Pham et al., 2013; Pieper et al., 2015; Rodríguez & Pham, 2017; Pham et al., 2017; Ríos et al., 2018; Chambault et al., 2018; Pham et al., 2020; Pereira et al., 2020). Notably, a staggering 83% of the sea turtles studied in the Azores were reported to ingest plastic items (Pham et al., 2017). Litter items, composed mainly by plastic, are ubiquitous throughout islands' coastline, with some locations showing densities comparable to highly polluted areas in other parts of the world (Pieper et al., 2015; Ríos et al., 2018; Pham et al., 2020). Furthermore, high quantities of litter items, especially lost or discarded fishing gears, have been observed floating at the surface (Chambault et al., 2018), but also on the seafloor near coastal areas (Rodríguez & Pham, 2017) and on offshore seamounts (Pham et al., 2013).

The objective of this study was to quantify the direct economic impact and cost associated to marine litter for the small-scale economy of the Azores archipelago. The Azores has a large marine territory, where marine-related activities such as fisheries and tourism are among the main pillars for the local economy. Through the use of face–to-face interviews, we provide a detail characterization of the frequency and type of incidents caused by marine litter to major sea-users. With the overarching goal of providing a comprehensive economic assessment for this problem, we also interviewed local authorities to estimate the cost of coastal clean-ups. Finally, we explored stakeholders' perceptions and opinions towards this issue. This socio-economic assessment contributes to a larger research effort aiming at quantifying and characterising the full range of impacts caused by plastic pollution in the Azores region.

2. Material and methods

2.1. Study area

The Azores is a Portuguese autonomous archipelago composed of nine islands and several inhabited islets located about halfway between Europe and North America (36º-40N, 24º-32W) (Fig. 1). This oceanic region is characterized by its volcanic origin, emerging from the adjacent seafloor and extending for more than 600 km along the Mid-Atlantic Ridge. The Azorean population was reported to 242,846 inhabitants in 2018. The largest island (São Miguel) holds about half of the population, while the smallest island (Corvo) has a population of around 465 inhabitants. The economy is mainly based on agriculture (dairy farming), tourism and fisheries.

This archipelago has one of the largest Exclusive Economic Zones (EEZs) of the European Union, with an estimated area of 954,496 km^2. Located in the middle of the Atlantic Ocean, the Azores EEZ is a region hosting a wide diversity of marine species associated with a mosaic of habitats and ecosystems, such as coastal reefs and island slopes, seamounts, harbouring deep-water coral gardens, reefs and sponge aggregations, deep-sea hydrothermal vents and abyssal plains, along with a diverse pelagic fauna.

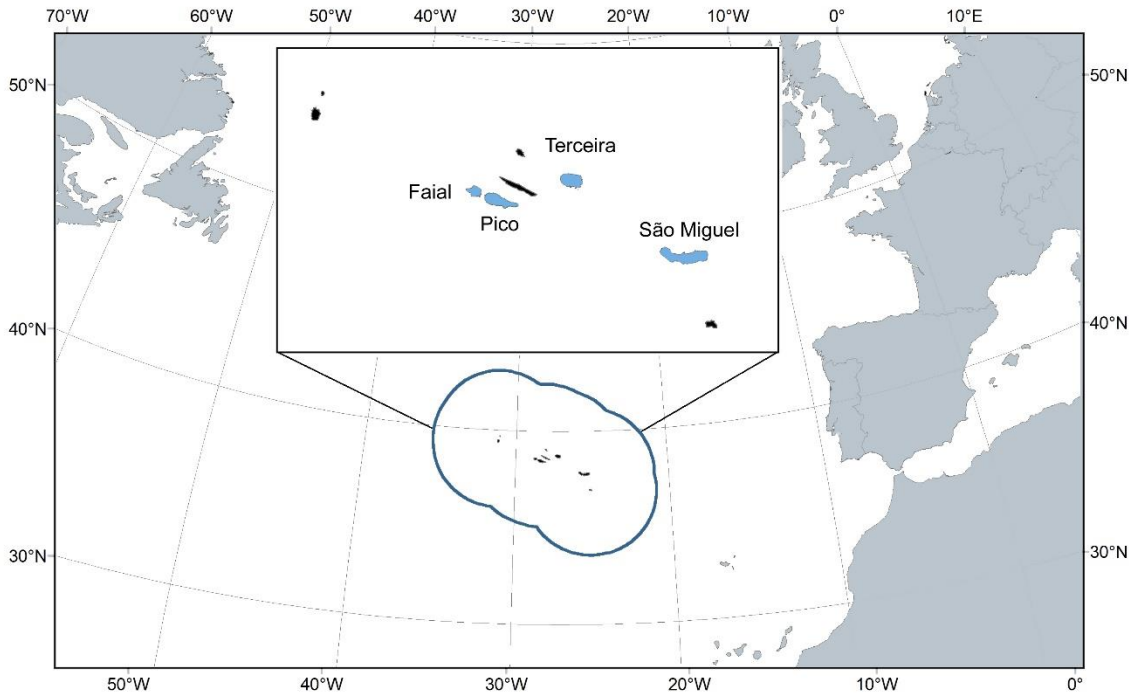


Fig. 1. Location of the Azores archipelago and the four islands where the face-to-face interviews were conducted. Dark blue line delineates to the Exclusive Economic Zone (EEZ) of the Azores territory.

2.2. The survey

Two questionnaire surveys were developed to evaluate the direct socio-economic impacts and costs of marine litter: one directed to fishers, tourist and passenger transportation, hereafter designated as "sea-users", one directed to parish councils, municipalities and harbours, hereafter designated as "local authorities". Interviews sought questions to characterise the economic costs of marine litter-related incidents and marine litter-related clean-ups for 2016.

Following a pilot survey aimed at testing and validating the questionnaires, both surveys were conducted during the summer of 2017. Questionnaires were applied using face-to-face interviews conducted by trained interviewers in four Azorean islands: Faial, Pico, Terceira and São Miguel (Fig. 1). These islands were chosen for the following reasons: (1) they hold the main fishing harbours; (2) they hold around 85% of the total population

of the archipelago and (3) they have most of the sandy beaches that are subject to cleaning actions.

2.2.1. Cost to sea-users

A total of 259 respondents participated in the sea-user survey including professional fishers (n=187), recreational fishers (n=30), marine tourist operators (n=40) and passenger transportation boats (n=2), (Table 1). Therefore, interviews covered from private individuals and companies owing a single boat to commercial operators and companies usually owing multiple boats. Overall, the interviews included 327 boats, corresponding to approximately 14% of the total number of active boats estimated for 2016 (data obtained from the Regional Directorate of Transports of Azores (http://www.azores.gov.pt/Portal/pt/entidades/srtop-drt/), (Table 1). In order to get a representative sample of the fleet operating in the Azores, fishing boats were further divided into three different categories, according to their total length (i.e.: (i) up to 8m; (ii) between 8 and 12m and (iii) larger than 12m (Table 1)) and marine tourist boats were differentiated according to their main use in order to include all the spectrum of the marine tourism activities operating in the Azores (i.e.: (i) whale watching; (ii) diving; (iii) big game fishing and (iv) others (e.g. sailing tours, boat trips) (Table 1)). Transportation included a unique category: passenger transport.

Costs of marine litter-related incidents to all sea-users were assessed using two indicators: money and time. Respondents were asked to characterise each incident during the year 2016 and discriminate all the costs involved in the repair (e.g. money spent hiring people/companies, equipment replacement, time spent removing entangled litter, etc.). When the incidents resulted in the disruption of the operation and/or economic activity, respondents were also asked to estimate the costs associated to the loss of work and/or clients. As a result, the total cost obtained per incidents was divided into two main groups; (i) repair and (ii) loss of work.

The survey also sought information to fully characterise marine litter incidents, this enabled to categorise the type of marine litter related incidents into four main categories: (i) entangled propeller, (ii) entangled fishing gear, (iii) clogged water pump and (iv) collision. It also enabled to categorise the litter items involved in the incidents into the following categories; (i) derelict fishing gear (longlines, ropes, fishing nets etc.), (ii) hard plastic (buckets, crates, etc.), (iii) soft plastic (plastic bags, raffia sacks used for animal feeds, etc.), (iv) processed wood and (v) unknown.

In a historical perspective, respondents were also asked to report information on their worst marine litter-related incident ever experienced throughout their working career.

Table 1. Number of respondents, number of boats assessed, number of boats operating in the Azores and percentage coverage of the interviews for the different groups of sea-users for estimating the socio-economic impacts of marine litter during 2016.

Sea-users	Nº of respondents	Nº of boats assessed	Total nº of boats operating in the Azores	% boats covered
Professional fishermen	187	205	638	32%
Recreational fishermen	30	30	1444	2%
Tourist operators	40	88	275	32%
Shipping companies	2	4	5	80%
Total	**259**	**327**	**2362**	**14%**

2.2.2. Cleaning costs for local authorities

A total of 21 interviews with city and parish council's representatives were carried in three different islands: São Miguel, Terceira and Faial (Fig. 1). Information was obtained for a total of 42 coastal sites, including sandy (62% of interviews) and rocky beaches (28% of interviews), as well as harbours (10% of interviews). The interviews consisted of a semi-structured questionnaire aiming to retrieve information on the frequency and costs of marine litter-related clean-ups in the Azores for 2016. Accounted costs included: number of employees involved, work time (number of days/h per month), materials and equipment used. Employee time was converted into a monetary value by using the minimum wage for the Azores in 2016 obtained from the Regional Statistical Services of the Azores (https://srea.azores.gov.pt/).

2.3. Data analysis

For the sea-users' survey, frequency of occurrence of marine litter-related incidents (%FO) was calculated by dividing the number of boats reporting marine litter-related incidents by the total number of boats assessed. The average number of marine litter-related incidents per boat was obtained by dividing the total number of incidents by the number of boats that reported incidents. Finally, the average cost per incident was calculated by dividing the total cost of incidents by the number of boats that reported incidents.

Differences in the average cost associated with different types of marine litter-related incidents and differences between the repair cost and loss of work were investigated using

the non-parametric Kruskal-Wallis One-Way Analysis of Variance since the data did not follow a normal distribution. The pairwise Wilcoxon rank-sum test was subsequently used as a post-hoc test to examine which type of incident significantly differed from each other. P-values were adjust using the Bonferroni method. Results were considered statistically different with p-values<0.05. Analyses were performed using the statistical software R (R Core Team, 2019).

Extrapolation of the costs of marine litter-related incidents to the sea-users of the Azores region that were not covered by the interviews was calculated by multiplying the total number of fishing boats and marine tourist operators known to operate in the region in 2016 (http://www.azores.gov.pt/Portal/pt/entidades/srtop-drt/) by the average cost of marine-litter related incidents. Finally, total costs for the sea-users operating in the Azores in 2016 was calculated by summing the extrapolated costs with the costs obtained from the interviews. The standard deviation of these parameters was used as a basis for error propagation of final cost estimation. Based on our survey results to municipalities we calculated an average cost of coastal clean-up per site. This value was used to estimate the total cost for the coastal sites in the region that are subject to regular cleaning but that could not be covered in the interviews (n=8).

3. Results

3.1. Cost to sea-users

3.1.1. Frequency of marine litter-related incidents

A total of 95 boats reported incidents from the 327 boats assessed (percentage frequency of occurrence (%FO) of marine litter-related incidents of 29%). The %FO for the different groups of fishermen ranged between a minimum of 20% for recreational fishermen to a maximum of 31% for professional fishermen operating boats between 8 and 12m (Fig. 2). For the activities related to tourism, %FO ranged from 15% for whale watching boats to 47% for big game fishing boats. For the passenger transportation, two out of the four boats reported incidents with marine litter, corresponding to a %FO of 50% (Fig. 2).

Overall, a total of 112 different incidents were reported. The average number of incidents per boat (that reported an incident) was 1.19 (±0.05, SE) throughout the different sea-users, ranging between 1 and 3 incidents per boat per year. No significant differences were found in the average number of incidents per boat between the different sea-users (Kruskal-Wallis: $\chi^2 = 5.76$, df = 8, p-value = 0.67) (Fig. 2).

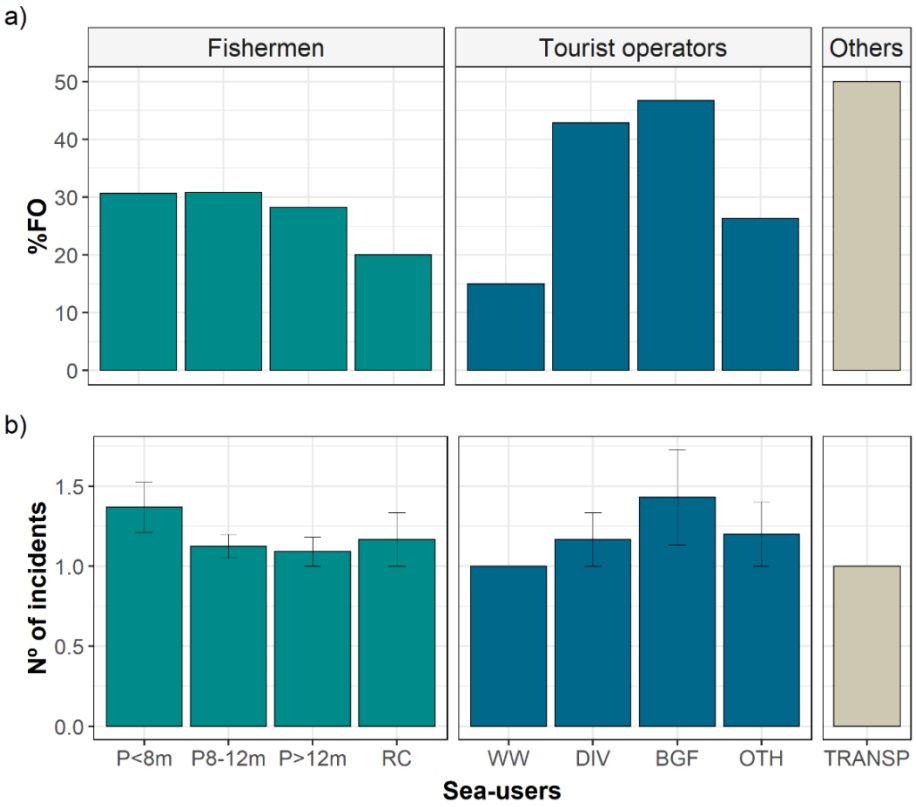


Fig. 2. a) Percentage frequency of occurrence (%FO) of marine litter-related incidents and b) average number of incidents per boat for the different sea-users. Error bars denotes the standard error. P = professional fishermen; RC = recreational fishermen; WW = whale watching, DIV= diving; BGF = big game fishing, OTH = other tourism activities, TRANSP = passenger transportation.

3.1.2. Characterization of marine litter-related incidents

Marine litter entanglement was the most commonly reported incident (92%; Fig. 3), usually occurring in the boat's propeller (68%; n = 76), but also in active fishing gear (24%; n = 27) of both professional and recreational fishers (Fig. 3). Other type of incidents included litter items clogging the water pump (4%; n = 5), affecting all sea-users except recreational fishermen. Collisions (4%; n = 4) were reported by professional fishermen and tourist operators only.

The most frequent category of marine litter causing incidents was derelict fishing gear (78%; n = 87), which was generally associated with propeller entanglements (82%; n = 62). Derelict fishing gear included both, floating items and lost gears trapped on the seafloor. The second most frequent category of litter items causing incidents was soft plastic (16%; n = 18; Fig. 3). Soft plastic was the only type of items reported to cause problems to the water pump in fishermen and tourist operators.

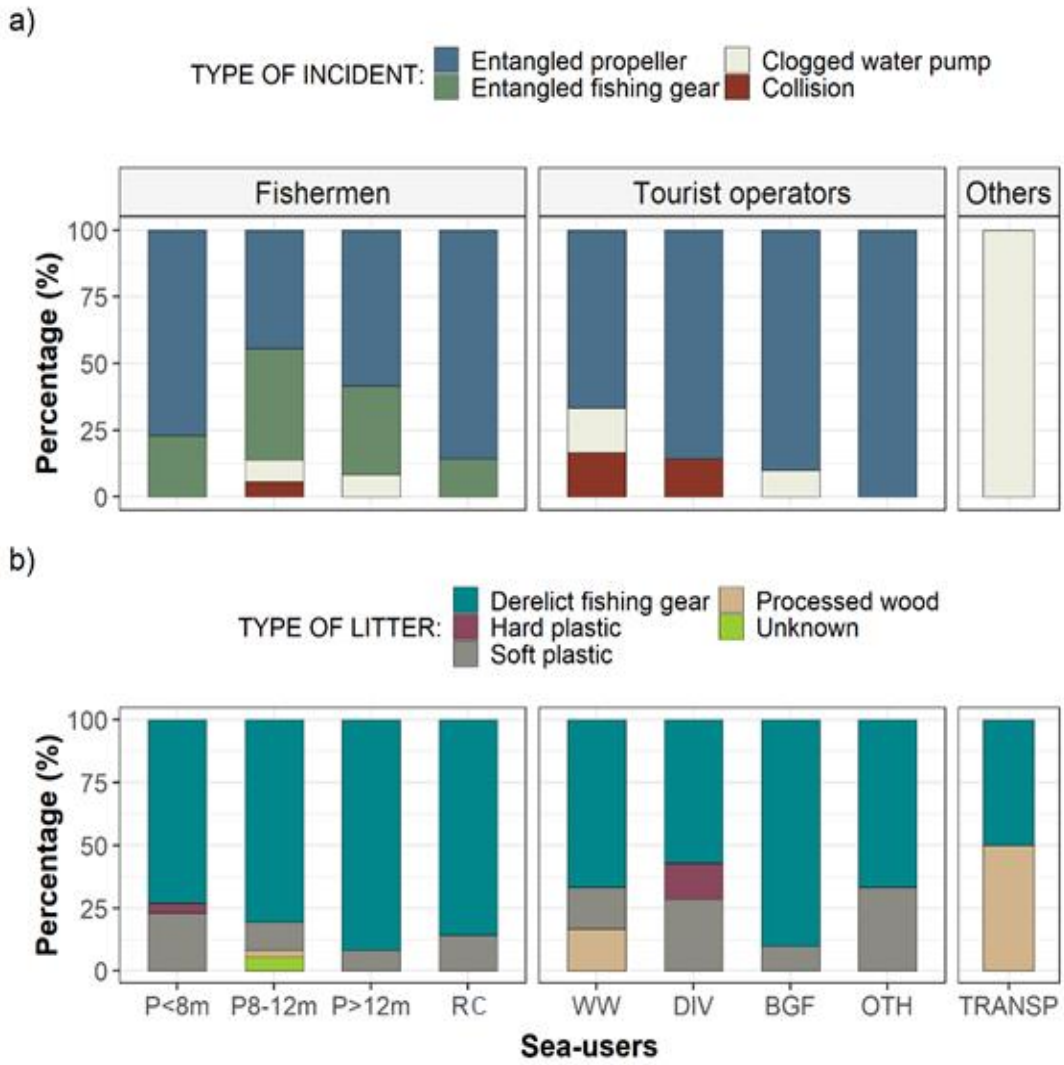


Fig. 3. a) Typologies of marine litter-related incidents reported by the different sea-users assessed during this survey and, b) typologies of marine litter causing incidents to the different sea-users assessed during this survey. P = professional fishermen; RC = recreational fishermen; WW = whale watching, DIV= diving; BGF = big game fishing, OTH = other tourism activities, TRANSP = passenger transportation.

3.1.3. Evaluation of the economic impacts and costs

Throughout the 259 interviews covering 327 boats, the total cost of marine litter-related incidents was €181,208. The total cost of marine litter-related incidents reported by the professional fishermen was €108,630 for a total of 74 incidents, followed by the tourist operators that spent a total of €70,599 euros for 29 incidents. Overall, the average cost per incident was €1618 (±401, SE). We found significant differences in the average costs of marine litter-related incidents between sea-user groups (Kruskal-Wallis: $\chi^2 = 19.23$, df = 8, p-value = 0.014). The groups with the highest average costs per incidents were the whale watching operators with €9458 (±4,106, SE), followed by the professional

fishermen (boats >12 meters) with an average cost per incident of €3741 (±2499, SE; Fig. 4).

The costs of an individual incident ranged from 0.28 cents, when for example an entangled rope was cut from the propeller, losing few minutes to fix the problem, to a maximum of €30,627. This maximum value was suffered by a professional tuna fishing boat (>12 m), for which a soft plastic was pulled into the water pump, causing a direct repair cost of €600 and a loss of 60 of days of work, equivalent to €30,027. The cost resulting from the work lost (average ± SE = 880 ± 317, n = 112) was on average significantly higher (χ^2 = 24.36, df = 1, p<0.001) than the cost associated with the repair itself (average ± SE = 74 ± 17, n = 112), representing 83% and 7% of the total cost, respectively. Loss of work revenue included cancellations of scheduled touristic trips, breaks in fishing activities and delays of passenger transportation.

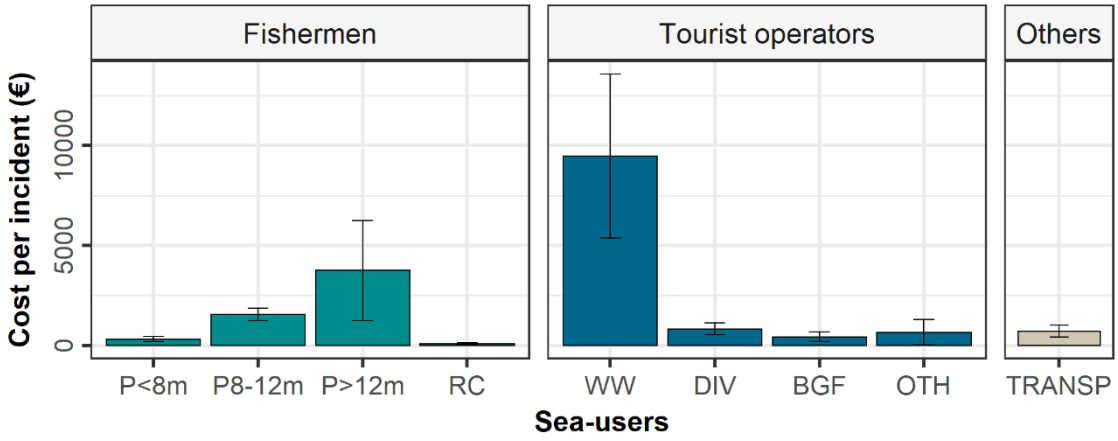


Fig. 4. Average cost of marine litter-related incidents for the different sea-users. Error bars denotes the standard error. P = professional fishermen; RC = recreational fishermen; WW = whale watching, DIV= diving; BGF = big game fishing, OTH = other tourism activities, TRANSP = passenger transportation.

Marine litter entangled in the propeller was the least expensive incident to be fixed with an average cost of €819 (±228, SE) per incident (Fig. 5). The average cost resulting from incidents to active fishing gears was €1599 (±288, SE). The most expensive types of incidents were those related to marine litter clogging the water pump (e.g. plastic bags and ropes), which costs an average of €6461 (±6045, SE), followed closely by collisions with floating litter (e.g. hard plastics and processed woods) costing an average of €6802 (±5618, SE). Whereas problems with the water pump typically resulted in a breakdown of the engine's cooling system it occasionally damaged the seawater system used for maintaining live bait in pole-and-line fishing vessels, collision with marine litter normally

damaged the hull of the boats. Significant differences were found between the average costs of the different type of incidents (Kruskal-Wallis; $\chi^2 = 27.73$, df = 3, $p<0.001$). Post-hoc comparisons using Pairwise Wilcoxon rank-sum test revealed the cost to repair an entangled propeller was significantly lower compared to the other three types of incidents (Fig. 5).

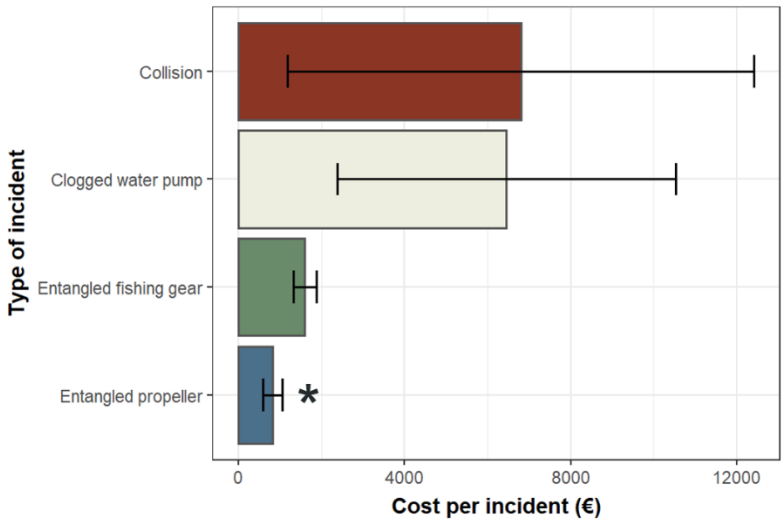


Fig. 5. Average costs estimated for different categories of marine litter-related incidents. The error bar denotes the standard error. Black asterisks represent significant difference.

3.2. Retrospective assessment

A total of 110 incidents were reported by the respondents. Fishing related items (65%, n = 72) and soft plastics (23%, n = 25) were the main typologies of marine litter reported to cause incidents. In a historical perspective, the maximum reported cost associated with a single marine litter-related incident was €59,899. This incident was experienced by a professional fishing boat (8-12m) in 2013 caused by a derelict fishing gear entangled in the propeller during navigation, which dislocated the engine out of its original position and stopped their fishing activity for two months. The second most expensive problem reported by the respondents was also related to a propeller entangled in a derelict fishing gear of a whale watching boat, costing a total of €47,700 in 2015. For this retrospective assessment, litter entangled in the propeller was the most frequent type of incident reported (71%), followed by litter clogging the water pump (16%).

3.3. Cleaning costs for local authorities

Our interviews revealed that the 21 local authorities spent a total of €214,900 to clean marine litter from 42 coastal sites. The average cost of cleaning per local authority was estimated at €10,233 (±3597, SE). Specifically, the average cost of labour force per local

authority was €4442 (±1144, SE) per year. The labour force was higher during the summer months (average ± SE: 2721 ± 494) compared to the winter period (average ± SE: 1003 ± 210), when cleaning is less frequent. The average number of hours per year dedicated to do the clean-ups was 666.36 hours (±130.68, SE) for sandy beaches, 272.83 hours (±60.30, SE) for rocky beaches and 940.16 hours (±470.08, SE) for ports and harbours.

The average cost of equipment per local authority involved in clean-ups was €5791 (±2758, SE) per year. This value also includes specific gear, the maintenance of cleaning machines and the cost associated with the transport of the litter to waste management facilities. This value did not include the purchase of equipment that is used repeatedly over the years, such as cleaning machines used to remove small plastic fragments from the sand during the bathing season. The cost of this equipment was reported to be between €11,000 and €50,670 by the various local authorities interviewed.

3.4. Total estimated cost of marine litter for the Azores region

Overall, the total estimated economic cost of marine litter for sea-users and local authorities adds up to €710,698 ± 195,181 for 2016. This value corresponds to 0.02% of the total Gross Domestic Product (GDP) for the Azores for the same year (GDP: €3,962,000,000, SREA). The total cost of marine litter-related incidents to sea-users was estimated at €471,147 ± 178,696 for all the boat operating in the Azores archipelago during 2016 (Table 2), while the total costs for coastal clean-ups was estimated at €239,551 ± 16,485. These values represent, respectively, 66% and 34% of the total cost of marine litter estimated for the Azores region.

Table 2. Estimated total costs of marine-related incidents in the Azores during 2016.

Sea-users	Activity	Boats operating in the Azores	Nº of boats estimated to suffer marine litter-related incidents	Total estimated costs (€)
Fishermen	Professional fishing (<8m)	309	95	40,576 ± 14,134
	Professional fishing (8-12m)	227	70	121,350 ± 21,063
	Professional fishing (>12m)	102	29	117,412 ± 64,686
	Recreational fishing	1444	289	27,682 ± 15,070

Tourist operators	Whale watching	71	11	100,729 ± 35,700
	Diving	81	35	33,051 ± 10,431
	Big Game fishing	92	34	20,541 ± 10,378
	Another tourist operator	31	10	8053 ± 6,626
Others	Passenger transport	5	3	1754 ± 609
Total		2362	576	**471,147** ± **178,696**

3.5. Social concerns regarding marine litter in the Azores

A total of 93% of the sea-users were highly concerned about marine litter and 64% considered this issue as "very relevant" for both, their professional activities and the welfare of the archipelago. In addition, the majority of sea-users (94%) answered affirmative to the question "we need to pay attention to floating marine litter while sailing". Similarly, local authorities (96%) agreed that marine litter stranded on coastal areas is an "important concern" for the Azores archipelago and half of them confirmed that cleaning efforts increased the cost of human resources and materials. When asked to classify marine litter into a specific problem, the option of environmental concern including harmful effects to organisms was the first selected by sea-users (62%) and local authorities (50%), followed by the option of marine litter as a socio-economic problem by sea-users (12%) and an issue for human health for local authorities (31%). Sea-users classified plastic bags (31%) and fishing-related items (30%) as the most frequent floating items. Local authorities considered plastic bags (32%), but also plastic bottles (32%), as the most frequent typologies of marine litter that is stranding on the Azorean coastlines.

4. Discussion

Our results further demonstrate that marine litter is not merely an environmental issue, but can also have serious economic implications. We showed that marine litter is affecting different economic activities, thus corroborating the evidence of the high diversity of impacts that marine litter can cause to remote islands such as the Azores. The widespread abundance of marine litter stranding on the coastline is forcing local authorities to take action by conducting regular clean-up initiatives, while sea-users are frequently facing incidents with marine litter.

Our results suggest that marine litter is costing the Azores region a total of €710,698 ± 195,181 per year. Sea-users, mainly the fishing community, supported the greatest portion of this economic loss, similarly to what was found for the Shetland Islands (Hall, 2000). However, the total economic cost associated to marine litter in the Azores was

considerably smaller than for the Shetland Islands, evaluated to approximately £5.6 million per year (Hall, 2000). This difference may be related to the different approaches used by both studies and the wider diversity of sea-users operating in the Shetland Islands, which includes salmon farmers, crofters, lifeboat launching, power stations and voluntary labour that are not present in the Azores and whose activities may be more exposed to marine litter-related incidents. In addition, major differences between both results maybe related with the national minimum wages between countries. For example, minimum wages are generally below €600 in southern European countries such as Portugal and above €1400 in northern Europe (Eurostat, 2020). Therefore, direct comparison should take into account the economic reality of each region.

We found that the total cost of marine litter-related incidents and beach clean-ups represented 0.018 of the total GDP of the Azores in 2016. For the APEC region damage due to marine litter pollution was estimated to $10.8bn for a GDP of $44,238bn in 2015, which was 0.024% of GDP without including clean-up costs of coastal areas (McIlgorm et al., 2020). For the Azores, the costs related to marine litter-related incidents (excluding clean-up) represents 0.012% of the total GDP of the Azores, which lies within the range reported for the islands states of the APEC region: 0.008% of GDP in New Zealand, 0.028% of GDP in the Philippines and 0.053% of GDP in Indonesia (McIlgorm et al., 2020). These differences reflect significant variation between island state economies and differences in marine litter levels (McIlgorm et al., 2020).

Entanglement was the most frequent marine litter-related incident reported by sea-users, but the least expensive to be fixed. This result ties well with previous studies, in which entangled ship propellers and lost fishing time were the most common type of problems caused by marine litter in other regions (Hall, 2000; Cho, 2005; McIlgorm, 2009; Mouat et al., 2010; McIlgorm et al., 2011). In addition, our findings demonstrated that derelict fishing gear caused the highest number of marine litter-related incidents, reflecting the results of a recent study reporting that lost fishing gear are abundant at the surface of the Azores EEZ (Chambault et al., 2018).

Fishermen were not only affected by floating litter but also by fishing gear lost on the seafloor, in which they are getting entangled when deploying their own fishing gear. This result reveals the presence of a negative feedback loop whereby the fishermen are suffering the consequences of their own intentional or unintentional discards, sometimes found in high numbers on Azorean fishing grounds (Pham et al., 2013; Rodríguez &

Pham, 2017). Actually, in other regions, fisheries and tourism have been reported to contribute significantly to marine litter (Newman, 2015), whereas simultaneously are the sectors mostly affected by marine litter (e.g. Hall, 2000; Mouat et at., 2010). In the Azores, the contribution of both sectors towards the total emission of marine litter remains unknown.

Professional fishermen with smaller boats reported a higher frequency of occurrence (%FO) of marine litter-related incidents along with a higher average number of marine litter-related incidents per boat per year. Chambault et al. (2018) found the abundance of floating litter to be higher closer to the islands, suggesting that smaller boats operating closer to shore are more exposed to marine litter than larger vessels operating further offshore. Similarly, reports from fishermen in Shetland and Esbjerg determined that small inshore boats appear to be more susceptible to marine litter than large pelagic boats (Hall, 2000). Although professional fishermen with smaller boats (<12m) reported a slightly higher occurrence of marine litter-related incidents, the amount of money spent to fix the incidents was significantly lower compared to professional fishermen operating larger boats.

Throughout the different stakeholders, we found that the economic loss associated with the time needed to fix an incident was more expensive than the cost of repair itself. This issue could be related to the remoteness of the islands, where supporting services and/or equipment are not readily available, significantly delaying any repairing process. Hence, our findings support the idea that remote regions such as the Azores, are particularly vulnerable to marine litter-related incidents. In fact, this was reflected during our interviews, since the stakeholders considered first and foremost marine litter as an environmental and economic issue, demonstrating a real preoccupation for the state of the marine environment by the inhabitants. Similarly, a previous study focused on understanding the perception of the Azorean population about local environmental problems also reported that marine litter was one of the most frequent concerns identified (Ressurreição et al., 2012).

Tourism in the Azores has significantly increased over the past years especially since the National Geographic Traveler magazine awarded the region as being second in the top five island destinations in the world for sustainable tourism in 2008 (Ressurreição et al., 2012). Considering the growing importance of this industry, it will be important to assess if this activity may be eventually affected by marine litter, as already observed in other

locations (Jang et al., 2014, Krelling et al., 2017). For instance, a recent report for the APEC region includes an estimate of the lost opportunity to the marine tourist sector arising from tourists taking holidays at alternative locations due to the perception of high amounts of marine litter (McIlgorm et al., 2020).

Up to now, previous studies assessing the cost of marine litter have based their estimations on insurance statistics (Takehama et al., 1989) and interviews to beach visitors (Balance et al., 2000). Our approach, based on face-to-face interviews to a large portion of the main stakeholders provides a more detailed characterization of the costs of marine litter-related incidents. With the exception of recreational fishermen, which were challenging to encounter, we were able to cover a large fraction of the sea-users and local authorities, making our estimates precise in comparison to other studies. Nevertheless, we acknowledge some level of uncertainty in our final estimates due to the fact that it is likely that not all registered boats were effectively operating during our reference year. We also recognize some uncertainty in the total cost allocated to coastal clean-ups since the level of litter accumulation is highly variable between beaches (Ríos et al., 2018), therefore the resources used for removing litter items are difficult to extrapolate for the beaches not surveyed. Despite the limitations outlined above, the present estimation serves as a valuable baseline on the frequency, cost of marine litter-related incidents, cleaning costs and overall impact for the economy of this region. While the direct economic impacts associated to marine litter investigated herein are relatively easy to quantify, total economic loss caused by marine litter is far more complex to evaluate because it needs to account for the indirect costs associated to the impairment of ecosystem services or biodiversity loss caused by marine litter (Newman, 2015). Although significant advances on the potential impacts of marine litter for some organisms have been made, larger scale ecosystem effects are still largely unknown.

5. Conclusion

This study is the first detailed approach aimed at understanding the magnitude of marine litter impacts for the economy of remote islands in the North Atlantic. Overall, we found that sea-users are often victims of incidents with marine litter and that local authorities have to deal with important costs to maintain their coastal areas clean. With the result of the present and previous studies, it is becoming evident how this region is forced to tackle marine plastic pollution at various levels (e.g., Pham et al., 2017; Pham et al., 2020). Small islands economies generally have a low GDP and thus the costs associated with

marine litter can be significant for a small population, as in the Azores with only 250,000 inhabitants.

Our findings highlight that remote places such as oceanic islands, where the outplacement services and/or money to face problems related with marine litter result in extra costs for the local economy. Moreover, removing litter from coastal areas is forcing isolated archipelagos to deal with more quantities of trash that their waste disposal systems/landfills could support. At some point, this anthropogenic pressure may oblige coastal regions, such as the Azores, to create specific policies and management actions to remove marine litter from the shoreline. In such cases, socio-economic studies on the impacts of marine litter for stakeholders will be crucial to produce effective management plans to reduce the input of litter in the marine environments at the regional and global level. Throughout the globe there is still a limited understanding of the economic implications of marine litter for coastal communities, mostly for those in remote regions. By showing that this problem is even present in a remote oceanic archipelago, we hope to encourage other researchers to perform similar economic evaluations of marine litter in new locations. Since our society is predominantly driven by economic interests, such economic assessments may raise the awareness and help driving future efforts to control the input of litter items at the source, and in parallel, will once more raise the alarm on the consequences of our increasing consumption of plastics.

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