

Evaluating the impact of northwest African upwelling-derived marine litter on animal entanglement in the Canary Islands

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Evaluating the impact of northwest African upwelling-derived marine litter on animal entanglement in the Canary Islands

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Gestión Inteligente y creación del Producto Turismo Azul



Subproyecto 2. Promoviendo la salud oceánica de las Islas Canarias



Abstract:

Marine debris, particularly that derived from fisheries, poses a serious threat to marine ecosystems in the Canary Islands. This study integrates a Lagrangian modeling approach with observational data to investigate the transport routes, origins, and ecological impacts of floating litter, particularly on sea turtles and cetaceans, in three Special Areas of Conservation (SACs): Tenerife, Gran Canaria, and Fuerteventura. Results indicate that the Canary Current, coastal upwelling, and mesoscale eddies play a central role in the advection and seasonal accumulation of marine debris in these regions. Entanglement was found to be the most significant threat to sea turtles (45%), while cetaceans were more affected by bycatch and vessel strikes. Most debris analyzed was plastic, with fishing gear, raffia sacks, and packaging materials being the most frequent. Backward trajectory simulations suggest that a significant portion of this debris originates from northwest African ports. These findings underscore the urgent need to improve marine waste management, implement effective monitoring, and foster international cooperation for mitigating cross-border marine pollution.

Keywords: Marine debris, Lagrangian modeling, Canary Islands, sea turtles, cetaceans, entanglement, plastic pollution, ocean dynamics.

1. Introduction

In 2023, global plastic production reached 413.8 million metric tons (Apete et al., 2024; Statista, 2023). The continued accumulation of debris in marine ecosystems has become an increasingly urgent global concern and poses a significant threat to marine biodiversity (Derraik, 2002; Gall & Thompson, 2015; Stefatos et al., 1999). An estimated 13.8 million metric tons of plastic enter the ocean each year, accounting for approximately 80% of all marine pollution (UNESCO, 2022). It is noteworthy that a considerable proportion of this plastic comes from marine sources (Apete et al., 2024), and it is estimated that 46.4% comes from fishing activities that remain lost in the ocean (GESAMP, 2021).

The Canary Islands are experiencing an increasing accumulation of fishery-derived macroplastics, especially in sensitive marine areas where convergence lines concentrate more than 90 % of floating debris (Campillo et al., 2023). Satellite telemetry and field surveys show that at least 150 fishing vessels continue to deploy driftnets despite the international moratorium, and that 87 % of the ghost nets stranded in the archipelago come from this type of illegal fishing (Cardoso & Caldeira, 2021; Oceana, 2010). Distinguishing European gear made of transparent monofilament bearing the CE mark under Regulation (EU) 2019/1241 (Regulation (EU) 2019/1241 of the European Parliament and of the Council of 20 June 2019 on the Conservation of Fisheries Resources and the Protection of Marine Ecosystems through Technical Measures, 2019) from African gear, made of dark multifilament with Arabic or French markings (Mghili et al., 2020), is key to tracing its provenance. Morocco's fisheries framework, set out in the Coastal Fisheries Law 15 12 (Ministerio de Agricultura y Pesca de Marruecos, 2014) lacks effective measures to prevent the abandonment of nets, especially within the artisanal fleet which represents 70% of the sector (AGRIS, 2025). This regulatory gap, combined with the influence of the Canary Current and subtropical gyres described by several authors (e.g., Hernández-Guerra et al., 2002; Machín et al., 2006; Pelegrí et al., 2005) drives large-scale marine debris transport towards the islands. Lagrangian back-tracking models (Chassignet et al., 2021) confirm the pattern, pinpointing major sources near ports such as Dakhla and Tan Tan (Belhabib et al., 2016).

The persistence of the problem is evidence of the implementation failures of Morocco's "National Marine Litter Plan" (Mejjad et al., 2023), despite the country's accession to the Barcelona Convention (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025a). To reverse this trend, bilateral Spanish-Moroccan agreements are proposed to introduce "Radio Frequency Identification" (RFID) traceability systems in the networks (Gilman et al., 2022), accompanied by cooperation programs to improve port management and develop predictive accumulation models based on ocean dynamics (Maximenko et al., 2012).

Plastic poses a serious environmental threat due to its resistance to degradation, which can last hundreds or even thousands of years (Cole et al., 2011). This persistence constitutes a significant risk to numerous species, such as sea turtles and cetaceans, which often ingest or become entangled in plastic debris, mistaking it for food (Gall & Thompson, 2015). The magnitude of the problem has led to the recognition of marine

debris, in particular plastics, as one of the main threats to ocean ecosystems and the biodiversity they harbor (Gall & Thompson, 2015).

The Canary Islands harbor the highest biodiversity of cetaceans and turtles in European waters (Herrera et al., 2021; Liria-Loza et al., 2021; McIvor et al., 2022), with up to 30 cetacean species recorded (Puig-Lozano et al., 2018). Sea turtle strandings on the Canary coasts are a frequent phenomenon (Camacho et al., 2013), driven by persistent anthropogenic pressures (Orós et al., 2004), including fishing nets and plastics, which cause a 51% of the strandings. (Orós et al., 2016).

In this context, Special Areas of Conservation (SACs) play a fundamental role in safeguarding the marine ecosystems of the archipelago. Established within the framework of the Natura 2000 Network, these areas aim to protect natural habitats and species of community interest by regulating human activities that may threaten their ecological integrity (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025c). In the Canary Islands, several marine SACs such as the Teno-Rasca Marine Strip (Tenerife) (Gobierno de Canarias, 2025b), the Mogán Marine Strip (Gran Canaria) (Gobierno de Canarias, 2025a) and the Sebadales de Corralejo (Fuerteventura) (Gobierno de Canarias, 2025c) have been designated for their ecological importance, serving as key areas for cetaceans and sea turtles in terms of feeding, reproduction, and migratory routes.

Several studies have linked the transport and accumulation of plastic debris to the oceanographic dynamics of the Canary Islands (Cividanes et al., 2024; Vega-Moreno et al., 2021, 2024). The Canary Current is a cold, low-salinity, upper ocean current that flows southwestward along the northwest coast of Africa, from the Iberian region to approximately Cape Verde latitudes (Pelegrí et al., 2005). It is part of the North Atlantic subtropical gyre and originates as a branch of the Gulf Stream, after its transformation into the Azores Current (Valdés & Déniz-González, 2015). This current plays a key role in the transport of temperate waters and coastal upwelling, as its southward movement facilitates the upwelling of nutrient-rich deep waters off the northwest African coast (Mittelstaedt, 1991).

Plastic accumulation in subtropical gyres is notable (Maximenko et al., 2012), as well as in island wake zones (Vega-Moreno et al., 2021, 2024). In addition, mesoscale activity is significant in the Canary Islands region, where a long-lived eddy pathway known as the Canary Eddy Corridor has been identified and characterized in oceanographic studies (Sangrà et al., 2009). This area may enhance the transport and accumulation of marine debris (Vega-Moreno et al., 2021, 2024).

Recent studies have revealed that the Canary Current transports marine debris from the Atlantic Ocean (Cividanes et al., 2024; Liria-Loza et al., 2021) to the Canary Islands. In this context, the accumulation of marine debris in the Canary Islands has been widely documented. Over the past 30 years, detailed records have been kept of the materials involved in entanglements in the Canary Islands (Cardoso & Caldeira, 2021; Herrera et al., 2021; Liria-Loza et al., 2021; Orós et al., 2004).

This study aims to analyze the influence of oceanographic processes, such as the Canary Current, upwelling off northwest Africa, and mesoscale eddies, on the arrival and accumulation of marine debris, using a Lagrangian model coupled with a hydrodynamic model. Additionally, it seeks to characterize the types of marine debris, with particular attention to the origin of fishing gear and its impact on the entanglement of sea turtles and cetaceans in Tenerife, Gran Canaria, and Fuerteventura. Furthermore, it aims to assess the spatial overlap between debris accumulation zones and Special Areas of Conservation (SACs), in order to examine the implications of entanglement events for the ecological integrity of these protected habitats and to inform targeted conservation strategies.

2. Materials and methods

2.1. Study zone

The selection of the study areas was based on criteria of ecological relevance and the availability of data on the presence of marine litter and interactions with sea turtles and cetaceans (Baulch & Perry, 2014; Liria-Loza et al., 2021; McIvor et al., 2022).

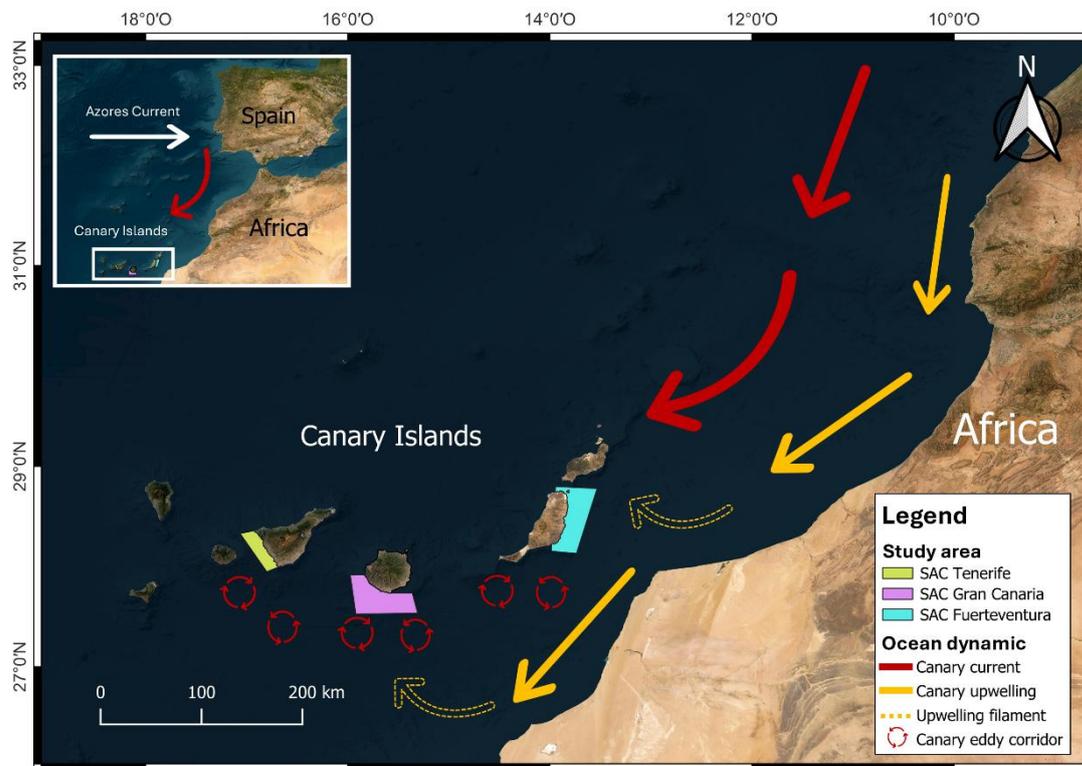


Figure 1. Base map made with QGIS 3.28.11 using images provided by ESRI Satellite. The study area is shown with a green polygon for Tenerife, a purple polygon for Gran Canaria and a blue polygon for Fuerteventura. The red arrows indicate the Canary Current, the orange arrows represent the Canary Coastal Upwelling Current, and the red circles mark the Canary Eddy Corridor.

Special Areas of Conservation (SACs) are areas designated in accordance with Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, and are integrated into the Natura 2000 Network as essential instruments for guaranteeing the survival of habitat types and species of community interest (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025c). In the Canary Islands archipelago, the SACs are of special importance due to their high rate of endemism and the existence of unique terrestrial and marine ecosystems (Consejería de Transición Ecológica, 2025). These areas do not imply a general prohibition of uses, but rather promote sustainable management of human activities through plans that ensure compatibility between ecological conservation and rational economic use of resources (Gestión de Zonas Especiales de Conservación, 2025). In addition, SACs play a strategic role in ecosystem resilience in the face of climate change, acting as reservoirs of biodiversity and regulators of fundamental ecological processes. Three marine SACs are selected to perform our analyses: the Teno-Rasca Marine Strip in Tenerife (green polygon in Figure 1), the Mogán Marine Strip in Gran Canaria (purple polygon in Figure 1) and Los Seadales de Corralejo in Fuerteventura (blue polygon in Figure 1). These locations stand out as priority conservation nuclei for protected species such as cetaceans and sea turtles. The coordinates that delimit these study areas are shown in Table 1.

Table 1. Coordinates of the vertices of the polygons analyzed in Tenerife, Gran Canaria and Fuerteventura.

Island	Point 1	Point 2	Point 3	Point 4	Point 5
Tenerife	28.36° N	28.33° N	27.97° N	28.00° N	-
	16.89° W	17.22° W	17.14° W	16.67° W	
Gran Canaria	28.01° N	28.02° N	27.70° N	27.64° N	27.74° N
	15.82° W	16.13° W	16.19° W	15.43° W	15.37° W
Fuerteventura	28.75° N	28.82° N	28.79° N	28.18° N	28.23° N
	13.73° W	13.74° W	13.14° W	13.25° W	13.93° W

The Teno-Rasca Marine Strip (SAC code ES7020017) covers the western sector of the island of Tenerife, with an area of approximately 69.489 hectares and bathes the coastline of the municipalities of Buenavista del Norte, Santiago del Teide, Guía de Isora, Adeje and Arona. It is also recognized as a Site of Community Importance (SCI) (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025b) and as a Special Protection Area for Birds (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025d). In particular, the Teno-Rasca SAC is recognized as a critical area for cetacean conservation, hosting resident populations of short-finned pilot whales (*Globicephala macrorhynchus*) and bottlenose dolphins (*Tursiops truncatus*), as well as sea turtles such as the loggerhead sea turtle (*Caretta caretta*) (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025c). The high biodiversity of the region, combined with intense maritime and tourist activity, makes it a key area for studying the impact of marine debris.

The Mogán Marine Strip (SAC code ES7010037) is a marine protected area belonging to the Natura 2000 Network, located off the southwest coast of the island of Gran Canaria, in the municipality of Mogán. This SAC occupies approximately 16,370 hectares and extends along a marine corridor of great depth and biodiversity (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025c). The ecological importance

of this area lies in its role as a critical habitat for a remarkable diversity of cetaceans, including resident species such as the bottlenose dolphin (*Tursiops truncatus*) and the pilot whale (*Globicephala macrorhynchus*) (Herrera et al., 2021), as well as migratory species such as the fin whale (*Balaenoptera physalus*) (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025c). In addition, the Mogán Marine Strip is home to sebadales (*Cymodocea nodosa*) underwater meadows that are essential ecosystems for feeding, reproduction, and shelter for juvenile sea turtles (Liria-Loza et al., 2021).

Finally, the SAC Sebadales de Fuerteventura (SAC code ES0000093) was included, a protected marine area that is part of the Natura 2000 Network and is located on the east coast of the island of Fuerteventura, between the towns of Puerto del Rosario and Gran Tarajal (Ministerio para la Transición Ecológica y el Reto Demográfico, 2025c). It covers approximately 1.431 hectares and its main ecological value lies in the extensive presence of sebadales (*Cymodocea nodosa*), a habitat of priority Community interest in the Habitats Directive (Directive 92/43/EEC). The area east of Fuerteventura was selected due to the extensive data collected by the Fuerteventura Marine Debris Observatory, OBAM. This organization has documented a significant accumulation of floating debris and entanglements of marine fauna in the region, mainly attributed to the arrival of fishing gear waste and other debris transported from other regions (OBAM, 2021).

2.2. Backward trajectories

Tracking real marine debris in the open ocean is inherently challenging due to the vastness of the environment, the diversity of debris types, and the lack of continuous in situ observations. To overcome these limitations, virtual massless particles are commonly used as proxies in Lagrangian models to simulate the drift of floating debris. This approach assumes that the synthetic particles follow similar trajectories to real debris under the influence of surface ocean currents, wind-induced drift, and Stokes drift. It also relies on the assumption that the constructed velocity field adequately represents the actual surface flow conditions during the simulation period. Therefore, a velocity field was generated by combining three components: the total ocean current velocity, a wind-induced drift (windage), and Stokes drift. All datasets were obtained from the Copernicus Marine Environment Monitoring Service (CMEMS) and ERA5.

The total ocean current velocity was extracted from the CMEMS product GLOBAL_MULTIYEAR_PHY_001_030, while the Stokes drift velocity was obtained from GLOBAL_MULTIYEAR_WAV_001_032. Wind velocity components were extracted from the ERA5 dataset 'derived-era5-single-levels-daily-statistics', using the u and v components at 10 meters above sea level.

To incorporate wind speed, a scale factor (α) of 0, 0.01 and 0.03 was applied. This component was included to take into account the buoyancy of marine debris that protrudes little above the water surface (0.01), such as fishing nets, and floating items that protrude more above the sea surface (0.03), such as carafes or raffia bags, which are more affected by the drag of the wind. In addition, an alternative model was included in which only the total ocean current velocity was applied, excluding wind-induced drift. The final velocity field was calculated as the vector sum of the three components:

$$V_{\text{total}} = V_{\text{currents}} + \alpha \cdot V_{\text{wind}} + V_{\text{Stokes}}$$

where:

- $V_{\text{currents}} = (u_{\text{curr}}, v_{\text{curr}})$ represents the velocity components of ocean currents,
- α = corresponds to the windage scaling factor (0, 0.01 and 0.03),
- $V_{\text{wind}} = (u_{\text{wind}}, v_{\text{wind}})$ corresponds to wind velocity at 10 meters above sea level,
- $V_{\text{Stokes}} = (u_{\text{Stokes}}, v_{\text{Stokes}})$ corresponds to the components of Stokes drift

All datasets were interpolated onto the ocean current data grid, which has a spatial resolution of 0.083° ($1/12^\circ$), and were temporally resampled to a daily resolution. The distribution of marine litter in the waters of the Canary Islands was examined. To this end, we analyzed its distribution during summer, autumn, spring, and winter. Accordingly, the particle release dates were chosen to represent each season: March 30, 2023; June 30, 2023; September 30, 2023; and December 31, 2023. The year 2023 was chosen as it was the most recent year with available data on entanglements and marine litter.

In this study, a backward-in-time approach was chosen to estimate the potential origin of floating marine debris observed in the coastal waters of the Canary Islands. Unlike forward simulations, which track the fate of particles released from known sources, backward trajectories allow us to identify probable source regions that may have contributed to the debris reaching specific coastal zones. This approach is particularly useful when the point of observation (e.g., accumulation zones or entanglement hotspots) is known, but the origin of the material remains uncertain. By tracing virtual particles backward in time, we can infer the pathways and likely upstream regions responsible for the delivery of marine litter to vulnerable coastal habitats.

Once the velocity field was prepared from the hydrodynamics model, the Lagrangian model OpenDrift was used to estimate backward trajectories. A total of 10,000 particles were released within a region bounded by specific coordinates for each of the islands under study (Figure 1, Table 1), and their trajectories were tracked backward in time over 90 days from each release date, with position updates every 6 hours. These particles serve as proxies to simulate the movement of marine litter of various sizes in response to prevailing oceanic and atmospheric conditions. OpenDrift is an open-source Lagrangian particle-tracking framework that has been widely used in oceanographic studies (Dagestad et al., 2018). More information about OpenDrift can be found on its official website: <https://opendrift.github.io/>. The images generated by the model were further processed using the Matlab program (The MathWorks, 2023).

2.3. Entanglements and marine litter

Published literature was reviewed to identify documented impacts of entanglements on sea marine turtles and cetaceans, using Liria-Loza et al. (2021) and other existing reviews (López Vega et al., 2025; Puig-Lozano et al., 2020; Tortosa et al., 2024) as valuable resources for historical records compiled in Table 2.

Table 2. Bibliographic review of turtle and cetacean entanglements in Tenerife, Gran Canaria and Fuerteventura.

Island	Animal	Year	Individuals	Reference
Tenerife	Turtle	1987-2019	1671	(Liria-Loza et al., 2021)
	Turtle	2024	23	(López Vega et al., 2025)
	Turtle	2018-2020	8	(Tortosa et al., 2024)
	Cetacean	2000-2018	13	(Puig-Lozano et al., 2020)
Gran Canaria	Turtle	1987-2019	1608	(Liria-Loza et al., 2021)
	Cetacean	2000-2018	9	(Puig-Lozano et al., 2020)
Fuerteventura	Turtle	1987-2019	674	(Liria-Loza et al., 2021)
	Cetacean	2000-2018	7	(Puig-Lozano et al., 2020)

The same procedure was applied for the analysis of marine litter, also using the scientific literature available to date (Cardoso & Caldeira, 2021; Herrera et al., 2021; Liria-Loza et al., 2021; Orós et al., 2004). In the specific case of Fuerteventura, data were provided by the OBAM, corresponding to the period 2020-2021. The information related to entanglements and the presence of marine litter was processed and graphically represented using RStudio program (R Core Team., 2023). This analysis made it possible to examine the arrival of marine debris to the coasts of the Canary Islands due to oceanic drift, as well as the threats that such debris represents for turtles and cetaceans in the archipelago.

3. Results

3.1. Types of marine debris registered in the Canary Islands

During the last 30 years, a record has been kept of the material involved in the entanglement of sea turtles and cetaceans in the Canary Islands archipelago (Liria-Loza et al., 2021). The data indicates that approximately 70 % of the marine debris arriving in the islands corresponds to unidentified materials. This is followed, in frequency, by raffia bags (9,1 %) and fishing nets (8,8 %), which represent the types of waste with the greatest impact on these marine organisms (Figure 2). Other materials identified include nylon

fragments (5,2 %), fishing lines (2,5 %) and various objects of marine origin, such as buoys, pots and cages, as well as waste of land origin, such as plastic rings, plastic bags and net bags, which together make up 4,3 % of the total waste recorded.

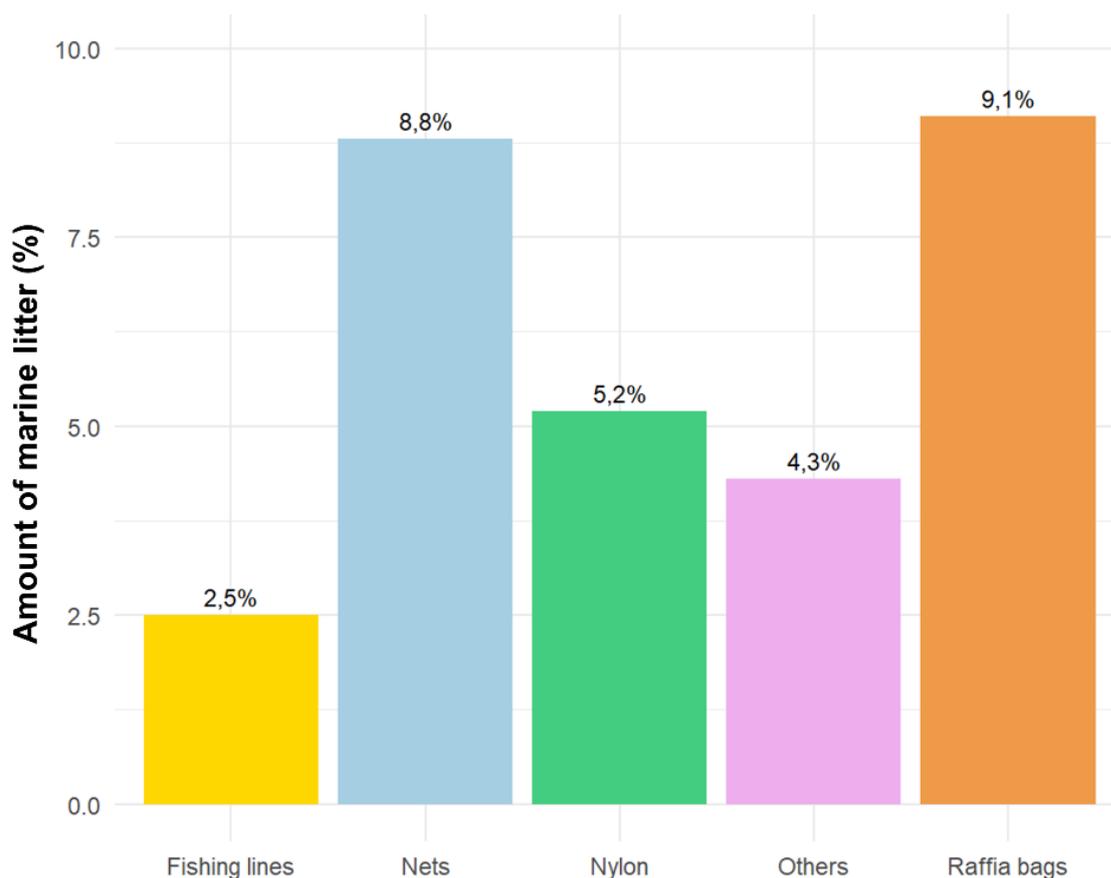


Figure 2. Percentage of marine litter types recorded in the Canary Islands from 1987 to 2020. (Liria-Loza et al., 2021).

3.2. Fuerteventura Observatory of Marine Litter (OBAM)

Data provided by the OBAM were represented (OBAM, 2021), which recorded a total of 28 tons of waste collected during the period 2020-2021, of which 70 % corresponded to plastic materials. In the analysis of marine litter collected by OBAM, a total of 445.023 items were identified within the eight most frequent types of waste. These included 7.966 fishing nets, 44.208 caps and plugs, 22.198 items classified as glass, 20.620 cigarette butts, 15.833 bottles and carafes, 14.554 bags and wrappers, 14.056 cans and 9.558 miscellaneous products. The latter include wipes, ear buds and other personal hygiene items (Figure 3).

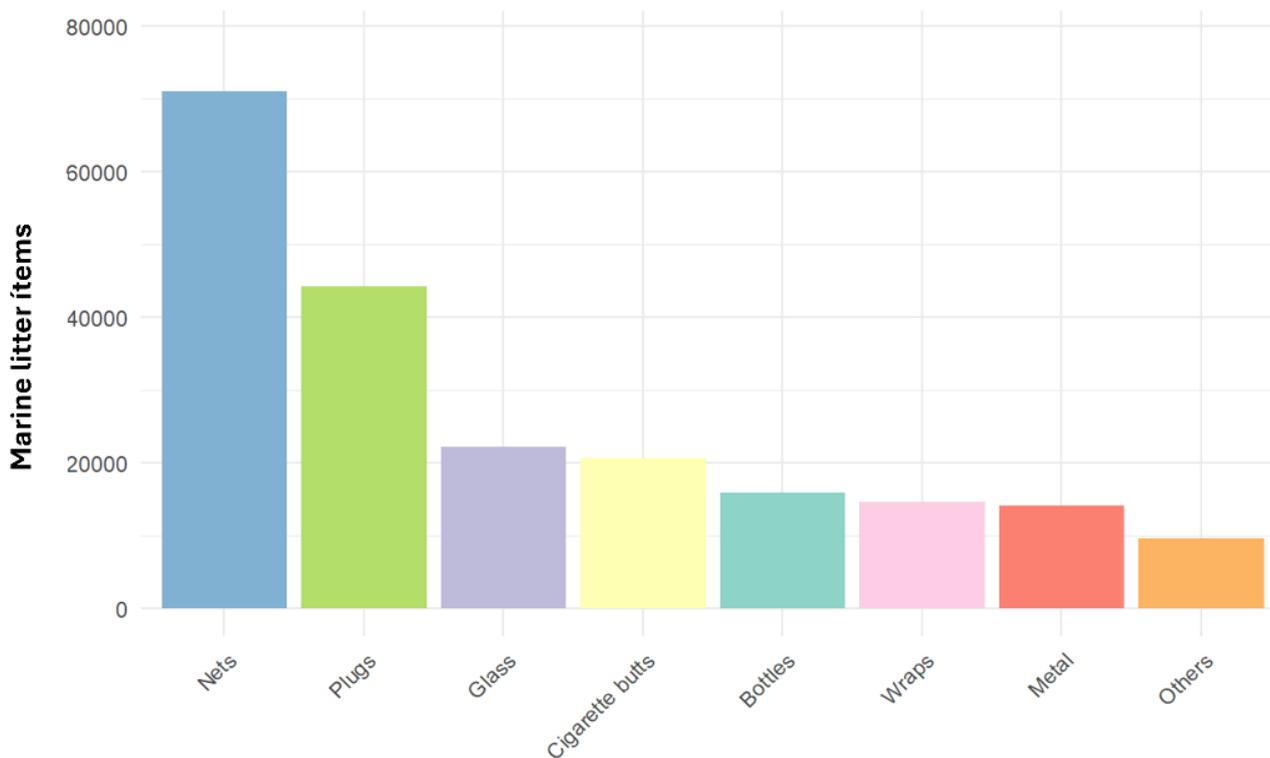


Figure 3. Classification of marine litter collected by the Fuerteventura Marine Litter Observatory between 2020 - 2021 (OBAM, 2021).

3.3. Main threats to marine turtles and cetaceans in the Canary Islands

An analysis of the data on sea turtle and cetacean entanglements in the Canary Islands archipelago, collected between 1987 and 2020 and shown in Figure 4, was carried out. In the case of cetaceans, 23 entanglement events were recorded in the Teno-Rasca marine strip (Tenerife), 9 in the Mogán strip (Gran Canaria) and 7 in the seadales of Fuerteventura, all of which occurred between 2000 and 2015. Regarding sea turtles, 1.702 cases were documented in the Teno-Rasca strip, 1.608 in the Mogán strip and 674 in the seadales of Fuerteventura, with records comprised between 1987 and 2019.

Additionally, a spatial analysis of the areas with the highest accumulation of marine litter, indicated by dashed lines in Figure 4, was performed. The results show that the areas with the highest concentration of debris coincide with the Special Areas of Conservation (SAC) on the islands of Tenerife and Gran Canaria. However, in the case of Fuerteventura, the main area of garbage accumulation is located in the south of the island, outside the limits of the established SAC.

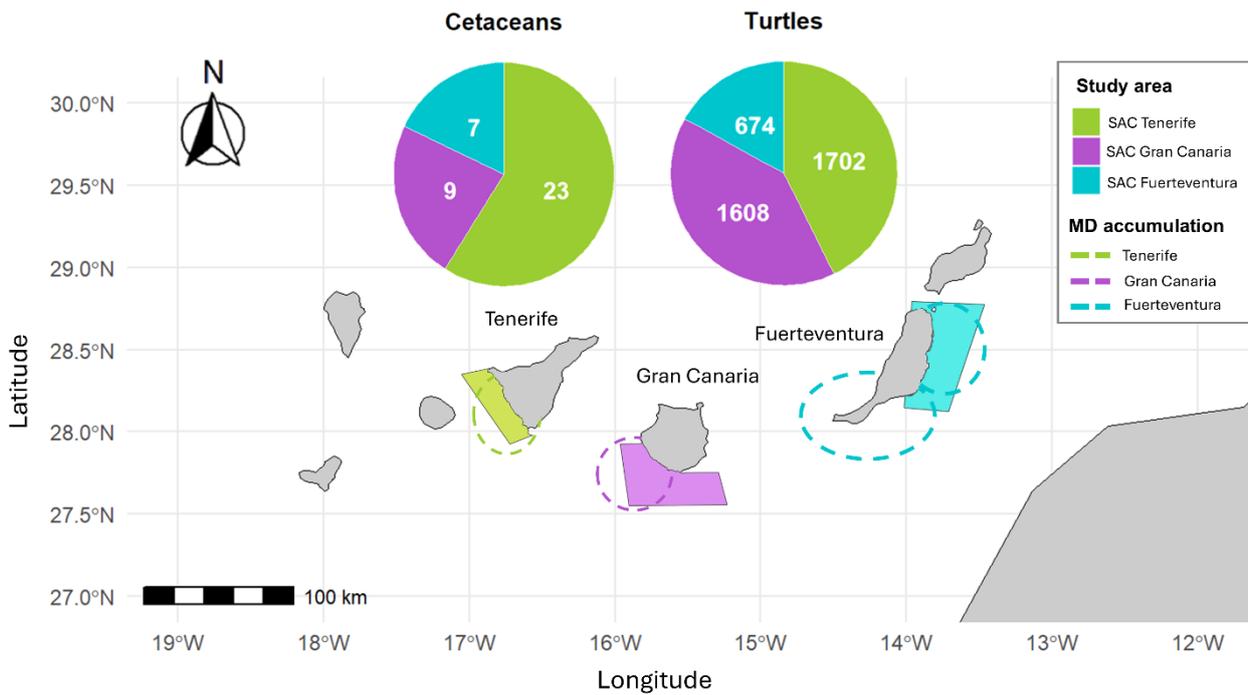


Figure 4. Cases of sea turtle and cetacean entanglement recorded in Tenerife (green), Gran Canaria (purple) and Fuerteventura (blue). The colored polygons represent the Special Areas of Conservation (SAC) that make up the study areas. The dashed lines indicate the main areas of marine debris (MD) accumulation on each island. Data were obtained from 1987 to 2020.

Figure 5 shows the main threats to cetaceans and sea turtles in the Canary Islands with data collected between 1987 and 2020. In the case of cetaceans, the most frequent threats were bycatch (35%), collisions with vessels (25%) and entanglement (15%), while diseases, undetermined causes, spills and other factors presented a lower incidence (10%, 7%, 5% and 3% respectively). On the other hand, in sea turtles, entanglement was the predominant cause, representing 45% of the cases, followed by undetermined causes (20%), diseases, incidental capture, collisions and other threats, all with percentages lower than 15% (11%, 10%, 4%, 8% respectively). These results reflect that, although both taxonomic groups face diverse threats of human origin, entanglements critically affect sea turtles, while in cetaceans, risks related to fishing activities and maritime traffic predominate.

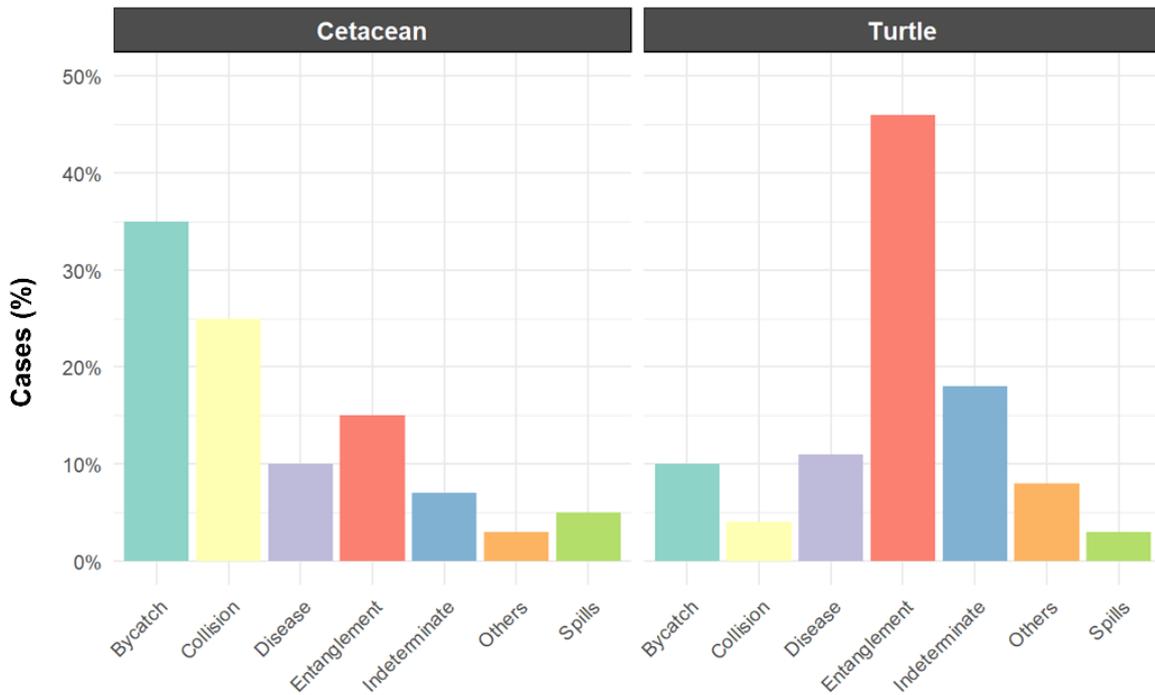


Figure 5. Percentage of the main threats to turtles and cetaceans in the Canary Islands from 1987 to 2020.

Figure 6 illustrates the seasonal distribution of localized entanglement events. For sea turtles, the highest proportion occurred during the summer months, accounting for 40% of the recorded cases, followed by spring (25%), winter (22%), and autumn (13%). In contrast, cetacean entanglements were most frequent in spring (70%), with lower occurrences in winter (10%), summer (12%), and autumn (8%).

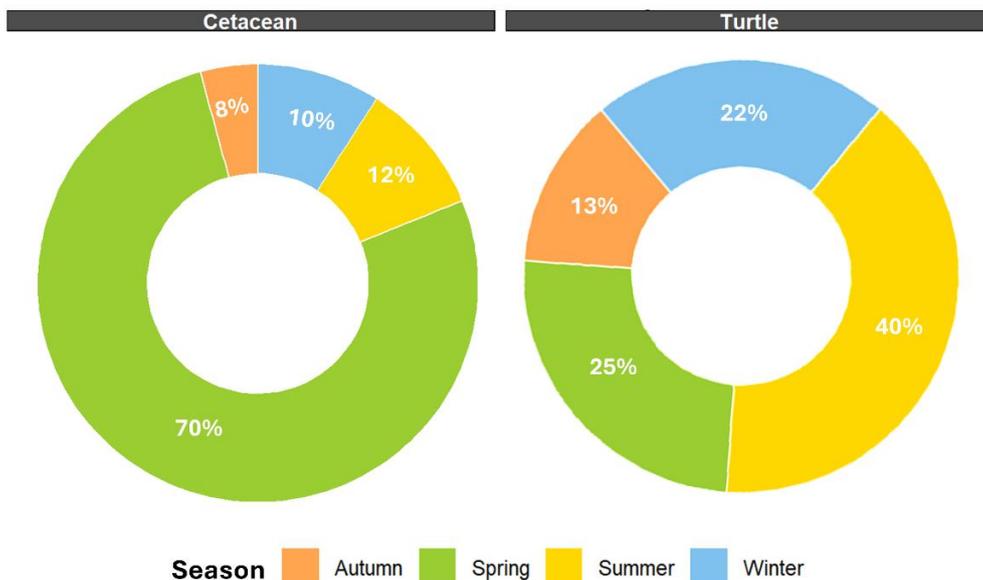


Figure 6. Seasonal distribution of sea turtle and cetacean entanglements found in the Canary Islands between 1987 -2020.

3.4. Backward trajectories

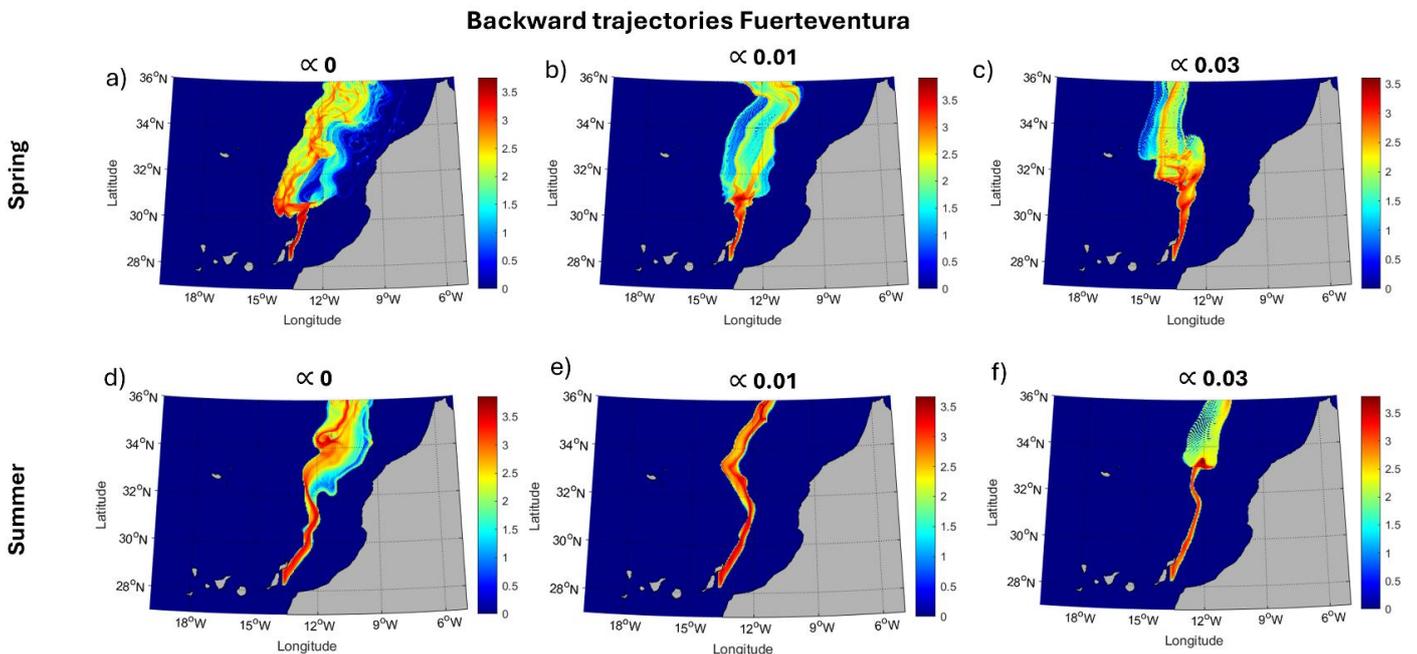
The backward trajectories for the 4 seasons of the year (spring, summer, autumn and winter, respectively), under 3 cases of windage (α), are presented in Figure 7 (Fuerteventura), Figure 8 (Gran Canaria), and Figure 9 (Tenerife). A windage of 0 corresponds to floating particles that do not protrude the water surface, such as sunken nets, without exposure to the wind, and a windage of 0.01 corresponds to bloom particles that are partially exposed, such as fishing nets and some containers, and a windage of 0.03 represents objects with a higher buoyancy and a higher wind exposure, such as canisters or raffia sacks.

3.4.1. Backward trajectories from Fuerteventura

For the case of Fuerteventura (Figure 7), the results show that the backward trajectories predominantly follow a North-South direction, indicating an influence of the currents associated with the subtropical gyre and the African upwelling system. The spatial dispersion and the source of the residuals vary according to the season and the windage value.

For the cases (a-f) corresponding to the spring and summer months, the backward trajectories present a more centered and linear configuration towards Fuerteventura, especially in the cases of $\alpha = 0$ and $\alpha = 0.01$, the particles present a greater displacement from higher latitudes ($\sim 34 - 36^\circ\text{N}$). In contrast, for an $\alpha = 0.03$, the particles origin show a larger drift to the Northeast.

For cases (g-l), which correspond to the autumn and winter months, a greater dispersion in the backward trajectories is observed, especially for $\alpha = 0.01$ and $\alpha = 0.03$. In autumn, the trajectories tend to bifurcate eastward, indicating that the particles originate from more continental areas of North Africa. In contrast, during winter, the trajectories are more consistent and concentrated, suggesting a more localized and less variable origin.



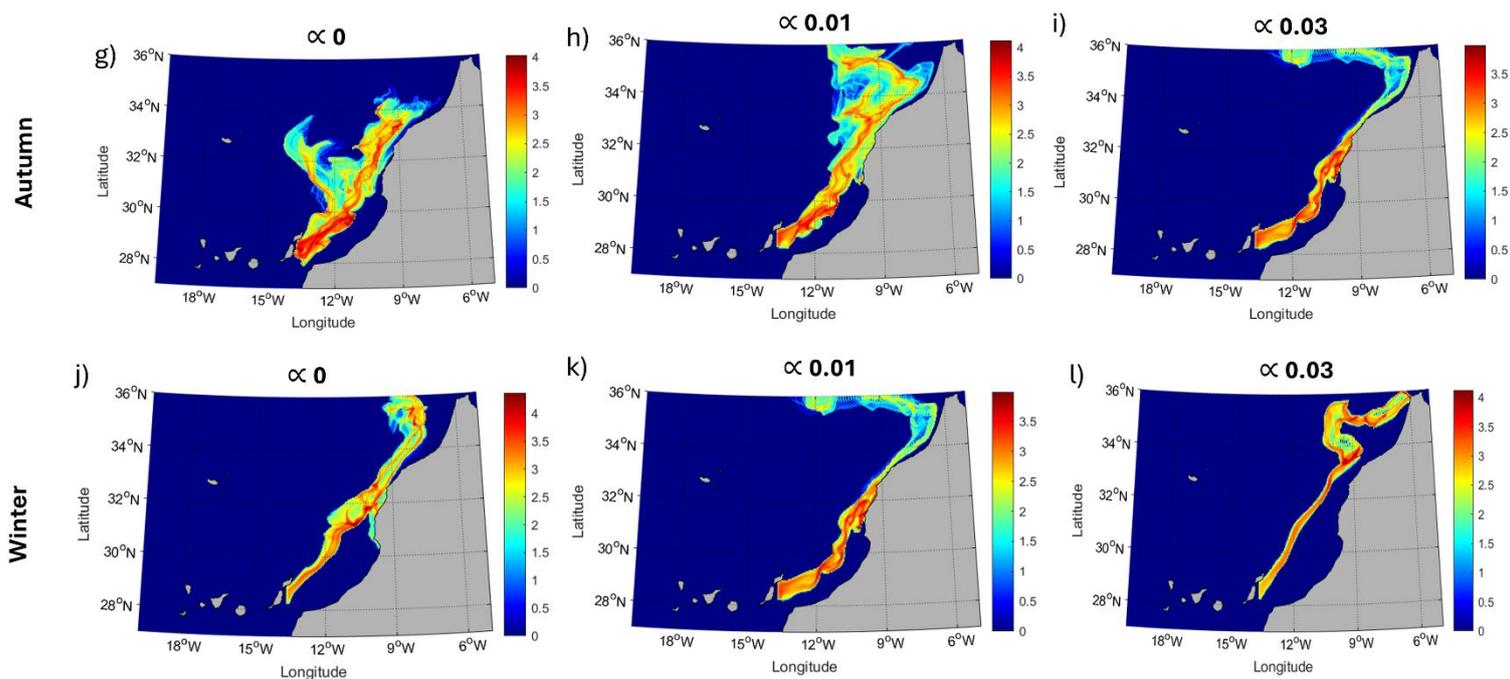


Figure 7. Backward trajectories from the study area in Fuerteventura for the 4 seasons (spring, summer, autumn and winter) and for 3 windage cases ($\alpha = 0$, $\alpha = 0.01$ and $\alpha = 0.03$). The color bar indicates the number of particles passing through that zone on a logarithmic scale.

3.4.2. Backward trajectories from Gran Canaria

Figure 8 shows the particle backward trajectories from the Mogán marine strip. In general, they follow a north-south orientation, although seasonal differences and differences according to the windage value are observed.

Figure 8 shows the cases corresponding to spring (a–c). For a windage of 0, the particles originate from a broad and dispersed area of open ocean west of the archipelago. For $\alpha = 0.01$, the origin is concentrated between approximately 34° and 36°N, also in the open ocean. In the case of $\alpha = 0.03$, the backward trajectories indicate that the particles come clearly from the northeast, that is, from open waters in the central North Atlantic.

During the summer months, corresponding to cases (d–f), the backward trajectories show that the particles mostly originate from the north, that is, from the northeastern Atlantic Ocean, especially for $\alpha = 0$ and $\alpha = 0.01$. In the case of $\alpha = 0.03$, there is some lateral dispersion, but the predominant origin is from the northwest, still in open ocean waters.

In the cases of autumn (g–i) and winter (j–l), for $\alpha = 0$, the particles originate from areas close to the release point, though with greater dispersion in winter, always from surrounding oceanic waters. For $\alpha = 0.01$ in winter, the trajectories show an origin near the northwest coast of Africa, whereas in autumn, the particles come from more distant and scattered regions of the open Atlantic Ocean. For $\alpha = 0.03$, in both autumn and winter, the trajectories are more defined, with particles originating from areas east of the archipelago, close to the northwestern African coastline.

Backward trajectories Gran Canaria

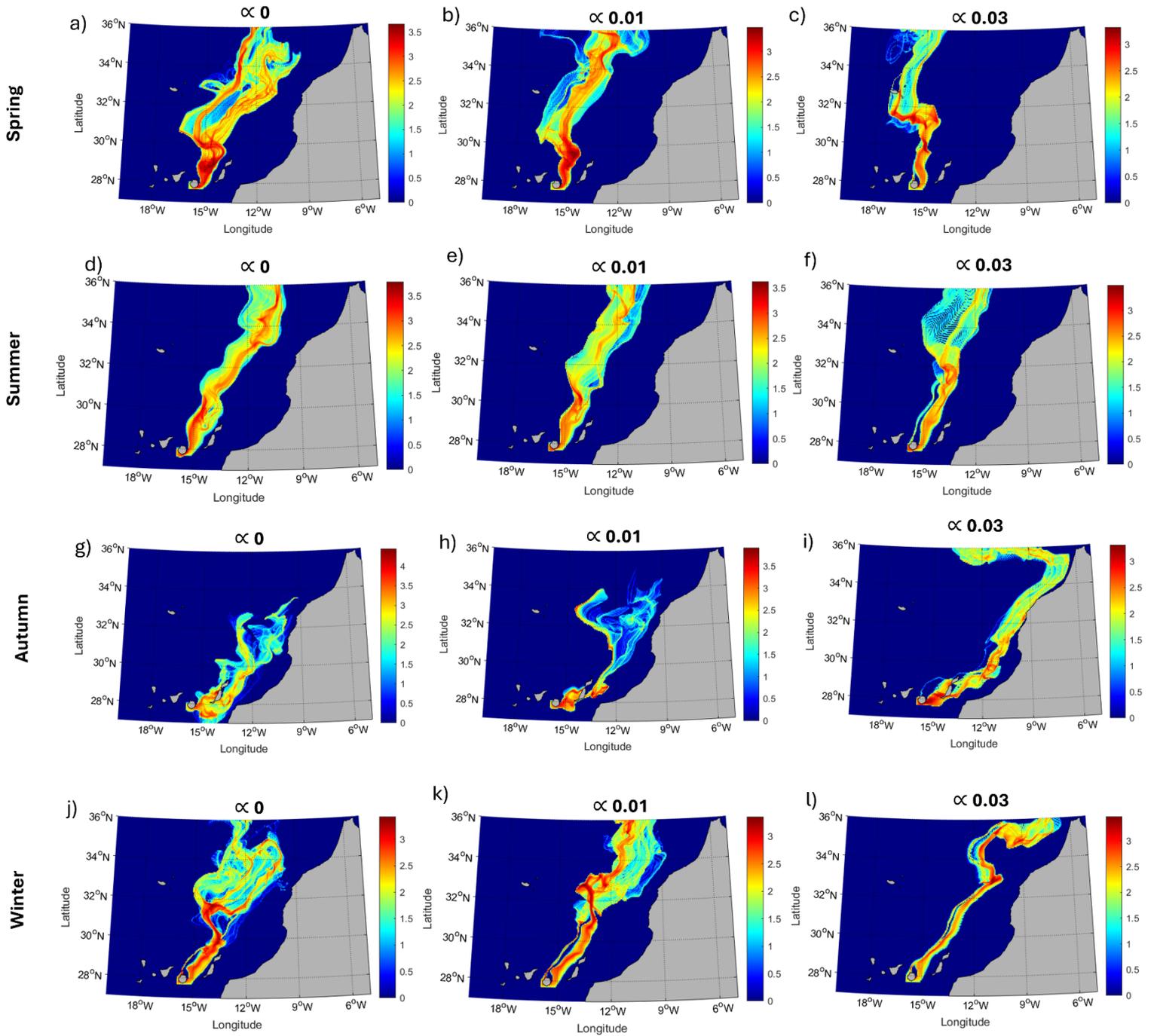


Figure 8. Backward trajectories from Mogán Marine Strip in Gran Canaria for the 4 seasons (spring, summer, autumn and winter) and for 3 windage cases ($\alpha = 0$, $\alpha = 0.01$ and $\alpha = 0.03$). The color bar indicates the number of particles passing through that zone on a logarithmic scale.

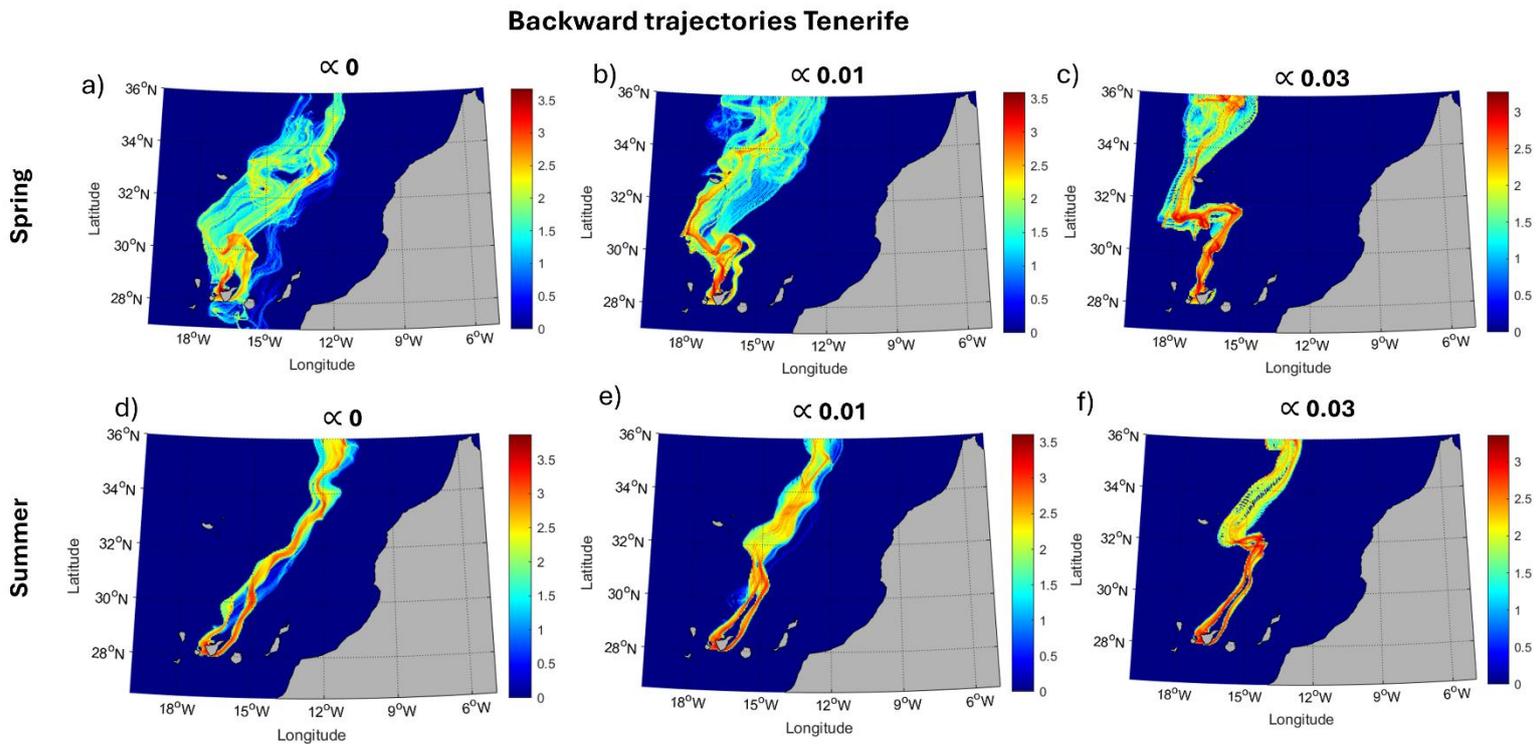
3.4.3. Backward trajectories from Tenerife

For the case of backward trajectories from Tenerife, an initial model was developed, with the results presented in Annex I. This model shows that the particles do not leave the study area, indicating that this region acts as an accumulation zone for marine debris.

In order to identify the possible origin of the particles, the release area around Tenerife was slightly expanded westward. The results are shown in Figure 9, where a clear seasonal variation can be observed. During the spring months (a–c), greater particle dispersion is seen for windage coefficients $\alpha = 0$ and $\alpha = 0.01$. In contrast, for $\alpha = 0.03$, the particles tend to be more concentrated. In all three cases, the trajectories head north of the Canary archipelago, from the coast of Madeira.

In summer (d–f), the trajectories appear more concentrated and well-defined, moving from the nearest areas of the African continent toward the Canary archipelago. This pattern holds across all three windage scenarios.

In autumn (g–i), for $\alpha = 0$, the particles are widely dispersed and do not follow a clear trajectory. However, for $\alpha = 0.01$ and $\alpha = 0.03$, the particles follow more clustered and well-defined routes from the African coast. During winter (j–l), most particles remain near the Canary coast, particularly close to the release point. The exception is the case of $\alpha = 0$, where slightly greater dispersion is observed across the archipelago.



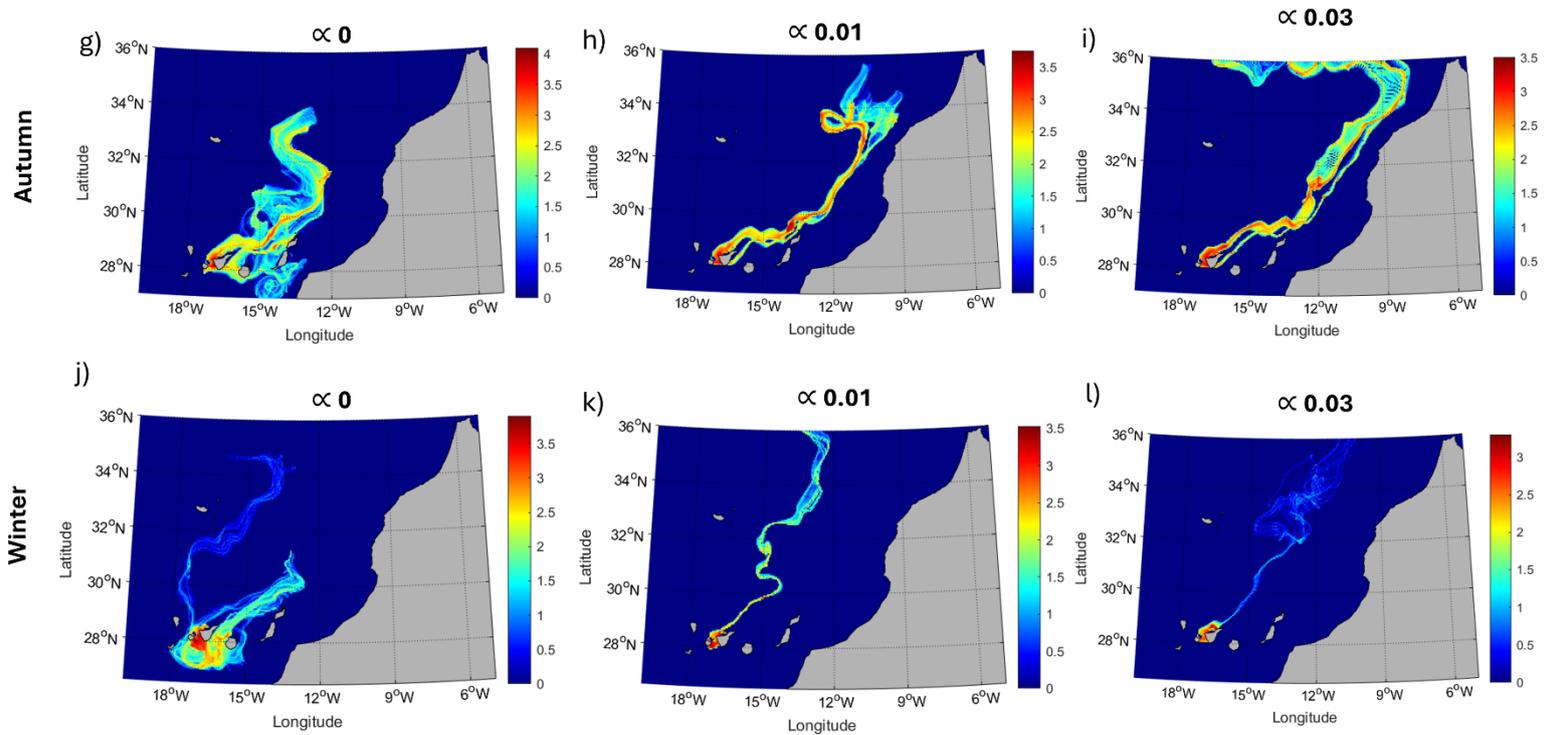


Figure 9. Backward trajectories from the Teno-Rasca marine fringe in Tenerife for the 4 seasons (spring, summer, autumn and winter) and for 3 windage cases ($\alpha = 0$, $\alpha = 0.01$ and $\alpha = 0.03$). The color bar indicates the number of particles passing through that zone on a logarithmic scale.

4. Discussion

The sustained increase in plastic waste in the marine environment not only represents an urgent environmental threat but also provides an alternative pathway to study the physical processes of the ocean. Floating debris from fishing activities, such as abandoned fishing nets, can be regarded as unintentional markers that allow the tracking of surface transport routes driven by ocean dynamics. In this study, such debris was used as a tracer within a Lagrangian backtracking approach from various coastal points in the Canary Islands, aiming to identify their potential source regions. This strategy enabled the analysis of how ocean currents, eddies, and the African upwelling system contribute to channeling and concentrating floating litter around the islands. Thus, what initially constitutes an environmental problem also becomes a valuable tool for understanding the mechanisms governing oceanic circulation in the region. At the same time, these findings underscore the need to strengthen prevention policies in source countries and to promote more effective and coordinated management of marine debris at the regional scale.

An analysis of the types of marine debris collected between 1987 and 2019 by Liria-Loza et al. (2021) revealed that a significant proportion of the materials involved in entanglement cases could not be identified, accounting for approximately 70% of the total. This finding is consistent with the records documented by Gall & Thompson (2015) and Puig-Lozano et al. (2020) and reflects a common limitation in stranding studies,

where recovered debris often shows a high degree of fragmentation or deterioration. Nevertheless, among the identified items, raffia sacks (9,1%) and fishing nets (8,8%) stood out, both of which are widely recognized in the literature as major contributors to entanglements in marine species, particularly sea turtles and cetaceans (Baulch & Perry, 2014; Gall & Thompson, 2015).

In this context, recent data provided by OBAM reinforce this diagnosis. During the 2020–2021 period, 70% of the collected debris was composed of plastics, with a high prevalence of fishing nets, bottle caps, bottles, and wrappers. These results not only reflect the persistence of certain types of floating debris but also their potential impact depending on their physical behavior at sea. Some objects, such as fishing nets, have intermediate buoyancy (Rios-Fuster et al., 2023), allowing them to drift for extended periods (*floating*), which increases the likelihood of interaction with marine fauna (Lofty et al., 2024). Other lighter items, or those with greater wind exposure, may travel longer distances before beaching on shorelines or shallow coastal zones, which also influences their availability to cause entanglement (Van Sebille et al., 2020). This dual behavior, prolonged floating or beaching, complicates management efforts and underscores the need for preventive measures that address both source reduction and active monitoring in accumulation areas.

The analyzed data on threats affecting sea turtles and cetaceans in the Canary Islands archipelago reveal distinct patterns between the two groups. In the case of sea turtles, entanglement stands out as the primary impact factor, accounting for 45% of the recorded cases. In contrast, among cetaceans, incidental capture (35%) and vessel collisions (25%) are the leading causes, with entanglement ranking third (15%). These results are consistent with findings reported by Puig-Lozano et al. (2020), who identified interactions with fishing gear as one of the main causes of cetacean strandings in the Canary Islands, particularly in areas with high fishing activity.

For sea turtles, several studies have highlighted entanglement as a critical global threat, with direct effects on mobility, feeding capacity, and survival (Domènech et al., 2019; Gall & Thompson, 2015). The high proportion observed in this study reinforces this concern, especially in a context like the Canary Islands, where the convergence of ocean currents and the accumulation of marine debris increase the likelihood of interactions with floating objects. The particular vulnerability of turtles to this threat may be related to their coastal movement patterns and high exposure to floating debris hotspots, as documented in the region by Liria-Loza et al. (2021) and Orós et al. (2004).

In cetaceans, although entanglement represents a significant threat, the data suggest that human activities related to maritime traffic and industrial fishing pose an even greater risk. Previous studies have shown that ship strikes are one of the leading causes of mortality in large cetaceans, such as fin whales and sperm whales (Jensen et al., 2003; Laist et al., 2001). While incidental capture recurrently affects dolphins and other coastal species through non-selective fishing gear (Read et al., 2006).

The analysis of entanglement cases recorded between 1987 and 2020 reveals that sea turtles have been the most affected group, with over 1600 incidents documented on the islands of Tenerife and Gran Canaria. In comparison, only 29 cetacean entanglement cases were recorded during the same period. This marked difference may be related to several factors, including the ecological behavior of the species, the frequency with which

they use coastal habitats, and especially the higher probability of detection in stranded turtles. Turtles, spending more time at the surface and near the shore, are more likely to be found and reported, whereas many entangled cetaceans may die offshore and remain undocumented (Gall & Thompson, 2015; Orós et al., 2004; Read et al., 2006).

The high incidence of entanglements in Gran Canaria, followed by Tenerife, may be influenced by multiple factors, including human population density, fishing activity in surrounding waters, and the intensity of maritime traffic. Moreover, these islands contain marine debris accumulation zones (Cardoso & Caldeira, 2021; Vega-Moreno et al., 2021) that spatially coincide with protected areas such as Special Areas of Conservation (SACs), suggesting a direct threat to priority ecosystems and protected species.

The seasonal analysis of entanglement cases showed that sea turtles are most affected during the summer, accounting for 40% of recorded incidents, while cetaceans exhibit the highest entanglement rates in spring, with 70% of the cases. These differences may be linked to biological and ecological factors specific to each group, such as migration patterns, seasonal distribution, and reproductive behavior, as well as the temporal dynamics of floating debris, as documented in previous studies (Baulch & Perry, 2014; Puig-Lozano et al., 2020).

In the case of sea turtles, it has been observed that *Caretta caretta* uses the waters around the archipelago as a migratory corridor and foraging area during the warmer months, following long migrations from the Caribbean and other regions of the Atlantic (Liria-Loza et al., 2021; Marcovaldi et al., 2010). Their increased presence in summer coincides with higher sea surface temperatures and greater food availability, which may explain the higher frequency of encounters with marine debris during this season. As for cetaceans, while some species reside year-round in the Canary Islands, such as the short-finned pilot whale (*Globicephala macrorhynchus*) and common bottlenose dolphin (*Tursiops truncatus*) (Herrera et al., 2021), spring months bring migratory species like the fin whale (*Balaenoptera physalus*), which travels northward along trophic migration routes (Aguilar & García-Vernet, 2018). This seasonal increase in marine activity overlaps with areas where floating debris accumulates due to seasonal currents, consequently elevating entanglement risks.

On the other hand, these seasonal peaks in entanglement may also be associated with anthropogenic factors. Spring and summer coincide with the high tourism season in the Canary Islands (Instituto Canario de Estadística (ISTAC), 2025), leading to a substantial increase in maritime traffic, particularly from recreational vessels, tourist excursions, and water sports activities (Lloret et al., 2008; Katsanevakis, S., 2008). Moreover, there may be an underestimation in the recorded data, as entanglement cases were primarily reported by observers. The actual number of animals becoming entangled along the coasts of the Canary Islands remains unknown. This limitation is not exclusive to the region and reflects a broader trend documented at the global level. For example, the UK: Marine Conservation Society (2019) points out that entanglement data worldwide are often based on opportunistic sightings and documented strandings, which can lead to a significant underestimation of the true extent of the problem. Many animals affected by marine debris die offshore or go unnoticed, and published estimates typically reflect only those areas where systematic monitoring has been implemented. Therefore, the true scale of

entanglement is likely much greater than reported figures suggest, highlighting the urgent need to improve monitoring systems and expand reporting efforts in a more structured and continuous manner.

Virtual Lagrangian trajectories have been widely used by numerous authors to study the exposure, distribution, and transport of marine pollution (Delpeche-Ellmann & Soomere, 2013; Liubartseva et al., 2018; Van Sebille et al., 2015, 2020), demonstrating their effectiveness as a complementary tool to fieldwork (Werner et al., 2007). In this study, the application of Lagrangian backtracking models in the islands of Fuerteventura, Gran Canaria, and Tenerife made it possible to identify that a significant proportion of the floating debris reaching the shores of the archipelago originates from North Africa. The predominant north-to-south direction of the trajectories, along with the seasonal variability and differences in windage coefficients, confirms the decisive role of oceanographic conditions in the accumulation of marine litter. This retrospective modeling approach has proven especially useful in clarifying the entry routes of debris into sensitive areas and enhances our understanding of ocean connectivity, in line with previous studies conducted in similar contexts (Cardoso & Caldeira, 2021; Mohtar et al., 2018).

The predominant north-to-south orientation of the trajectories, along with the observed seasonal variability, demonstrates how changes in atmospheric and oceanographic dynamics influence the arrival of floating debris. For example, during summer and spring, seasons in which higher rates of entanglement are recorded, the trajectories are more linear and directed toward the islands, suggesting greater transport efficiency from the African coastline. This result is consistent with the work of (Delpeche-Ellmann & Soomere, 2013; Liubartseva et al., 2018). Who notes that warm seasons favor the accumulation of floating plastics in insular areas due to weaker dispersion systems and stronger surface currents.

In the case of Fuerteventura, the backtracking simulations revealed moderate dispersion and a marked influence of upwelling filaments from the African coast, consistent with previous oceanographic studies identifying the island as a natural receptor of debris carried by the coastal flow (Sangrà et al., 2009; Vega-Moreno et al., 2021). In Gran Canaria, the dispersion was broader, especially under high windage conditions ($\alpha = 0.03$), suggesting that debris with greater wind exposure, such as bottles and raffia sacks, may follow more erratic and longer trajectories. This behavior was described by (van Sebille et al. (2020), who distinguish between low-buoyancy particles that mainly follow marine currents and high-buoyancy debris that is strongly influenced by wind and waves.

For Tenerife, initial models revealed that debris tends to remain trapped within the study area, acting as an accumulation zone. However, when the spatial domain was expanded, the backtracking trajectories showed links with areas near Madeira and the African coast, depending on windage coefficient and season.

Overall, these findings confirm that the trajectories of marine debris are strongly influenced by physical drivers such as prevailing currents, eddies, and wind, but also by the intrinsic properties of the debris itself (buoyancy, shape, and size). This retrospective approach, based on inverse trajectories, has proven to be highly effective in inferring likely source regions, complementing strandings studies and field-based debris

characterization (Cividanes et al., 2024). Furthermore, it provides a valuable framework for developing seasonal accumulation forecasts and guiding preventive actions at critical source areas, such as the ports of Dakhla and Tan Tan, previously identified as major entry points for fishing-related debris (Belhabib et al., 2016; Mejjad et al., 2023).

For future research, it would be advisable to extend the temporal coverage of the Lagrangian modeling to include longer historical series, enabling the identification of long-term trends in the arrival of marine debris. Likewise, the incorporation of high-resolution data on fishing activities in African waters, obtained through tracking systems or the implementation of RFID technologies in fishing gear, could significantly improve the traceability of debris origins. Additionally, satellite sensors or drones could be integrated for the remote detection of debris accumulations, which would allow for model validation and enhance response capacity during high-concentration events. Furthermore, it would be beneficial to establish active collaboration programs with source ports in Morocco and Mauritania, including awareness campaigns and training for local fishers, aimed at reducing the loss and abandonment of fishing gear at its source.

5. Conclusions

This study highlights that marine debris, mostly of fishing origin, poses a critical threat to marine wildlife in the Canary Islands, particularly around Tenerife, Gran Canaria, and Fuerteventura. Sea turtles were the most affected group, accounting for 45% of reported entanglements, mainly caused by fishing nets and raffia sacks, whose intermediate buoyancy prolongs interactions with marine fauna.

Entanglements showed clear seasonality, likely linked to species migration patterns and increased human activity during the peak tourist season. Backward Lagrangian simulations revealed connections with potential source regions along the African coast, especially in spring and summer, though significant inputs were also detected in autumn and winter. Particle trajectories showed a predominant north–south transport pattern driven by the Canary Current and coastal upwelling. Fuerteventura showed strong links to African upwelling filaments; in Gran Canaria, debris followed more scattered and erratic paths; and Tenerife initially acted as an accumulation zone, with sources potentially extending to Madeira and the African coast. Most debris documented was marine-sourced and closely linked to fishing activities. Data from the Fuerteventura Marine Debris Observatory and literature reviews confirmed the long-term persistence of plastics in the region and the lack of effective mechanisms for their retention or degradation, exacerbated by weak enforcement of policies such as Morocco’s National Marine Debris Plan. The ecological implications are of great importance. Entanglement of sea turtles and cetaceans, especially during spring and summer, remains a frequent threat. The overlap between seasonal accumulation zones and designated Special Areas of Conservation (SACs) raises concern about the exposure of vulnerable species to unmanaged transboundary pollution. While SACs offer legal protection for critical habitats, upstream pressures driven by ocean dynamics can undermine conservation efforts without coordinated political action.

In conclusion, this study emphasizes the need to integrate physical oceanography with ecological and policy perspectives to fully understand the dynamics and impacts of marine debris. International cooperation, particularly between Spain and Morocco, is essential to implement traceability systems such as RFID for fishing gear, improve waste management in ports, and develop predictive tools based on ocean circulation. The overlap of plastic accumulation zones with protected areas underscores the urgent need to strengthen monitoring systems, establish bilateral agreements with source countries, and adopt integrated prevention and management strategies. Only through such coordinated approaches can effective mitigation strategies be developed to safeguard biodiversity and the ecological integrity of the Canary Islands and the wider Macaronesian region.

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ANNEX
ANNEX A

Backward trajectories Tenerife

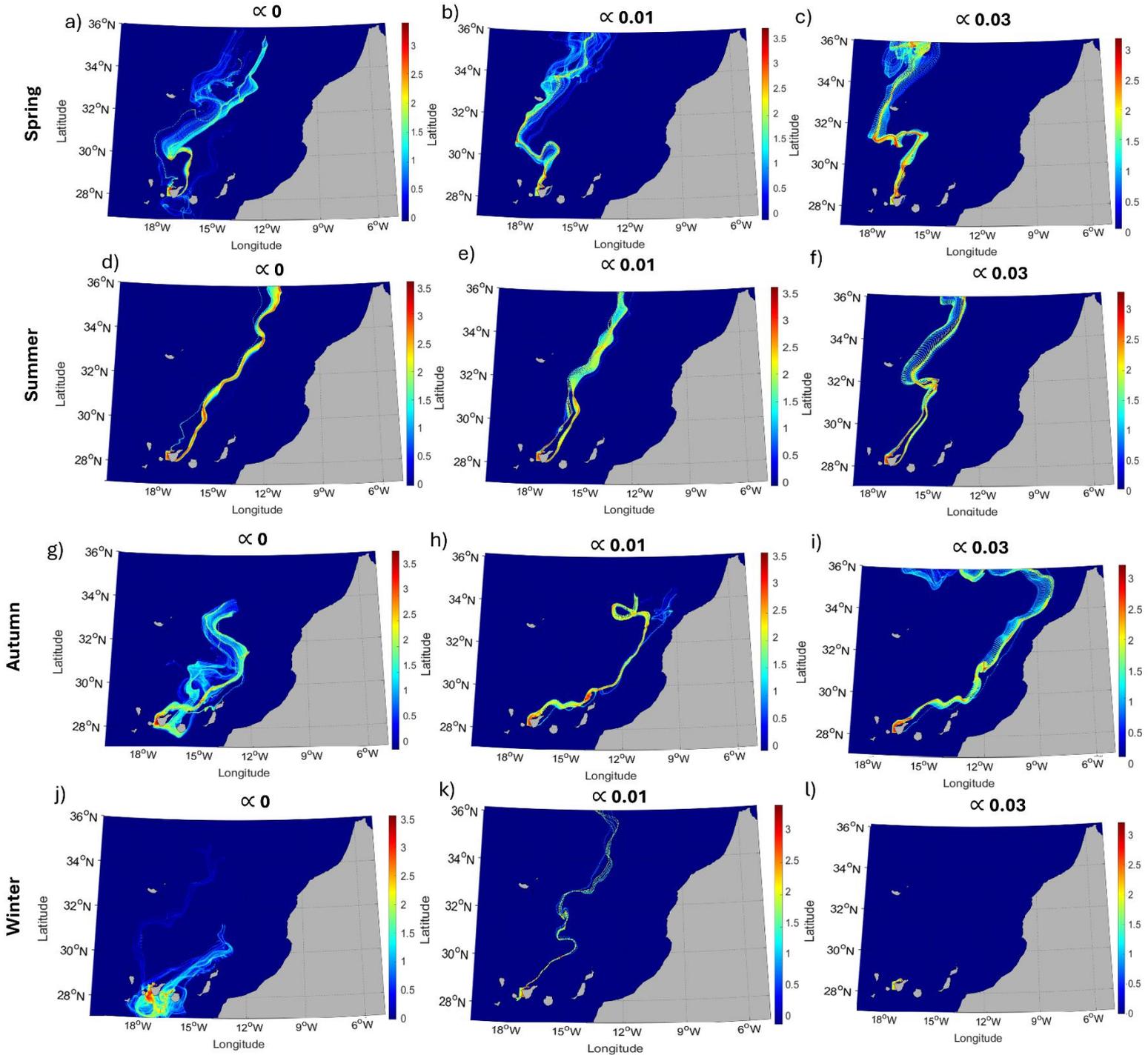


Figure A1. Backward trajectories from the Teno-Rasca marine fringe in Tenerife for the 4 seasons (spring, summer, autumn and winter) and for 3 windage cases ($\alpha = 0$, $\alpha = 0.01$ and $\alpha = 0.03$). The color bar indicates the number of particles passing through that zone on a logarithmic scale.