Short Communication

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# A first assessment of marine litter on a beach of an uninhabited island in the Mozambique Channel

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## Abstract
Marine litter is ubiquitous and associated with both ecological and socio-economic consequences. Beaches are major sinks of marine litter and as such its assessment and monitoring are needed. An opportunistic marine litter survey was performed for 12 consecutive days on the island of Juan de Nova in the central Mozambique Channel in February 2007. Plastic dominated the marine beach litter with daily accumulation of plastic positively related to the tide height ($R^2$ = 0.768, p<0.01). Annual deposits could reach an average of 1 $t.km^{-1}$, suggesting that regular cleaning of the coastline should be conducted to limit the impact on the local wildlife of this protected area.

**Keywords:** marine debris, plastic pollution, daily accumulation rate, Indian Ocean, Juan de Nova

## Introduction
Marine litter consists of any persistent, manufactured or processed solid items deliberately discarded or accidentally lost, and that end up in the marine environment (UNEP, 2009). Plastics dominate marine litter comprising at least 85 % of total waste (UNEP, 2021). The amount of marine litter and plastic pollution has been growing rapidly and therefore has become one of the biggest challenges in the environment worldwide (Geyer *et al*., 2017). Emissions of plastic wastes into aquatic ecosystems are projected to reach approximately 12,000 Mt by 2050 without meaningful action (Geyer *et al*., 2017; UNEP, 2021). The scale of marine litter and plastic pollution are putting the health of the world ocean at risk, and as such their monitoring has become crucial to improve mitigation strategies (Galgani *et al*., 2019).

Marine beach litter is of great concern as it forms one of the main sinks of marine litter (Onink *et al*., 2021), it can cause damage to coastal wildlife (Kühn *et al*., 2015) and has socio-economic consequences (Newman *et al*., 2015). On beaches, most studies have demonstrated densities in the range of 1 $item.m^{-2}$ except for very high concentration due to local conditions (Galgani *et al*., 2015). Marine beach litter found at a given inhabited site is often of local origin, but in remote uninhabited islands, debris accumulating on the coast is usually transported over long distances by ocean currents (Onink *et al*., 2021; Vogt-Vincent *et al*., 2023). The regular monitoring of litter accumulation on beaches is the most common approach to reveal long-term patterns, cycles of accumulation and its origin (Ryan *et al*., 2009; Pieper *et al*., 2021).

Varying methods are used to investigate and quantify marine litter, which makes it difficult to draw a quantitative global picture of beach litter distribution (Galgani *et al*., 2015; Smith and Turell, 2021) and the total amount of beached plastic debris (Onink *et al*., 2021). At the scale of the beach, depending on the characteristics of various abiotic factors like wind or tide, the accumulation of the different components of the litter can vary drastically (Cesarano *et al*., 2023).

In addition, the sampling frequency can significantly influence estimates of the rate of litter accumulation (Smith and Markic, 2013; Ryan *et al*., 2014; Barnardo *et al*., 2020).

Marine litter is not limited to areas that are densely populated, but it reaches the most remote parts of the world, including uninhabited islands (Ryan and Watkins, 1988; Barnes *et al*., 2009; Onink *et al*., 2021). Due to its ubiquity in oceanic and coastal ecosystems, efforts to document marine litter are necessary to contribute to a better understanding of its sources, sinks and characteristics, and to predict trends, and ecological and socio-economic impacts. The objective of this study was to contribute to the global effort of marine beach litter survey by documenting its accumulation on a beach of a remote uninhabited coralline island of the central Mozambique Channel, in the southwest Indian Ocean.

## Material and methods

### Study site

During a field trip at Juan de Nova (Fig. 1) for seabird monitoring, an opportunistic and exploratory marine litter survey was conducted for 12 consecutive days, between the 10$^{th}$ and the 21$^{st}$ of February 2007, during the third quarter and the new moon phases, in the morning at the timing of the low tide in this isolated and uninhabited island. Juan de Nova lies in the central Mozambique Channel (17°03.15S and 42°43.24E), 150 km west of Madagascar and 300km east of Mozambique, with an area of 5 km$^2$, 200 km$^2$ of coral reef and a maximal elevation of 12 m. The island is located in the narrowest part of the Mozambique Chanel, where large-scale flows are strong but highly variable leading to the formation of mesoscale eddies (Ridderinkhof and de Ruitjer, 2003), which can favour the temporal retention of waters and the aggregation of particles. The tide is semi-diurnal and the amplitudes are

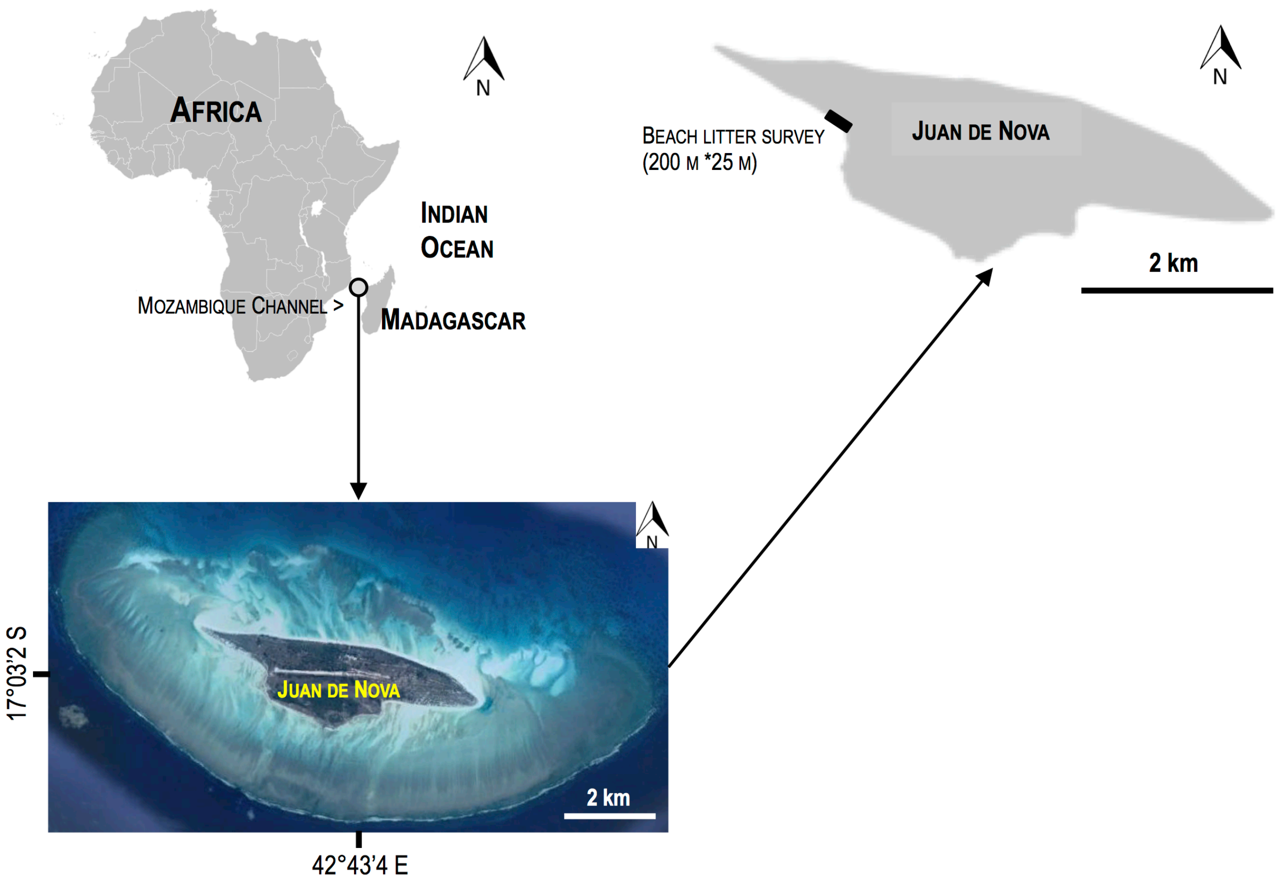


**Figure 1.** Map of the study area, with the location of Juan de Nova island in the Mozambique Channel, satellite view of Juan de Nova with the coral reef barriers surrounding the island, and position of the transect of marine beach litter survey.

high in the region (Chevane *et al.*, 2016) and this leads to large tidal movements. Juan de Nova constitutes, along with Europa, Glorioso archipelago, Tromelin and Bassas da India, the Scattered Islands, a district of the French Southern and Antarctic Lands (TAAF) administration. The island has been largely uninhabited for the last 50 years, except for military and scientific personnel (<20 persons), which highly limits local sources of pollution, as all wastes are regularly evacuated from the island by boat and plane (TAAF, 2015).

### Sampling

After initial cleaning (i.e. Day Zero clean-up) along a 200 m transect located on the west coast of the island in front of the largest part of the coral reef (2.2 km), all manufactured items that could be found at the surface of the sand (above 5 mm in size) were collected between the lower limit of the beach and the mark of the higher tide (~25 m). All collected pieces of litter were classified in 2 main categories (artificial polymer materials and metals) and 19 subdivisions according to their nature and size. This protocol was close to the standard protocols developed for the macro-litter monitoring along shorelines for African marine litter monitoring (Barnardo *et al.*, 2020).

### Data analyses

The standing-stock was calculated as the total number of items per 100 meters of beach. Then the daily accumulation rates in number and density of items per 100 $m^2$ and 100 meters of beach were then calculated for the different categories of wastes and their subdivisions. For this, the daily number of items collected was divided by the transect surface (5000 $m^2$) and length (200 m), and then reported both by 100 $m^2$ and 100 meters to standardize the results and allow comparison with other studies (Barnardo *et al.*, 2020). The mean daily accumulation rate in number of items was related to the high tide height during the survey using a linear model.

The annual amount of marine beach litter deposit was estimated at the scale of the island, based on the daily minimum and maximum of items collected during the survey along the transect. As the tide and the ocean currents in the vicinity of the island had an influence on the deposition of items all along the shoreline, two scenarios were considered, with a uniform deposition rate and with a non-uniform deposition rate. In this last scenario, the same deposition rate as in the uniform deposition scenario was used for half of the shoreline (6 km) and half of the deposition rate was used for the other part of the island (6 km). These values were extrapolated to the whole island to obtain a daily number of items for the island, considering 12 km of shoreline. Then the daily mass of litter for the island was estimated with an average mass of marine beach litter item of 15.6 g (Smith and Turell, 2021; Meakins *et al.*, 2022). Finally, this daily estimate was used to calculate a theoretical annual deposit.

## Results and discussion

At day zero the standing-stock was of 7 items.100 $m^{-1}$ of beach and the number of daily items collected during the 11 other days ranged from 0.5 to 42.5 items.100 $m^{-1}$. As the standing-stock fell within the range of daily items, data from day zero were added in all following analyses. A total of 436 items of marine beach litter were collected during the 12 days survey (Table 1), with a daily range of 1-85 items and a mean (± s.d.) daily number of 36.33 ± 30.60 items. The mean daily density for all categories of items (0.727 ± 0.612.100 $m^{-2}$) and for each item were lower than the densities generally observed for the marine beach litter (Galgani *et al.*, 2015). With two exceptions (rubber ball and aluminium foil), the litter was exclusively composed of plastic items of different size, nature and use. Plastic fragments of different sizes dominated the litter and plastic caps, plastic strapping bands, and plastic fishing net and ropes were regularly collected. All other items were rarely collected, with less than one item accumulated per day. Most collected items were eroded, suggesting that they spent several days at sea, and that they were not from a local land-based source. The very low standing-stock confirmed that there was no local source for this litter. The dominance of plastic in marine beach litter is common and support global data reports (UNEP, 2021), but also regional surveys both in Eastern Africa (Okuku *et al.*, 2021; Meakins *et al.*, 2022) and islands of the Western Indian Ocean (Duhec *et al.*, 2015; Bouwman *et al.*, 2016; Dunlop *et al.*, 2020; Mulochau *et al.*, 2020). The overall density of items in Juan de Nova was low compared to beaches of South Africa (Meakins *et al.*, 2021) and Kenya (Okuku *et al.*, 2021), and slightly lower than in the Seychelles (Duhec *et al.*, 2015; Dunlop *et al.*, 2020) and Saint Brandon Rocks in Mauritius (Bouwman *et al.*, 2016). This lower density of debris on the beach of Juan de Nova can be explained by the fact that the island is uninhabited, the survey was conducted in 2007 earlier than in other sites at a period when plastic pollution was slightly lower, and the circulation in the Mozambique Channel with the mesoscale eddies, which could trap and concentrate marine litter, therefore possibly limiting their deposit on beaches of Juan de Nova.

**Table 1.** Summary of marine beach litter composition, amount and daily accumulation rate of the number of items and density per 100 m and 100 m$^{-2}$ during the study period.

| | Total Number | Mean daily number ± s.d. (items.100 m$^{-1}$) | Mean daily density ± s.d. (items.100 m$^{-2}$) |
|---|---|---|---|
| **TOTAL** | **436** | **18.16 ± 15.30** | **0.727 ± 0.612** |
| **Artificial polymer materials** | **435** | **18.12 ± 15.35** | **0.725 ± 0.612** |
| Plastic fragments (<1cm) | 137 | 5.71 ± 7.67 | 0.228 ± 0.307 |
| Plastic fragments (1-5 cm) | 145 | 6.04 ± 5.38 | 0.242 ± 0.215 |
| Plastic fragments (>5-10 cm) | 59 | 2.46 ± 2.52 | 0.098 ± 0.100 |
| Plastic fragments (> 10 cm) | 1 | 0.04 ± 0.14 | 0.001 ± 0.005 |
| Plastic bottles | 4 | 0.17 ± 0.25 | 0.006 ± 0.009 |
| Plastic caps | 21 | 0.87 ± 1.17 | 0.035 ± 0.047 |
| Plastic strapping bands | 12 | 0.50 ± 1.30 | 0.020 ± 0.052 |
| Plastic fishing net and ropes < 50 cm | 22 | 0.92 ± 0.95 | 0.037 ± 0.038 |
| Plastic containers | 7 | 0.29 ± 0.33 | 0.011 ± 0.013 |
| Plastic bags | 4 | 0.17 ± 0.25 | 0.007 ± 0.009 |
| Plastic flip-flops | 7 | 0.29 ± 0.50 | 0.012 ± 0.019 |
| Plastic syringes | 1 | 0.04 ± 0.14 | 0.001 ± 0.005 |
| Plastic pens | 1 | 0.04 ± 0.14 | 0.001 ± 0.005 |
| Plastic pen caps | 4 | 0.17 ± 0.32 | 0.006 ± 0.013 |
| Plastic dowels | 1 | 0.04 ± 0.14 | 0.001 ± 0.005 |
| Plastic cutlery | 1 | 0.04 ± 0.14 | 0.001 ± 0.005 |
| Foamed polystyrene fragments < 50 cm | 6 | 0.25 ± 0.5 | 0.010 ± 0.020 |
| Rubber balls | 1 | 0.04 ± 0.14 | 0.001 ± 0.005 |
| **Metal** | **1** | **0.08 ± 0.29** | **0.001 ± 0.005** |
| Aluminium foil | 1 | 0.08 ± 0.29 | 0.001 ± 0.005 |

There was a strong positive relationship between the accumulation rate of marine beach litter during the survey and the tide height (Fig. 2). Marine beach litter accumulation reflects the long-term balance between inputs, land and ocean-based sources and outputs from various forms of export. Among factors influencing the densities of beach debris is the tide (Ryan *et al.*, 2009; Galgani *et al.*, 2015), though the relation between accumulation of marine litter on beach and tide is not always directional. In the case of Juan de Nova, the absence of land-based sources and standing stock in the sand suggests that the tide has a strong influence on the deposition of marine litter. The large coral reef ecosystem surrounding the island could act as a barrier for marine litter during lower tide height. In addition, during lower tide height, the surface of beach covered by the sea is smaller leading to a smaller surface for deposition.

The annual deposition of marine litter on the shore of Juan de Nova ranges between 0.25 and 29 t, based on the daily accumulation recorded during the survey, and depending of the deposition rate scenario (Table 2). This estimate is based on a limited number of observations that did not cover the full range of tidal heights, does not consider any other environmental factors that influence marine litter deposit, and does not consider possible resuspension rates. Onink *et al.*, (2021) simulated global marine plastic transport and highlighted coastlines and coastal waters as important reservoirs of marine plastic debris with limited transport of this debris between coastal zones and the open ocean. This suggests a limited loss of debris from the coastal zone of Juan de Nova, and increases the probability of debris being ultimately stranded, though some could remain trapped in the coral reefs (Mulochau *et al.*, 2020). In addition, daily sampling has been proposed to be a good approach for accurate quantification of available debris in coastal habitats and to estimate their accumulation on beaches (Smith and Markic, 2013; Barnardo *et al.*, 2020). Thus, this study provides a realistic order of magnitude estimate of the annual amount of marine litter stranded on Juan de Nova in 2007.

## Conclusion and perspectives

This was a first assessment of marine beach litter on a small island of the central Mozambique Channel, in a region where few studies have been conducted (Connan *et al.*, 2021) and in which the human population and economic development are rapidly increasing. In addition, the western part of the Indian Ocean is suspected to be a major concentration area in an

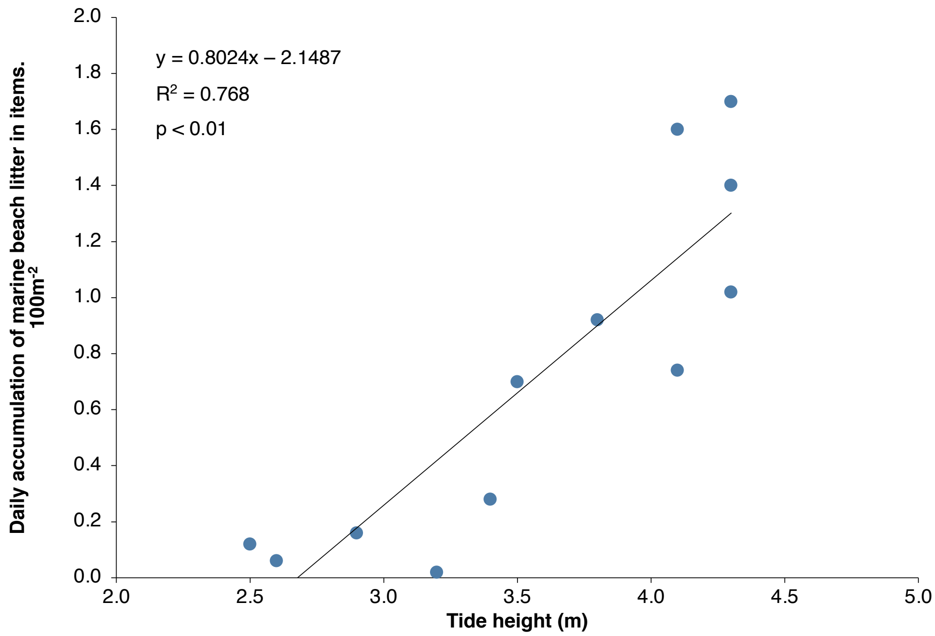


**Figure 2.** Relation between the tide height and the daily accumulation on marine beach litter at Juan de Nova Island in February 2007.

ocean basin that could harbour the second largest concentration of plastic of the world ocean (Erisken *et al.*, 2014; van der Mheen *et al.*, 2019). On the uninhabited island of Juan de Nova, marine beach litter was present and dominated by plastic. Although the survey was conducted in 2007, the estimated annual amount of debris stranded on the island was already significant for an uninhabited and isolated small island, with an average of ~1 $t.km^{-1}$. Most of marine litter in the western Indian Ocean originates from Asia (Vogt-Vincent *et al.*, 2023). As release of plastics in the sea has increased and should continue to increase in the future in Asia (UNEP, 2021), this suggests that the amount of marine litter deposited on Juan de Nova would increase in the future. As the island is a protected area with remarkable biodiversity, this marine litter likely has consequences on species both at sea and on land, which should be evaluated. In the future, it will be useful to monitor the marine beach litter based on standard methods to allow comparison with other studies, evaluate the long-term evolution of deposits and to clean up beaches to remove this pollution from the natural environment to limit it impacts on biodiversity. The TAAFs administration should strengthen controls on compliance with the regulations on waste management by fishing and transport vessels to limit the illegal dumping of waste at sea in the Economic Exclusive Zone of Juan de Nova as debris associated with fisheries and transport are a major risk in the western Indian Ocean (Vogt-Vincent *et al.*, 2023). New monitoring at the same site and at other uninhabited islands of the region will help to better understand the dynamics of plastic pollution in the western Indian Ocean.

**Table 2.** Estimation of the annual deposit of marine beach litter on the 12 km of shoreline of Juan de Nova Island assuming a uniform and a non-uniform rate of deposition around the island (see method).

| | Uniform deposition rate | Non-uniform deposition rate |
|---|---|---|
| Daily minimum number of item deposit | 60 | 45 |
| Daily maximum number of item deposit | 5 100 | 3 825 |
| Daily minimum mass of item deposit (kg) | 0.936 | 0.702 |
| Daily maximum mass of item deposit (kg) | 79.560 | 59.670 |
| Annual minimum mass of item deposit (ton) | 0.342 | 0.256 |
| Annual maximum mass of item deposit (ton) | 29.034 | 21.779 |
| Annual mean mass of item deposit (ton) | 12.299 | 9.224 |

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