2015

Worldwide

Race For Water Odyssey

Quantitative and Qualitative Assessment of Marine Plastic Debris Collected on Shorelines

RACE FOR WATER
A FOUNDATION TO PRESERVE WATER

December 2016

The *Race For Water* Foundation : The *Race For Water* Foundation is an organization dedicated to the preservation of water and the ocean in particular. This indispensable resource is under massive threat from plastic pollution and must be protected. The Foundation aims to identify, promote and implement solutions that will give end-of-life plastic a value and create new sources of income for the people most affected by pollution. Using this innovative approach inspired by the principles of a circular economy and social entrepreneurship, the *Race For Water* Foundation seeks to prevent plastic litter from reaching waterways and making its way to the ocean.

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Acronyms

BIOT : British Indian Ocean Territory

EPFL : Ecole Polytechnique Fédérale de Lausanne

EVA : Ethylene-Vinyl Acetate

HDPE : High Density Polyethylene

ICC : International Coastal CleanUp

LDPE : Low Density Polyethylene

na : Non Available

nd : Non Detected

NOAA : National Oceanic and Atmospheric Administration, USA

NGO : Non Governmental Organisation

PC : Polycarbonate

PE : Polyethylene

PET : Polyethylene terephthalate

PMP : Polymethylpentene

PP : Polypropylene

PS : Polystyrene

Executive Summary

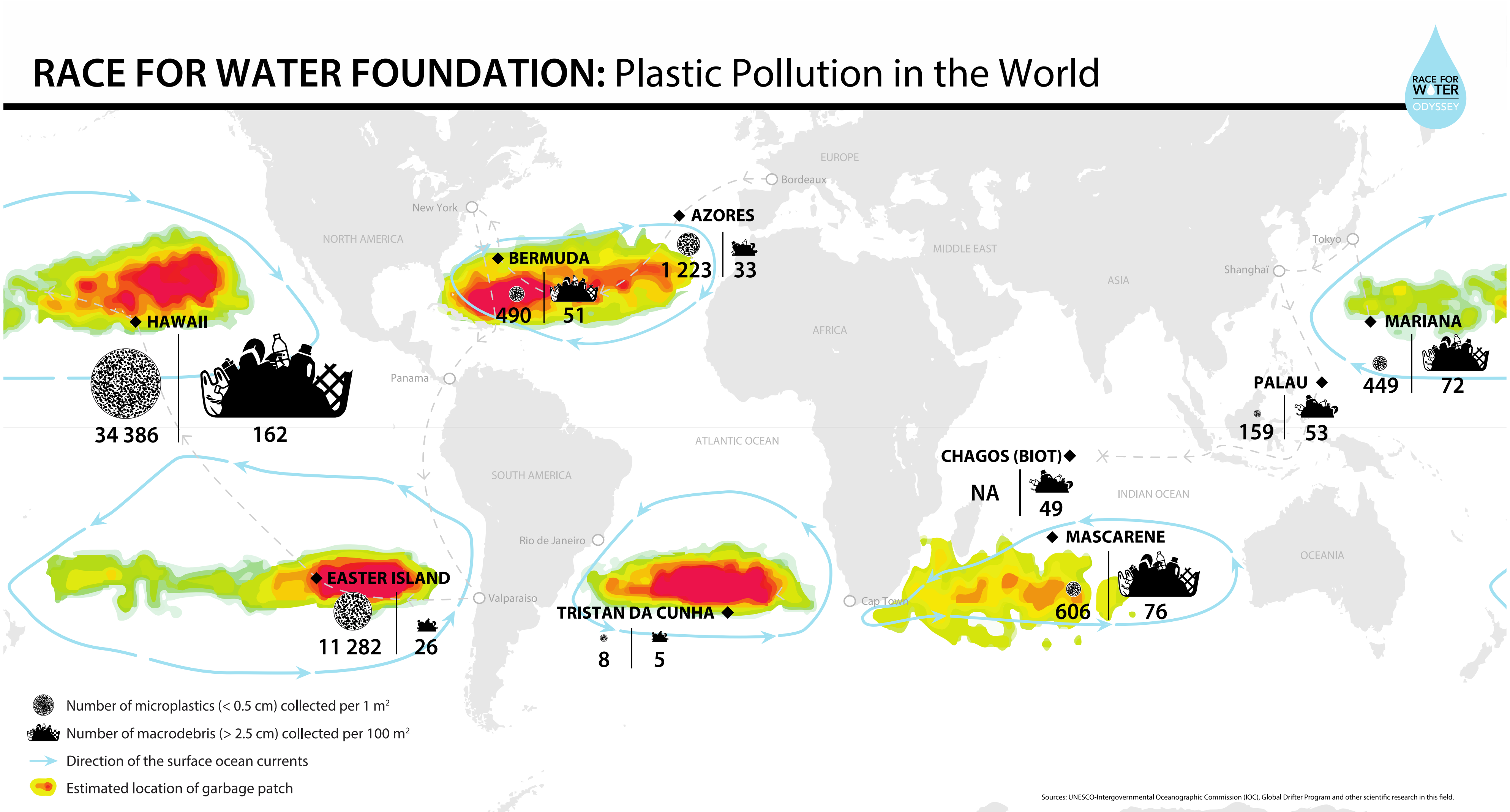
With the help of the local people we met during the course of the 2015 Odyssey, the main objective, obtaining a collection of comparable data about marine plastic pollution using the NOAA internationally recognized protocol, has been achieved.

It cannot be sufficiently stressed that not one of the 30 sampled shorelines during this worldwide journey was free from marine plastic debris. As for the recent identification of plastic debris in the Arctic and Antarctic areas, this observation confirms that plastic contamination in the oceans is ubiquitous.

Whether in terms of macrodebris (>2.5 cm) or microplastics (< 5 mm) concentrations, Hawaii constitutes by far the 2015 Odyssey's most notable hotspot. The highest macrodebris concentration registered at Kamilo Point in Hawaii (more than 3,500 macrodebris per 100 m^2) was almost ten times greater than the second hotspot of the 2015 Odyssey, Pago Bay (372) on Guam Island in the Mariana Archipelago. Hawaii also constitutes the highest microplastics concentration hotspot with more than 94,000 particles per m^2 collected once again at Kamilo Point again. For comparison, the second highest concentration, Ovahe beach on Easter Island, revealed more than 24,000 microparticles per m^2. Unfortunately, based on their locations, marine macrodebris concentrations can suffer bias due to direct waste disposal (intentional or accidental) of tourists and/or local residents, and also because of the consecutive shoreline clean-up campaigns. Therefore, microplastic concentrations are a more reliable indicator to establish a comparison between study sites. On that basis, Northeast Pacific islands – especially the Hawaiian Archipelago – experience the most significant marine debris accumulation, followed by those of the South Pacific, Northeast Atlantic, Indian, Northwest Atlantic, Northeast Pacific and South Atlantic Oceans respectively. The macrodebris and microplastic average concentrations are summarized below in Figure 1.

In qualitative terms, the hard plastic fragments category largely dominates the macroplastics content except for Palau and Chagos (BIOT). Other dominant categories are plastic foams, bottles and caps, and fishing lines and ropes. Foams were particularly predominant in Chagos, while bottles and caps constituted almost 70% of macrodebris in Palau. Besides, significantly higher bottle and cap concentrations were evidenced near the Asian continent. Fishing lines and ropes stood out particularly in Bermuda. Microplastic concentrations confirmed these trends with more than 80% of hard plastic fragments on every stopover, except Easter Island and Tristan da Cunha (around 60%). More specifically, Easter Island showed a significant concentration of pellets, while Bermuda confirmed a strong presence of fishing lines among the microparticles.

Lastly, the polymer analysis of the hard plastic fragments ranging from 1 mm to 2.5 cm revealed the prevalence of polyethylene (PE) throughout all of the study sites, except for Tristan da Cunha where polypropylene (PP) dominated. Hawaii, Mariana, Palau and Mascarene also showed significant PP concentrations (between 31 to 47% of items). Other kinds of polymer such as EVA and PMP, have been evidenced especially on Tristan da Cunha, but also on the Azores and Mariana.



<u>Figure 1 :</u> Macrodebris and microplastics average concentrations on islands/archipelago visited during the 2015 Odyssey

1. Introduction

The *Race For Water* Odyssey is an environmental expedition aiming at crossing the world's oceans in order to reach the 5 major ocean gyres (also know as the "trash vortexes", they define open sea areas with higher concentration of floating debris located in the North and South Atlantic and Pacific Oceans, as well as in the south of the Indian Ocean), in less than one year, and to witness the extent of plastic pollution washed on to the shorelines of islands located within and beyond the gyres.

Following oceanic surface currents, floating marine debris – mainly composed of plastic – are accumulating in these vortexes. Marine debris are regularly washed ashore on coastal areas exposed to open seas, and especially islands located within or close to the gyres, which act like physical barriers. Stranded marine debris categories and concentrations are therefore representative of the plastic pollution in the surrounding waters, and thus from those of the gyres. *Race For Water* samplings were performed entirely on shorelines.

Overall, the 2015 Odyssey made 7 stopovers on various islands and/or archipelagos (Azores, Bermuda, Easter Island, Hawaii, Mariana, Palau and Mascarene). Unfortunately, the Odyssey's sailboat capsized in the Indian Ocean and 2 other planned stopovers (Chagos and Tristan da Cunha) were not visited by *Race For Water*'s team. Nevertheless, samplings were carried out by a team of local volunteers, part of the *Race For Water*'s network, following the same protocol in order to get comparable data. Due to technical issues, microplastics samplings from Chagos were finally not exploited.

Over the different scientific stopovers, the protocol was carried out on 2 to 5 different beaches according to their accessibility and scientific interest. Several selection criteria were considered such as, for instance the nature of the substrate, the geomorphology, the vicinity of outflows (rivers, waste waters..), estuaries or cap, which could potential modify the currents and deposition patterns of marine debris, and the coastal exposition in order to obtain representative samplings. The type of tourism and the local clean-up activities were also taken into consideration and reported, but were not grounds for exclusion.

2. Objectives and methodology

The 2015 Odyssey's primary objective was to identify, tally and quantify the mass of debris above 2.5 cm also known as "macrodebris" in situ, and to collect debris between 2.5 cm and 5 mm know as "mesoplastics", and the debris of less than 5 mm known as "microplastics" according to the recent and standardized protocol published by the NOAA in 2013 (1). The systematic implementation of this protocol should provide for obtaining comparable quantitative and qualitative data from one gyre to another.

<u>Figure 2 :</u> Meso- and microplastics sampling on a quadrat (0.25 m² area and 10 cm depth), at Kamilo Point, Hawaii, on 30 June 2015 (F. Sciacca pictures).

<u>Figure 3 :</u> Macrodebris sampling at Ngerong and Ulong beaches, Republic of Palau, on 24 August 2015 (P. Charaf pictures).

In the case of macrodebris, identification, description, counting and weighing were performed directly in situ (Figure 3). Unlike debris of less than 5mm, no polymer analysis to determine the main plastic constituents was done owing to logistical issues.

In the case of microplastics, the following treatment step after on site collection was carried out in Switzerland at the Central Environmental Laboratory (CEL) of Ecole Polytechnique Fédérale de Lausanne (EPFL). As for macrodebris, meso- and microplastics were categorized (according to usual categories such as foam, thin film, fishing lines, pellets, hard fragments, etc.), counted and weighed, before identification of their polymeric structure (PP, PE, PS, PET, etc.). Processing steps are described further in in Figure 4 below.

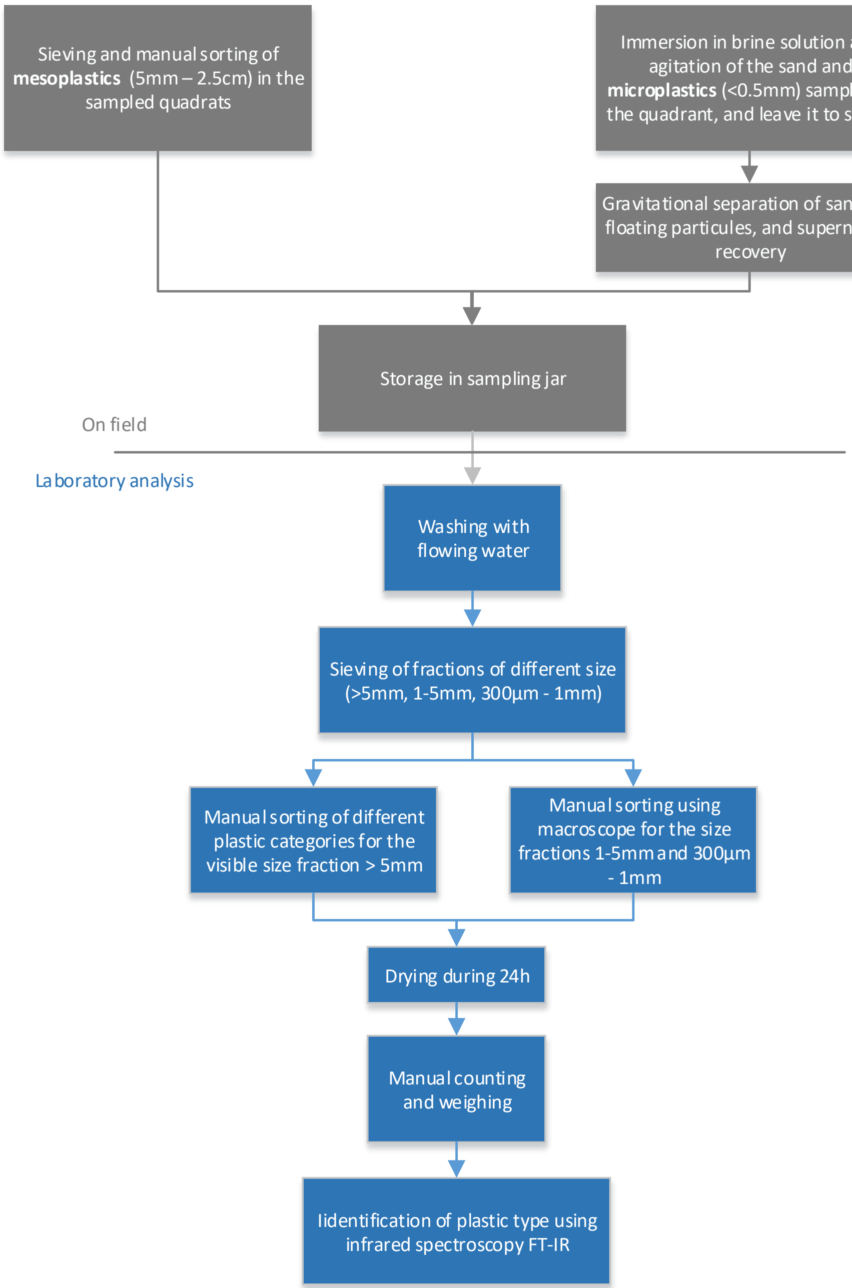


Figure 4 : Block diagram of the meso- (5 mm- 2.5 cm) and microplastics (< 5 mm) sampling and analysis methodology. Plastic debris were collected on a quadrat area (0.25 m^2 area and 10 cm depth).

3. Archipelagos/islands main results

3.1. Measured concentrations

At an initial stage, main results of each archipelago/island are presented comparing macrodebris and microplastics concentrations (in number and mass), then comparing concentrations among identified plastic categories, and finally according to polymer composition[1]. At a second stage, each stopover is presented independently in order to focus on the particularities of the different sampled sites of the same archipelago/island.

3.1.1. Macrodebris

During this 2015 Odyssey, 9 archipelago/islands representing a total of 30 different sites were sampled. Overall, more than 15,420 debris over 2.5 cm size were sampled over a total area of 20,796 m^2.

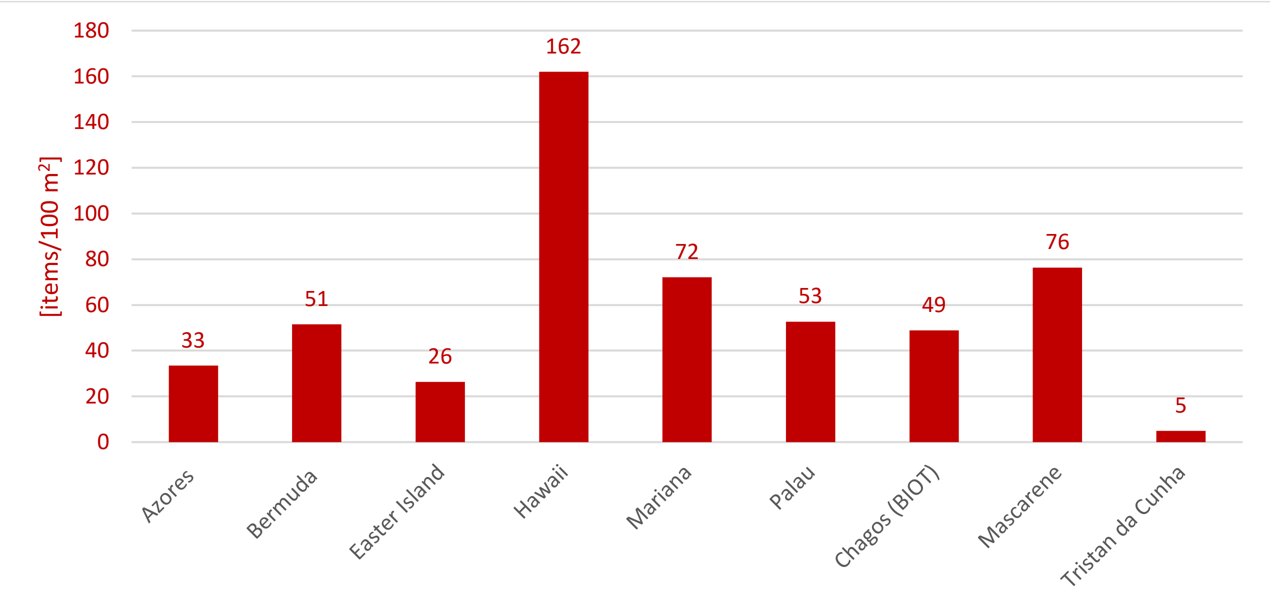


Figure 5 : Items concentration of macrodebris (> 2.5 cm) per 100 m^2. Macrodebris include plastic, metal, glass, rubber, cardboard/paper, cloth/fabric and other debris fractions. Items concentrations are highly variable between sampling sites on the same archipelago/island.

According to Figure 5 here above, macrodebris concentrations per 100 m^2 areas of shorelines vary from 5 (Tristan da Cunha) to 162 (Hawaii). Sampled sites in Hawaii (Northeast Pacific area) revealed an average concentration dramatically higher than equivalent areas of other visited stopovers. Following Hawaii, Mascarene (Indian Ocean) and Mariana (Pacific Northwest) had concentrations of 76 and 72 macrodebris per 100 m^2 area, respectively. Bermuda, Palau and Chagos had similar concentrations values with 51, 53 and 49 macrodebris over the same area, respectively.

[1] Mesoplastics are not considered in the following results because of the limited quantity collected.

Table 1 : Plastic debris percentage among collected macrodebris

	Azores	Bermuda	Easter Island	Hawaii	Mariana	Palau	Chagos (BIOT)	Mascarene	Tristan da Cunha
Plastic macrodebris	84%	70%	91%	93%	84%	79%	81%	94%	71%

Among the collected debris of over 2.5 cm (macrodebris), from 70% (Bermuda) to 94% (Mascarene) of the whole fraction of collected macrodebris were plastic debris (Table 1). Considering the whole set of collected macrodebris disregarding the location, almost 90% were made of plastic. Other debris were mainly made of rubber, glass and metal.

Regarding macrodebris concentration in weight (see Table 2), trends are different since Palau tops the ranking, followed by Mariana and Easter Island. Specifically, concentrations in weight on a 100 m^2 area are 2,656 gr in Palau, 2,030 gr in Mariana, and 2,090 gr in Mascarene and 1,609 gr on Easter Island.

This observation shows that there is no correlation between macrodebris number and weight concentrations. More specifically, Easter Island illustrates that big debris (such as ropes, big containers) on a small beach area can have a strong influence on concentrations. Nevertheless, quantitative data must be tempered since macrodebris concentrations are highly variable and depend – once again – on site-specific influences (such as wind exposure, weather conditions, vicinity of outflows, and popularity), but also, and above all, tourist numbers and the regularity of shoreline clean-up operations. On several visited places, methodic clean-up campaigns were carried out but with variable frequencies.

3.1.1. Microplastics

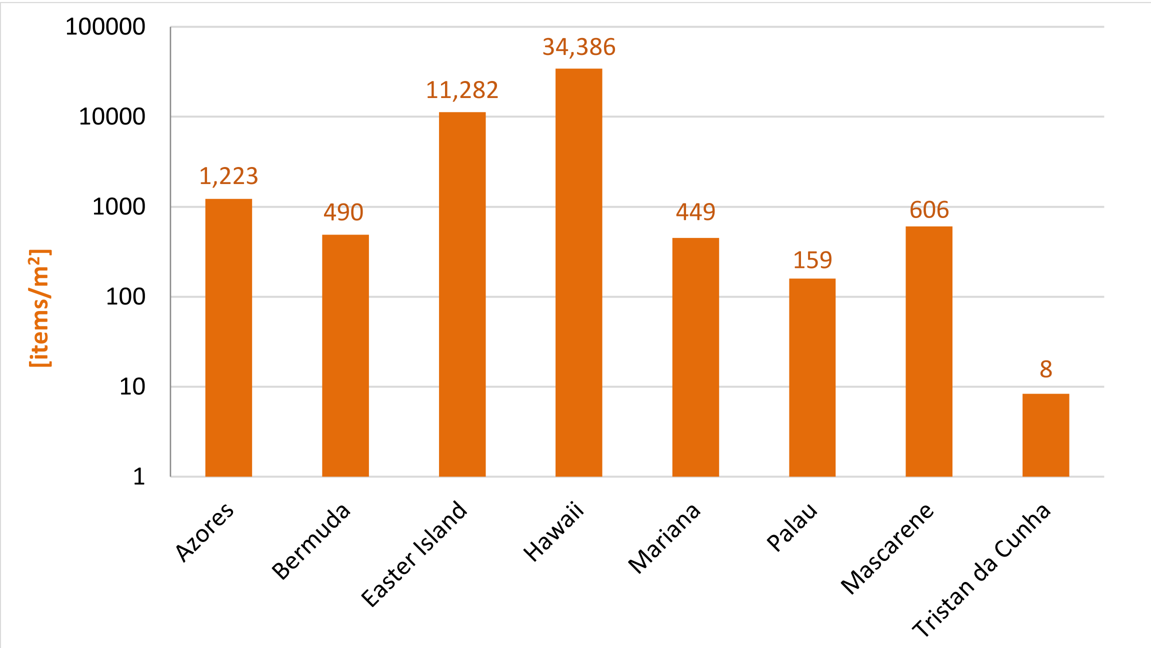


Figure 6 : Items concentration of microplastics (< 5 mm) per square meter. Logarithmic scale.

Microplastics concentrations in items are summarized in Figure 6 above.

Firstly, microplastics concentrations (< 5 mm) suffer high variability on sampled sites of the same island. Nevertheless, the average microplastics trends averaged per stopover demonstrate that Hawaiian shorelines (Kahuku, South Makapuu, Kahana, Kawa Bay et Kamilo Point) are the most affected areas with more that 30,000 microplastics per square meter of beach. Easter Island averaged microplastics concentration is of the same order of magnitude with more than 10,000 plastic microparticles per square meter, which is 10 times higher than the sampled beaches of Azores (Do Norte, Porto Pim, Conceição). Mascarene, Bermuda, Mariana and Palau complete respectively the list. Tristan da Cunha has the lowest recorded concentration with 8 microplastics per square meter. On that basis, the first observation is that the (North and South) Pacific Ocean constitute the area with the greatest microplastic concentrations, followed by the North Atlantic and the Indian Ocean. This finding is broadly consistent with modelling of drifting plastic debris on the world's oceans (2) (3) (4).

Table 2 : Mass concentration of microplastics (< 5 mm) and macrodebris (> 2.5 cm) per square meter of sampled shoreline.

Concentration in [g/m²]	Azores	Bermuda	Easter Island	Hawaii	Mariana	Palau	Chagos	Mascarene	Tristan da Cunha
Microplastics (< 5 mm)	16	3	150	133	2	1	na	3	<1
Macrodebris (> 2.5 cm)	1	2	16	13	20	27	14	21	<1

Regarding mass concentrations of microplastics, values are relatively well correlated with items concentrations (in order of magnitude). Overall, mass concentrations of microplastics were higher in the North and South Pacific, followed by the North Atlantic Ocean. This observation might indicate a longer accumulation of microplastics on the shorelines due to a more longstanding presence of plastic in the (North and South) Pacific and North Atlantic Oceans. However, to assume an older presence of plastic debris in some gyres, microplastics should be sampled according to a depth gradient in order to get a more reliable record of plastic pollution. Most importantly, collected marine plastic debris should be dated according to structural changes (including polymer oxidation).

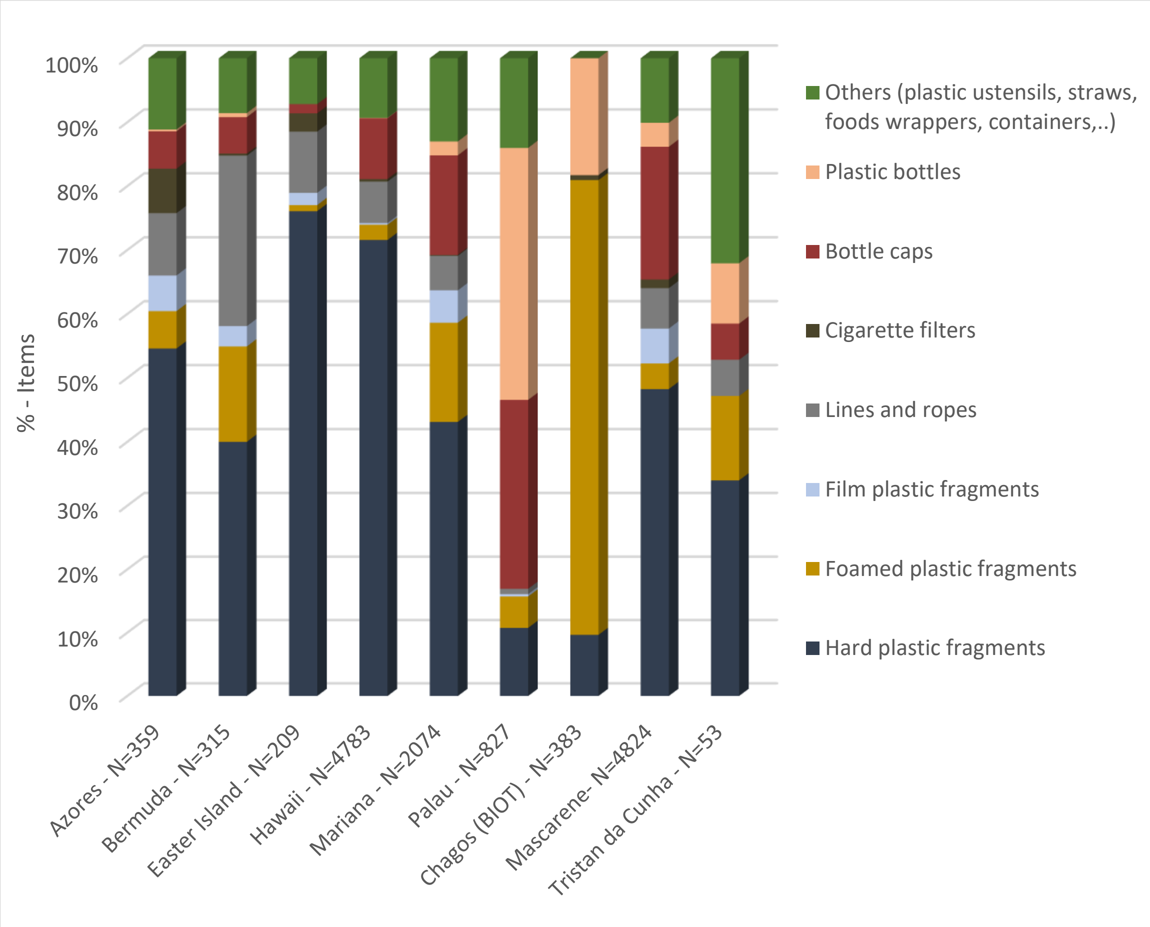
Moreover, it is noteworthy that mass concentration of microplastics per m^2 is higher than that of macrodebris of Azores (Faial), Bermuda, Easter Island and Hawaii. But in most cases sampled sites were regularly cleaned. Inversely, Mariana (Guam), Palau and Mascarene (Rodrigues), where local clean-up operations were not performed before our sampling, mass concentrations of macrodebris were higher than microplastics. This tends to confirm logically that macrodebris concentrations are dependent upon local clean-up frequencies. However, microplastics are not collected during such clean-up operations.

The opposing situation – significant littering due to high popularity and tourist numbers – can also accentuate macrodebris concentration. Mariana (Guam) and Mascarene (Rodrigues) illustrate this situation. Indeed, locally sourced waste on shorelines is not negligible in some cases. Waste management education and awareness among people are apparently still quite variable.

Finally, it is very difficult to draw firm conclusions based on the recorded macrodebris concentrations. Nevertheless, each value can be considered with regard to what influenced the sampling results, such as local and regional characteristics and weather related factors (see Annexes 1 and 2). On the other hand, microplastic concentrations on the shorelines seems to constitute a more reliable indicator of the plastic pollution levels reached.

3.2. Typology of collected plastic debris

3.2.1. Macroplastics



<u>Figure 7 :</u> Macroplastics (> 2.5 cm) distribution according to plastic categories.The "Other" category includes plastic fractions of packaging material, containers, lighters, plastic bags, buoys and floats, fishing lures and lines, cups, cutlery, straws, balls, cosmetic products and unclassifiable objects.

Among the collected microplastics on the beaches, the most represented item is undoubtely the hard plastic fragments and this ranges from 10 to 76% in total (Figure 7). Except for Palau and Chagos where hard plastic fragments do not exceed 11 and 10% respectively, this category constitutes more than a third of all the plastic debris collected on every other stopover. Hard plastic fragments come from the physical (mechanical fragmentation), chemical (UV radiations, oxidation and heat) and biological (marine fauna chips and chunks, bacterial colonization) degradation over time of bigger plastic products drifting on the surface of the oceans (5). Considering all the samplings sites, bottle caps, plastic fishing lines and ropes, foams, plastic bottles, containers, plastic films, cosmetic products, fishing lures and lines, lighters, cigarette filters, sticks and straws are the following categories of debris. On the Chagos, foams (which are likely to be expanded polystyrene) account for almost 60% of macroplastics, more than plastic bottles or hard plastic fragments. Whereas on Palau, the dominant categories are plastic bottles and hard plastic fragments followed the "Other" category, which is mainly made up of container fragments, lighters and cosmetic products. Fishing ropes and lines observed in Bermuda especially, and to a lesser extend in Azores and Easter Island, logically derive from fishing and maritime-related activities. Broadly speaking, Bermuda seems to be more exposed to marine debris issued from maritime-related activities than other visited areas.

3.2.1. Microplastics

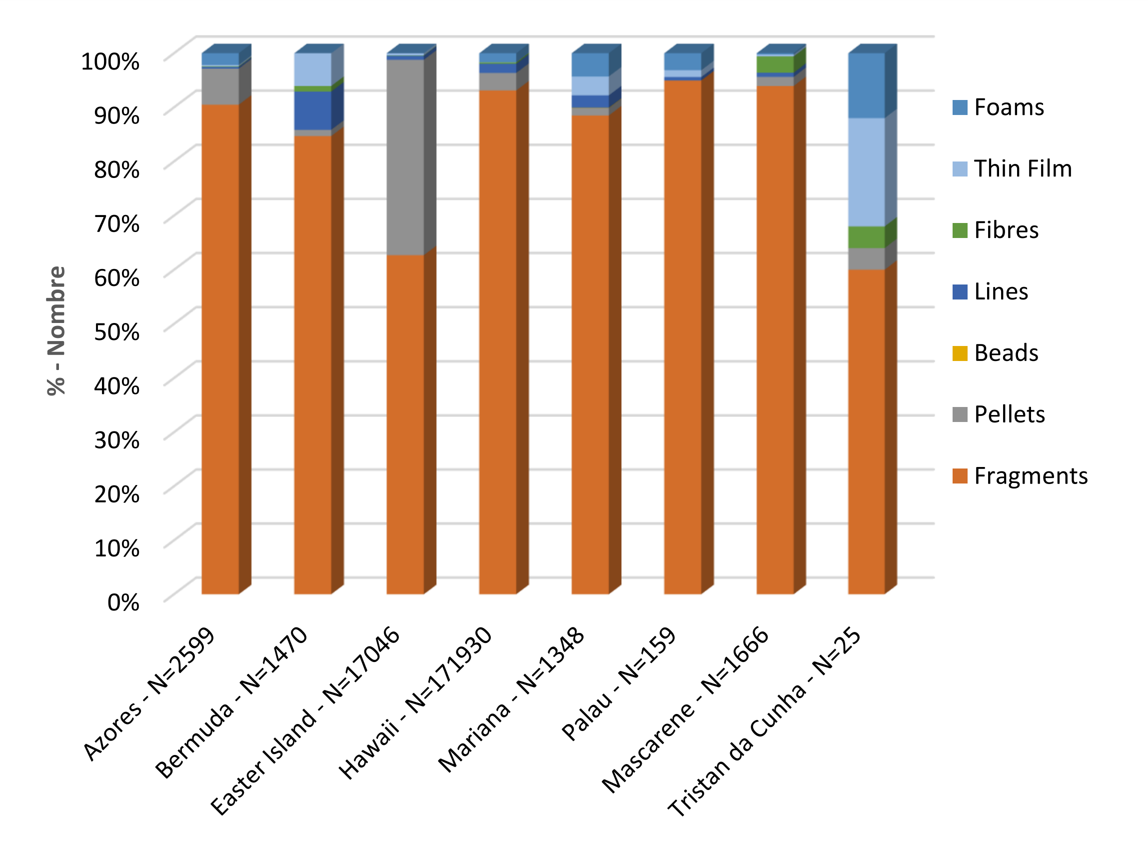


Figure 8 : Microplastics (< 5 mm) distribution according to plastic categories.

Microplastics categories considered in this study are illustrated in Annexe 3. Microplastics distribution are even more greatly dominated by hard plastic fragments than macroplastics (Figure 8), which is expected assuming that several categories of macroplastics (such as bottle caps, containers, plastic utensils…) fragment into non-identifiable hard plastic fragments over time. These microplastics are likely to be land sourced. In other words, they originate mainly from human activities on land. On Bermuda, fishing lines are always well represented and follow hard plastic fragments, which confirms the earlier observations on macrodebris. A significant fraction of debris originates from fishing and maritime-related activities. By contrast, pellets were the second dominant category (items concentration) after hard plastic fragments on the Azores, Easter Island and Hawaii. Pellets are primary microplastics (in contrast to secondary microplastics produced from the degradation of bigger debris) since they constitute the raw material at the basis of plastic products manufacturing. On Easter Island especially, pellets concentration is strikingly high and represents 36% of the collected microplastics. Container ships losing containers during extreme meteorological events is a common explanation for the dispersion of pellets at sea. However, mismanagement and consecutive spilling during on land industrial production, transformation, handling and storage can also be a significant contributor. Indeed, pellets accidentally spilled over an uncontrolled area can easily be dispersed into waterways following rainfalls and eventually end up in the oceans. Pellets were also in evidence in Tristan da Cunha, Hawaii and to a lesser extent in Mariana and Mascarene. On Tristan da Cunha, following hard plastic fragments concentration, foams and thin films were relevant fractions. Regarding fibres, they were identified on Tristan da Cunha, Mascarene and Bermuda especially.

Table 3 : Polymer composition of hard microplastic fragments collected. The "Other" category includes specifically polymethylepentene (PMP) and ethylene vinyl acetate (EVA).

% items	Azores	Bermuda	Easter Island	Hawaii	Mariana	Palau	Mascarene	Tristan Da Cunha
PE	**82.5**	**86.5**	**91.1**	**68.8**	**59.6**	**53.3**	**65.8**	16.7
PP	16.8	13.5	8.9	31.2	40.0	46.7	34.2	**66.7**
Other (EVA, PMP)	0.7	0.0	0.0	0.0	0.4	0.0	0.0	16.7

The analysis of the polymer composition of hard plastic fragments shows that polyethylene (PE) clearly dominates above all the various differents stopovers (from 16.7 to 91.1% of microplastics items collected), with the exception of Tristan da Cunha (Table 3). However, Tristan da Cunha results must be considered with caution since just a few microplastics (53 items) were found locally. The other trend that emerges is the presence of polypropylene (PP) as the second dominant constituent of microplastics (with concentrations ranging from 8.9 to 66.7%). In some cases (Azores, Mariana and Tristan da Cunha), reduced fractions of ethylene vinyl acetate (EVA) and polymethylpentene (PMP) were also identified.

PP and PE are mass consumption polymers. PP is largely used in automotive and packaging industries - for bottle caps and straws for instance, but PP is also used to produce technical fabrics. PE is used to produce hard containers (HDPE) such as bottles (milk bottles for instance), cosmetic and detergents, or reusable containers. It is also used to produce soft packaging (LDPE) such as plastic bags, garbage bags and sachets. Reticulated PE is also used to produce cable sheaths. Its resistance and durability make the PE extremely useful for a range of industrial applications, such as sports, safety and surgery equipments. Raw PP is more sensitive to UV radiations and oxidation than PE. The elastomer properties of EVA are even better than for PE (which is more flexible than PP, a brittle material), this is why various industrial applications such as packaging, food, medical devices, and civil engineering materials are also made with EVA. PMP is very stable to temperature variations, as rigid as PP, but more sensitive to oxidation, which is why additives are usually mixed with it. It is a constituent of electronic, laboratory, medical and cooking devices (6a) (6b) (7).

Microplastics laboratory handling confirmed that PP is very brittle and easily fragments during handling, even if they are already millimeter sized.

The low representation amongst stranded plastic marine debris of other highly consumed plastics (such as PC, PVC and PET) is due to their density, which is higher than water. Therefore, they usually do not float but sink rapidly.

4. Local results for each stopover (islands)

4.1. Azores (Faial)

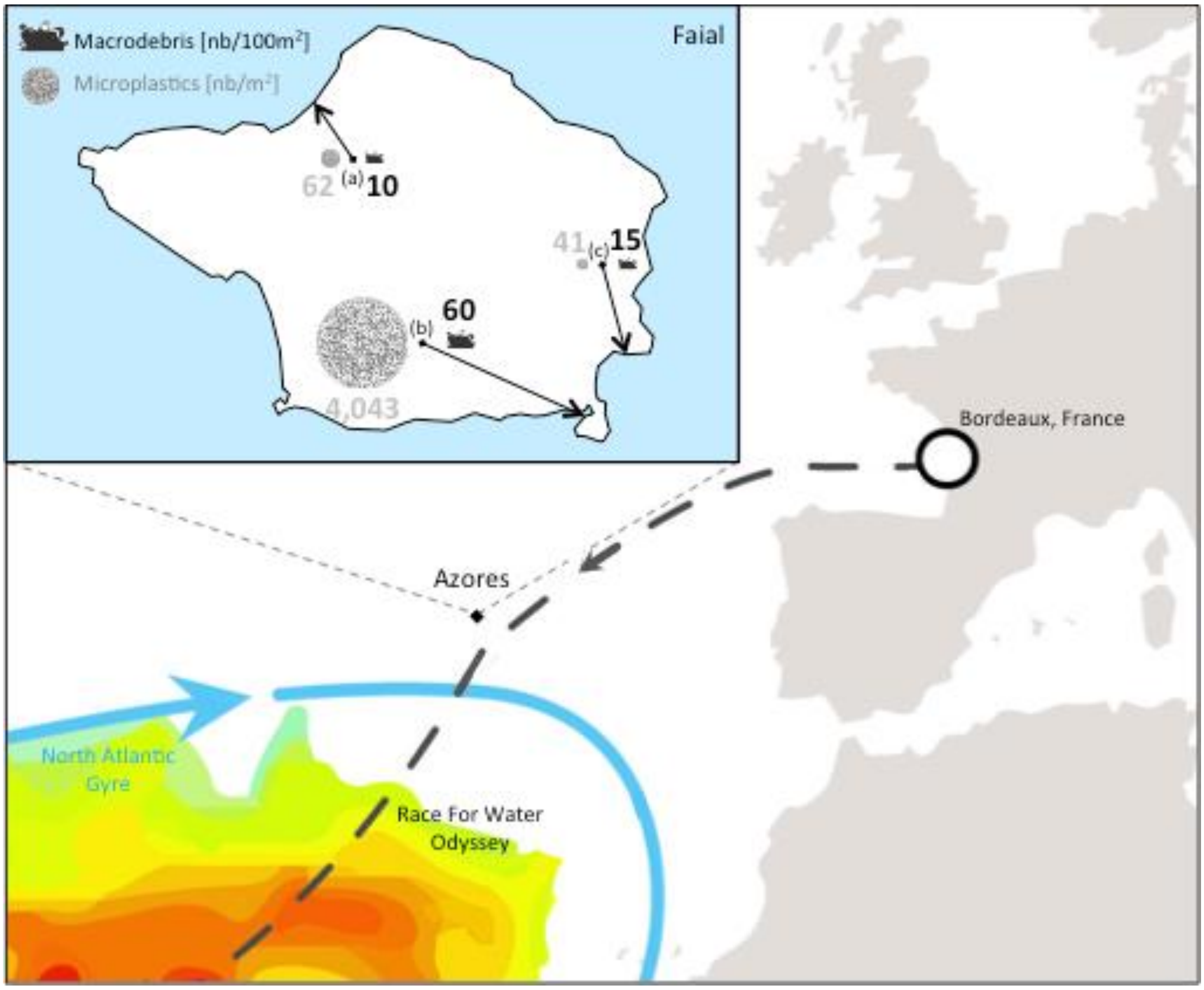


Figure 9 : Items concentration of macrodebris (black icons) per 100 m² and microplastics (grey circles) per m² on Faial island, Azores. Symbol size is proportional to the concentration, but with a different scale between the 2 categories. (a) Do Norte, (b) Porto Pim, (c) Conceição.

On Faial island, concentrations are extremely variable according to the geographical location (Figure 9 and 10). More specifically, the southern tip of Faial island where Porto Pim beach is located and facing west, acts as natural barrier against floating marine debris coming from the west. This is probably why the highest macrodebris (60 per 100 m^2) and microplastics (4,043 per m^2) concentrations were recorded in that location. In terms of oceanic currents, the Azores is mainly exposed to the Gulf Stream and westward propagating eddy corridors. Those currents are known to have a significant impact on floating particles trapping and retention on the Azores (8). Local residents confirmed that Porto Pim beach traps large quantities of floating marine debris.

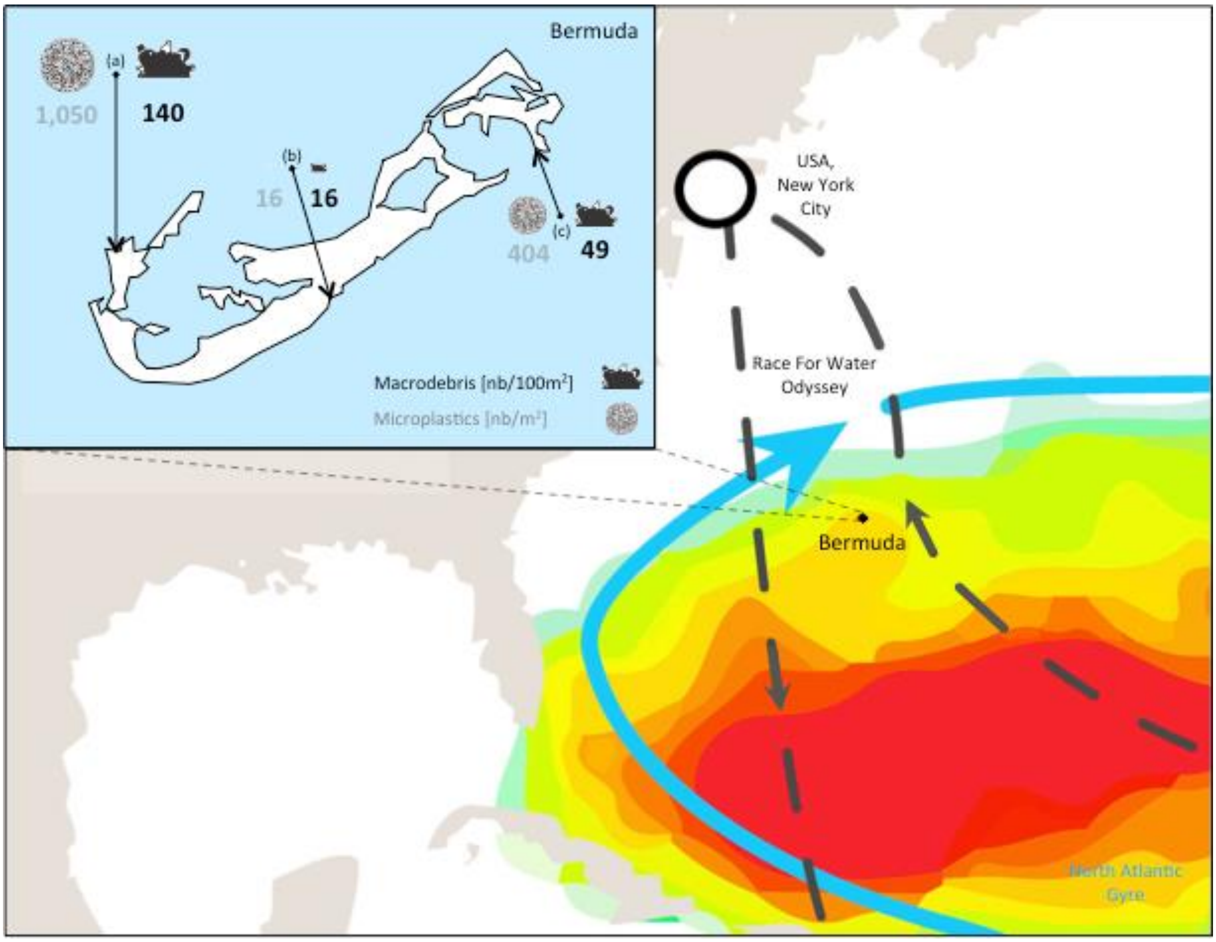
Do Norte beach (located on the Northeast of Faial island) presents specific features - such as a Northwest oriented shoreline, a significant slope, and a frequently strong swell with powerful waves hitting the bottom of the cliffs, which can explain why marine debris concentration is comparatively low (10 macrodebris per 100 m^2). This beach is also cleaned on a regular basis and the OSPAR (9) protocol is performed every year. Nevertheless, this beach is located near an open air landfill, which can be a source of local contamination. Similarly, the close urban center from Conceição beach (located in the Southeast of Faial island) can also be a source of waste contamination, but macrodebris concentration remained low (15 macrodebris per 100 m^2). These values are consistent with the results obtained during marine debris collection performed as part of the Azorlit project, with 7 and 14 macrodebris per 100 m^2 recorded on Do Norte and Conceição beaches respectively according to Christopher Kim Pham of the Azores University. According to the Azorlit project, Porto Pim concentrations were lower - with 0.11 macrodebris per m^2 - than the concentrations measured during the *Race For Water Odyssey* (0.6 macrodebris per m^2). Nevertheless, local residents are already aware of Porto Pim's specificity regarding marine debris deposition, and this allows the beach to benefit from a particular attention with regular clean-ups. An accumulation survey on Porto Pim showed that the highest macrodebris concentration can reach up to 194 per m^2 in February; however, with very high variability (10).






<u>Figure 10 :</u> Sampling performed on Faial island, Azores (P. Charaf pictures).

4.2. Bermuda (Main, Somerset and Cooper's)



<u>Figure 11 :</u> Items concentration of macrodebris (black icons) per 100 m² and microplastics (grey circles) per m² on Bermuda. Symbol size is proportional to the concentration, but with a different scale between the two categories. (a) Somerset Long Bay, (b) Grape Bay, (c) Well Bay.

On Bermuda, Somerset Long Bay beach located on the western part of Bermuda demonstrated the greatest concentrations with more than 1.4 macrodebris and 1,050 microplastics per m^2 (Figure 11 and 12). Contrary that observation, testimonies from local residents affirm that they face mass stranding of marine debris on the East windward coast. In that context, local clean-up activities performed just before our sampling on the eastern beaches may be an explanation for the differences between the Odyssey's macrodebris records and the local testimonies. In addition to these local considerations, Well Bay beach located on the Northeast of Bermuda is a small South-oriented inlet acting like a trap for marine debris drifting North. That may explain the significant marine debris concentration despite a recent clean-up. According to local residents, Well Bay seems to be the most exposed beach to marine debris. Marine debris strandings also affect Grape Bay but it is more regularly cleaned owing to personal initiatives that can explain the lower recorded values.

<u>Figure 12 :</u> Sampling performed on Bermuda (P. Charaf pictures).

4.3. Easter Island

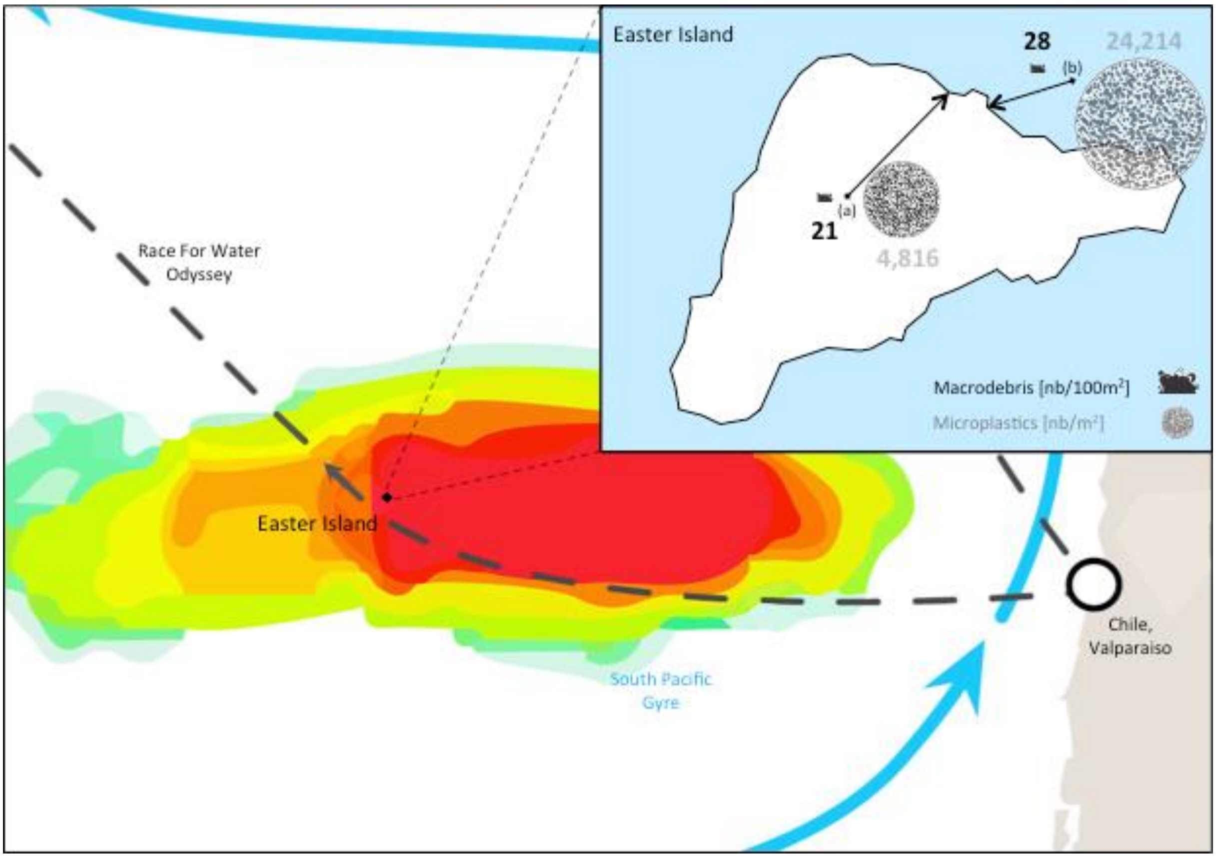


Figure 13 : Items concentration of macrodebris (black icons) per 100 m² and microplastics (grey circles) per m² on Easter Island. Symbol size is proportional to the concentration, but with a different scale between the two categories. (a) Anakena, (b) Ovahe.

Despite its remote location at around 3,680 kms from the chilean coast, Easter Island is not immune from plastic pollution. In fact, marine plastic debris are concentrated in the Centre-East of the South Pacific close to the island (11).

First of all, the sampling performed on Easter Island is not as representative as the others, since only two sites were sampled on the Northeast of the island (Figure 13 and 14). This is due to the fact that rocky and steep shores form most of the coast around Easter Island, except the two sampled beaches of Ovahe and Anakena. The shorelines orientation - East and North respectively - and the highest debris concentration on Ovahe could be an indication of a potential westward flow of debris at that very location.

On Easter Island, those two beaches have the particularity of being obviously very popular with local people and tourists. Consecutively, the municipality organizes local clean-up campaigns on a weekly basis for Ovahe and daily basis for Anakena. This logically explains why macrodebris - highly visible on the rocky shores of the island - are relatively sparse present on these two beaches. In comparison, microplastic concentrations are very high, particularly on Ovahe (24,214 microplastics per m^2) making it the second highest microplastics concentration recorded during the Odyssey after Hawaii. Once again, it confirms that microplastics constitute a much more reliable and robust indicator of the plastic pollution history than macrodebris. Hard plastic microparticles are the outcome of physicochemical and biological degradation of bigger marine plastic debris having drifted a long time over the surface of the oceans.

Figure 14 : Sampling performed on Easter Island (P. Charaf pictures).

4.4. Hawaii (Oahu, Big Island)

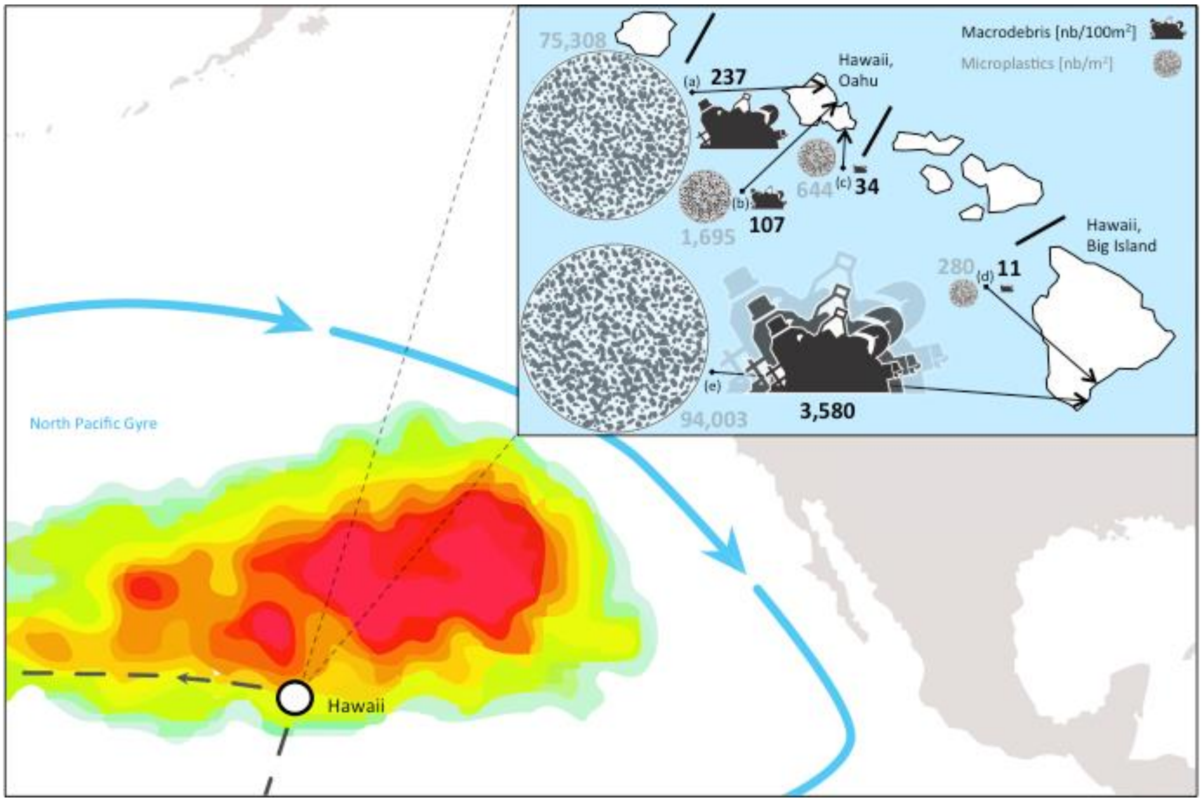


Figure 15 : Items concentration of macrodebris (black icons) per 100 m² and microplastics (grey circles) per m² on the Hawaiian Archipelago. Symbol size is proportional to the concentration, but with a different scale between the two categories. (a) Kahuku, (b) Kahana, (c) South Makapuu, (d) Kawa Bay, (e) Kamilo Point.

Samplings on the Hawaiian Archipelago were performed on five different shorelines, three located on Oahu island (Kahuku, Kahana and South Makapuu) and two on Big Island (Kawa Bay and Kamilo Point) (Figure 15 and 16). Macrodebris and microplastics concentration values follow broadly the same trends within the Archipelago. However, two sites – Kamilo Point and Kahuku – were dramatically affected by microplastic pollution though. Over all of the sites visited during the 2015 Odyssey, Kahuku and Kamilo Point showed the highest recorded concentrations with around 75,000 and 94,000 microplastics per m^2 respectively. As a comparison, except Ovahe beach on Easter Island with around 25,000 microplastics, the other highest concentrations recorded throughout the Odyssey did not exceed 5,000 microplastics per m^2. Recent computer modelling based on geostrophic currents, Ekman processes and Stockes theorem showed that the pic concentration of marine debris in the North Pacific – in other terms the center of gravity of the Northeast Pacific Gyre – is probably located in the Northeast of the Hawaiian Archipelago, which could explain why greater levels of pollution were observed on the Easter coastline (2). Even before the North Pacific Gyre identification by Charles Moore in 1997, few Hawaiian NGOs were already conducing clean-up campaigns to fight the marine debris accumulation on the shorelines.

Unlike other sites such as Kahana, South Makapuu or Kawa Bay, Kamilo Point is a remote and isolated place with no tourism. Despite this, clean-up campaigns are regularly organized over Kamilo Point because its has been spotted as a convergence area of marine currents, which leads to a critical accumulation of debris (12) (13) (14). Supervised by the Hawaii Wildlife Fund, several volunteers have collected almost 200 tons of marine debris since 2003. Since no tourists visit Kamilo Point, the site is a direct indicator of marine pollution affecting this area of the Pacific Ocean. However, the influence of local specificities – such as the marine currents – plays a significant role in the deposition patterns of marine debris, since Kawa Bay located a few kilometers north is much less affected by macro- and microplastics. Despite that, whether considering macrodebris or microplastics, Kamilo Point is the Odyssey's primary hotspot. Macrodebris concentration reached more than 3,580 per 100 m^2, which is almost ten times as much as the second highest recorded concentration of 372 macrodebris per 100 m^2 in Pago Bay on Guam island. Improbable debris such as a plastic table, a vacuum cleaner, a one cubic meter container, a few little dolls, and boat devices were found. As a whole, an impressive number of bottle caps, ropes, fishing lines, plastic containers and hard plastic fragments were collected. Over the Archipelago, Kahuku is the second most impacted site, and here, too, clean-up campaigns are organized on a regular basis. In September 2016, 1,633 tons of debris were collected over approximatively 1.6 kilometers of Kahuku's shoreline (15). A recent study of high resolution imagery for the detection of marine debris over the coast of the Hawaiian Archipelago also confirmed that Kamilo Point and Kahuku are hotspots in terms of marine debris concentration (16). This study also highlighted the strong prevalence of plastic among the identified marine debris.

<u>Figure 16 :</u> Sampling performed on the Hawaiian Archipelago (P. Charaf pictures).

4.5. Mariana (Guam)

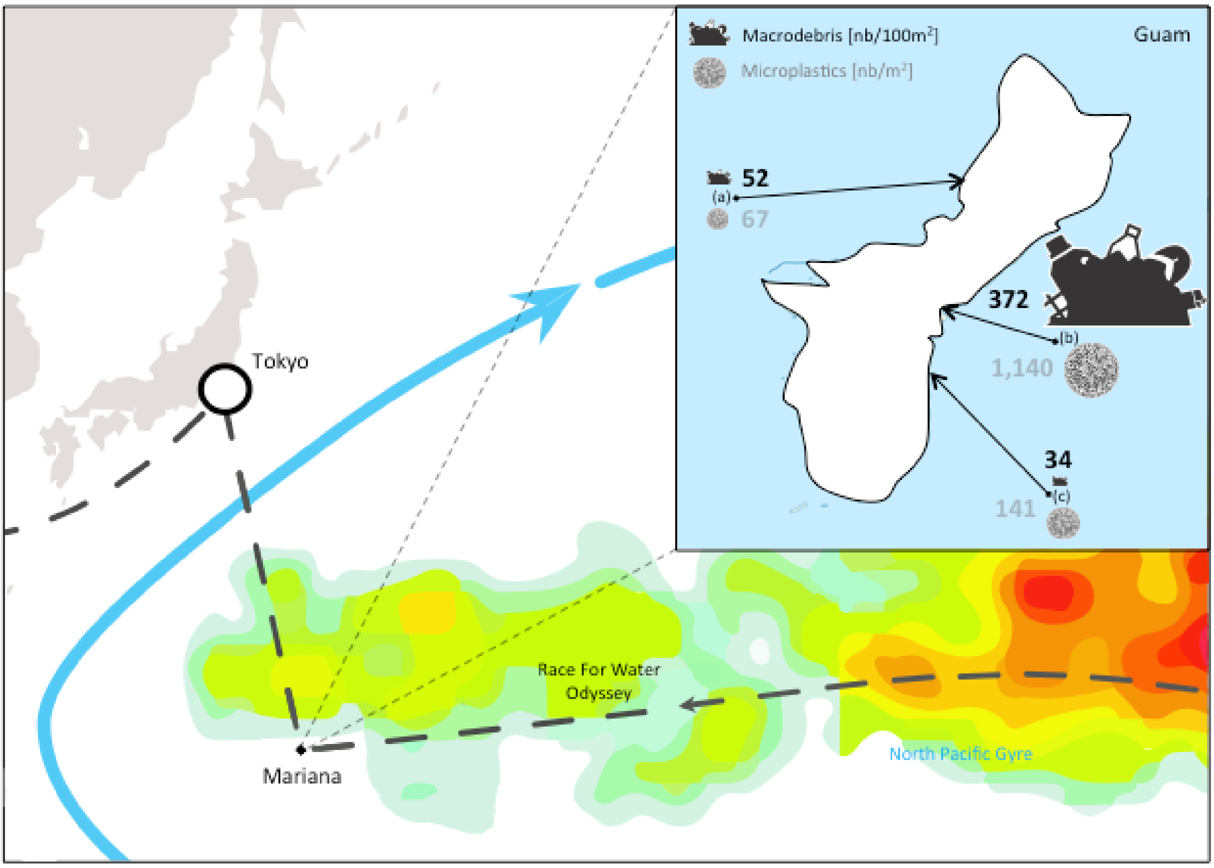


Figure 17 : Items concentration of macrodebris (black icons) per 100 m² and microplastics (grey circles) per m² on Guam island. Symbol size is proportional to the concentration, but with a different scale between the two categories. (a) Tanguisson, (b) Pago Bay, (c) Ipan.

Samplings in Guam were carried out on the 14th and 15th of July 2015, which is almost two weeks after the Chan-hom typhoon hit the island on the 5th of July and only a few days after another tropical storm (9th and 10th of July 2015). These extreme weather events may explain why plenty of debris were identified behind the shoreline (which is defined by the first barrier or primary substrate change).

Besides, according to some local people, it seems relatively common that some local residents dispose of their own garbage on the beaches to avoid paying the local waste treatment tax. Indeed, an important fraction of collected macrodebris had a local origin, especially on Tanguisson beach located on the western coast of Guam where fragments of plastic cutlery and other food packaging were found at the back of the shoreline. On the other side of the island on the windward coast, Pago Bay beach is the site where the highest local concentration was monitored with 372 macrodebris per 100 m² with a mix of marine and local pollution (Figure 17 and 18). More than nine months after our sampling, another sampling performed by Laura Biggs and other students of Guam University recorded almost twice as much as we did with 626 macrodebris per 100 m².

Despite the action of local environmental activist groups fighting plastic pollution such as Marine Mania led by Linda Tatreau - which has existed for over 25 years, the local waste management system remains inadequate to deal with this situation, but above all behavioral evolution seems to take time. On a broader scale, the last clean-up event organized by the International Coastal Cleanup (ICC) in 2015 collected a total of 91,183 macrodebris over 54 kms (which corresponds to approximatively 80 macrodebris per 100 m^2), and 1,411 macrodebris over the 800 meters of Pago Bay beach (which corresponds to approximatively 90 macrodebris per 100 m^2) (17). As often, concentration levels monitored are highly variable.

Finally, the state of preservation of the collected debris, and especially containers, bottles and caps - deserves to be emphasized. Notably, brand labels were still clearly readable (some indonesian ones especially), which seems to confirm the local origin of the collected marine debris.

Figure 18 : Sampling performed on Guam island, Mariana (P. Charaf pictures).

4.6. Palau (Ulong, Ngerong, Helen reef)

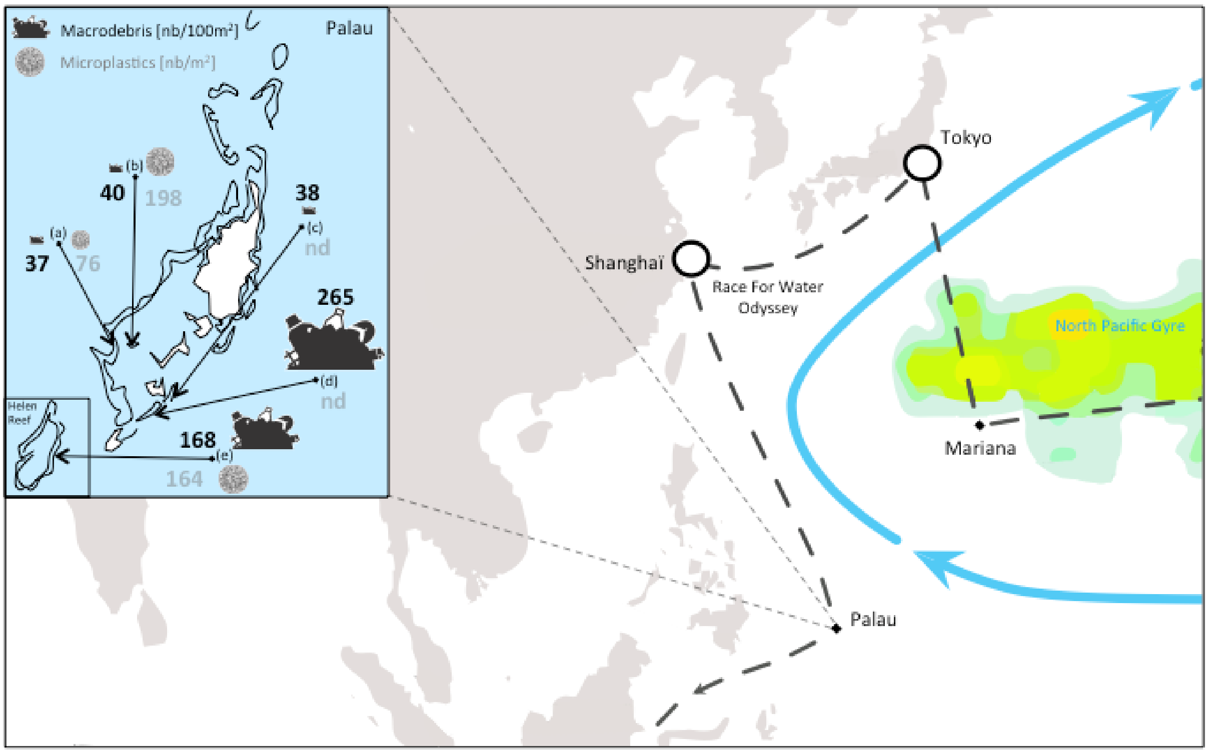


Figure 19 : Items concentration of macrodebris (black icons) per 100 m² and microplastics (grey circles) per m² on Palau. Symbol size is proportional to the concentration, but with a different scale between the two categories. (a) Ulong sand bank, (b) Ulong island, (c) Ngerong sand bank, (d) Ngerong island, (e) Helen reef.

Compared to Hawaii and Mariana, Palau's special feature is that it is located far away from the North Pacific Gyre (Figure 19). This archipelago is located, however, off the coasts of Philippines and close to the China Sea and other countries identified as major contributors of the marine plastic pollution, namely China, Philippines, Vietnam and Indonesia too (18). In order to avoid any bias due to the protection that the reef barrier surrounding the islands offers, the samplings were performed on beaches of remotes islets and sand banks located on or near the outside reef barrier.

With a maximum of 265 per 100 m^2 at Ngerong Island, macrodebris concentration of some sampled sites are significantly high but are lower than the maximum reached on Guam island (372 per m^2). However, unlike the other stopovers, the most represented macrodebris category was not the hard plastic fragments but the transparent PET bottles (39% of item concentrations), followed by the plastic bottle caps (30% and only 11% for the hard plastic fragments). The state of conservation of bottles with still readable brand labels indicated mostly regional origins, mainly Asian. In accordance with the results of the last International Coastal Cleanup (ICC) annual report in September 2016, plastic bottles remain one of the most frequently collected debris over the world's shorelines (19). Lastly, sandals (ressembling flip-flops) also constitute a significant fraction of the collected debris. As a whole, the results are consistent with the study carried out in 2007 over Palau that also identified a large part PET bottles and rubber sandals (20).

With 168 macrodebris collected per 100 m^2, Helen reef – which a remote atoll located almost 580 km in south of Koror city – is Palau's second hotspot. Only a few state rangers of Hatohobei are living there. According to the literature, the surrounding currents of Palau main island bring marine debris to this atoll (21).

Microplastics concentrations turned out to be highly variable, starting from non-detected to almost 198 particles per m^2 over Ulong island. Compared to other stopovers, the maximum reached is relatively low.

Figure 20 : Sampling performed on Palau (P. Charaf pictures).

4.7. Chagos (Diego Garçia, BIOT)

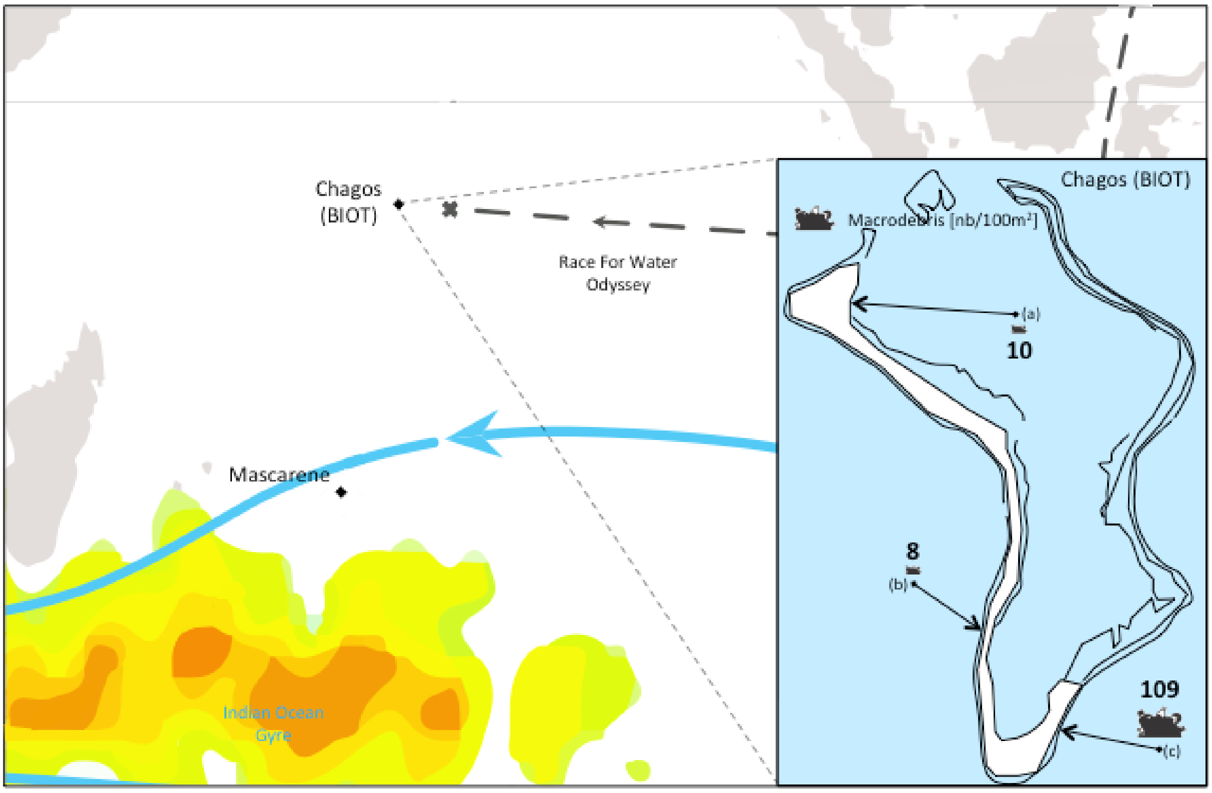


Figure 21 : Items concentration of macrodebris (black icons) per 100 m² on Diego Garcia island. Symbol size is proportional to the concentration, but with a different scale between the two categories. Sampled sites have no specific name[2].

On Diego Garcia, three different sites were sampled (Figure 21 and 22). Monitored macrodebris concentrations were not significantly high (maximum of 109 per 100 m² recorded). Nevertheless, it is noteworthy that the most represented category among debris was plastic foam debris (presumably polystyrene), followed by plastic bottle caps. Flip flops and rubber sandals were also collected in significant quantities. Even if the measured levels were not comparable, Price and Harris samplings carried out in 1996 and 2006 also confirmed that plastic bottles, foams and sandals are strongly represented among the marine debris categories over the Chagos (22).

Chagos Archipelago acts as a barrier against the eastward oceanic currents in this region of the Indian Ocean. This feature could be an explanation for the higher concentration recorded on the western shoreline exposed to these oceanic currents. Nevertheless, unlike the rest of Chagos, Diego Garcia is inhabited. There is indeed a British military base. The relatively low macrodebris concentration compared to other stopovers is probably due to the presence of servicemen aware of the problem, who clean up regularly (23).

[2] The *Race For Water* trimaran capsized approximatively 50 nautic miles before Chagos. The crew members were rescued by the British navy (BIOT) of Diego Garçia. Thanks to Helen Stevens, marine debris concentrations were recorded on Diego Garçia island. Unfortunately, we could not exploit microplastics informations.

<u>Figure 22 :</u> Sampling performed on Diego Garcia (BIOT), Chagos (P. Charaf pictures).

4.8. Mascarene (Rodrigues)

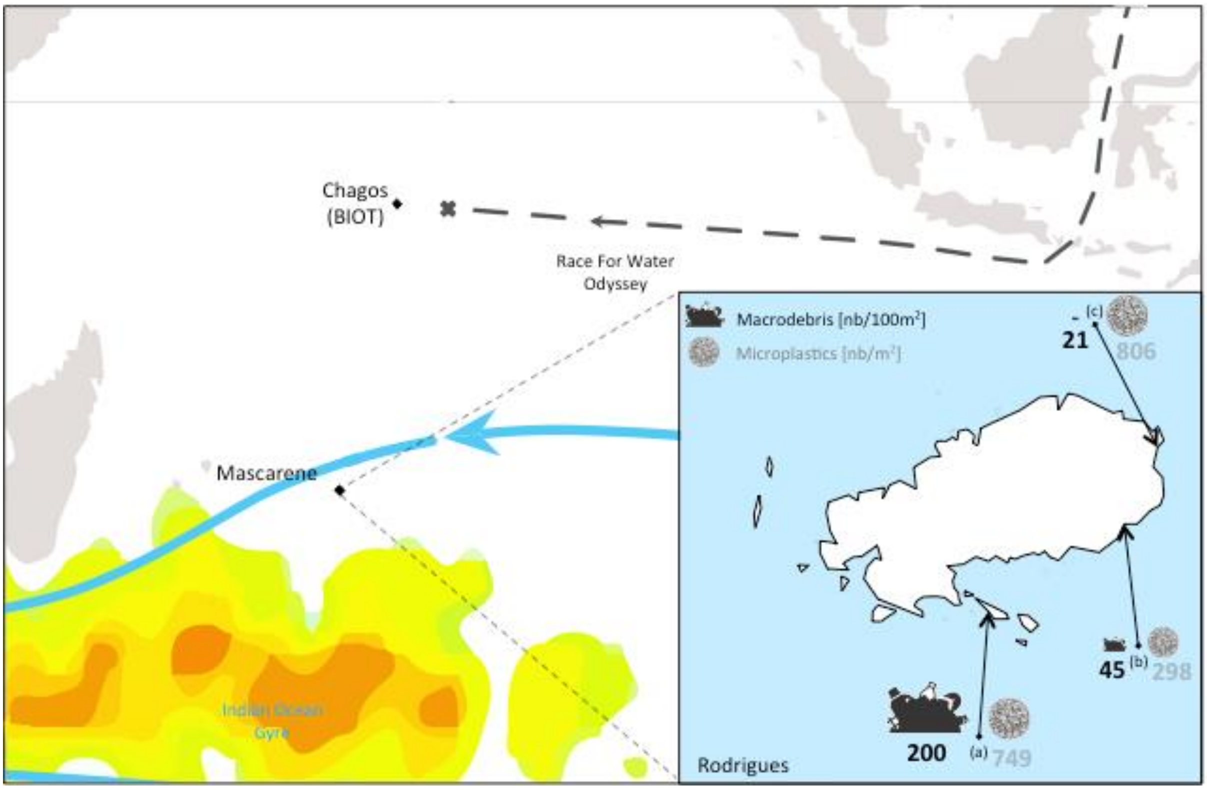


Figure 23 : Items concentration of macrodebris (black icons) per 100 m² and microplastics (grey circles) per m² on Rodrigues island. Symbol size is proportional to the concentration, but with a different scale between the two categories. (a) Gombrani, (b) Gravier, (c) Anse Ally[3].

Three different sites were sampled on Rodrigues island : Anse Ally (the most easterly site), Gravier and Gombrani islet (in the south) (Figure 23 and 24). Macrodebris concentrations start from 21 up to 200 per 100 m^2, whereas microplastic concentrations are between 298 and 806 per m^2.

Gombrani islet is a reserve, an entirely protected area. However, according to local people, the close channel would bring quantities of debris. Amongst the categories of macroplastic collected, hard plastic fragments clearly dominate, followed by plastic bottle caps, film fragments, ropes and fishing lines fragments, containers and plastic bottles. These major categories found are in accordance with the results of an other study published in 2015 (24).

[3] Since the boat capsized close to the Chagos Archipelago, *Race For Water's* team travelled by airplane to pursue the sampling.

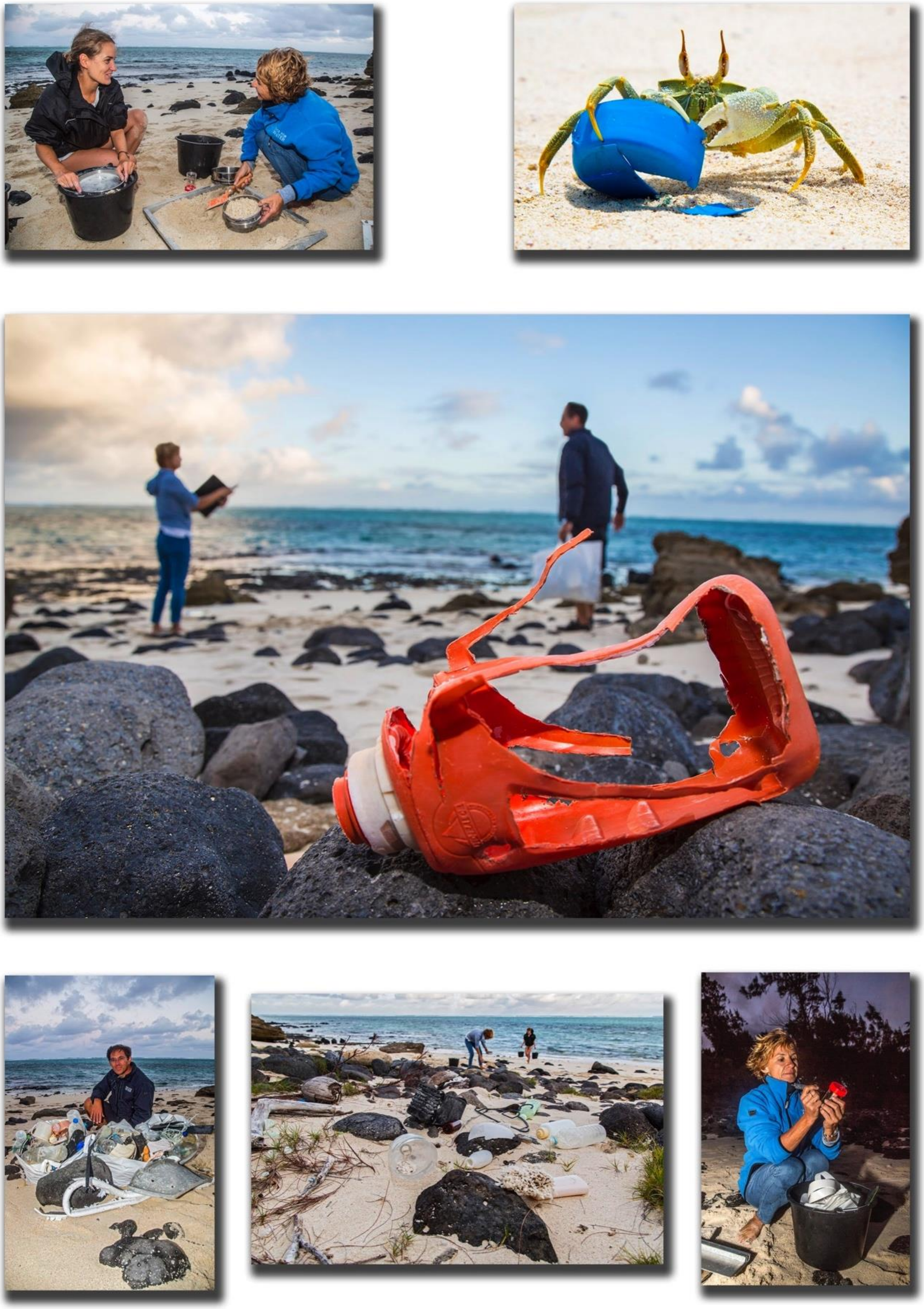


Figure 24 : Sampling performed on Rodrigues island, Mascarene (P. Charaf pictures).

4.9. Tristan da Cunha

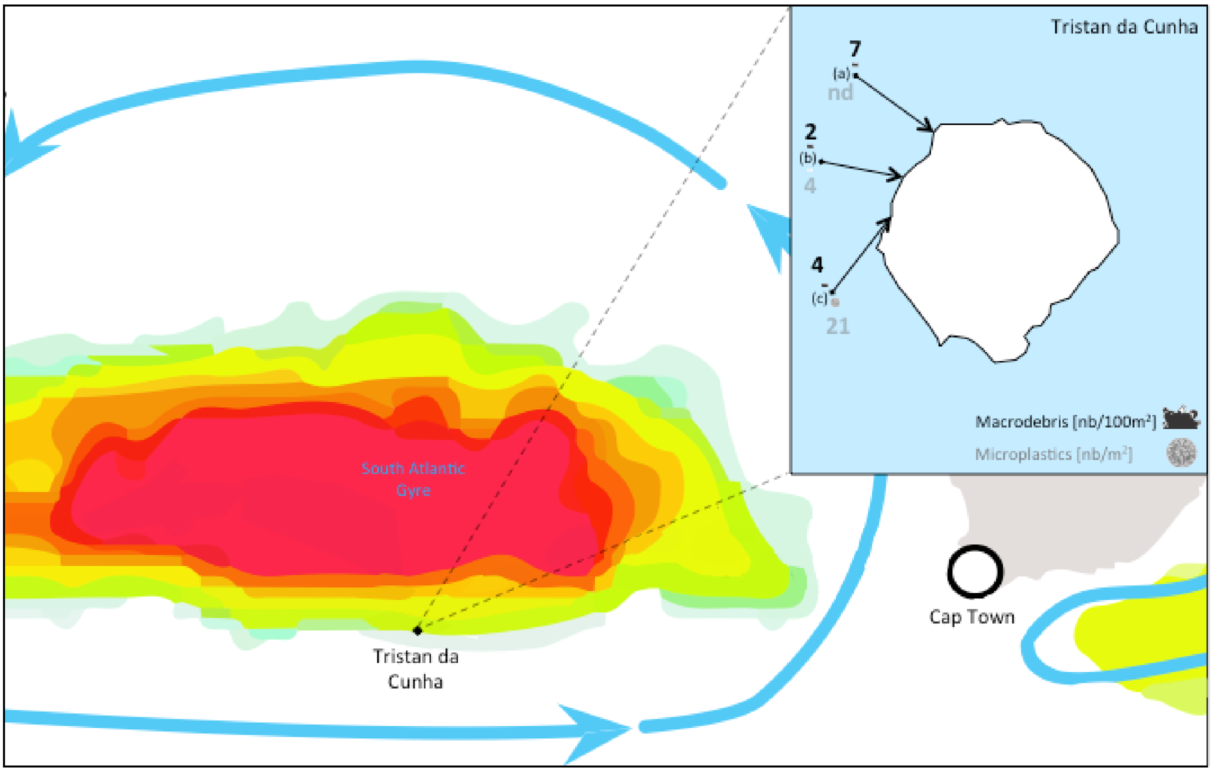


Figure 25 : Items concentration of macrodebris (black icons) per 100 m² and microplastics (grey circles) per m² on Tristan da Cunha island. Symbol size is proportional to the concentration, but with a different scale between the two categories. (a) Hottentot Point, (b) Runaway, (c) The Bluff[4].

Tristan da Cunha is a volcanic island located theoretically close to the South Atlantic Gyre (Figure 25 and 26). The geomorphology of the island did not allow a sampling campaign evenly distributed around the island. Indeed, the rocky coast has number of cliffs and inaccessible shorelines. Beaches are often composed of pebbles, and the sampling could not be carried out on 100% sandy beaches. Unfortunately, this feature can have a significant impact on the microplastic collection, since they can easily reach depth of more than 10 cm with pebbles. Indeed, recorded microplastic concentrations are really low, and are not even detected for exemple on Hottentot Point beach in the north of the island.

Macrodebris concentrations are also relatively low. According to a study realized by Peter G. Ryan from Cape Town University (South Africa), samplings made between the island's harbour and Hottentot Gulch also highlighted a low concentration (147 macrodebris on approximatively one kilometer of shoreline, which is equivalent to less than one macrodebris per 100 m²). Main debris collected were - once again – plastic bottles with caps, foams, hard plastic fragments and polystyrene foam (Peter G. Ryan, Cape Town University). These categories are predominant in our results too (see Figure 7). The distance between Tristan da Cunha (floating density in the surrounding waters of 1.0 ± 0.4 items/km²) and areas of higher density in marine debris in the South Atlantic Gyre (6.2 ± 1.3 items/km²) could explain these relatively low concentration levels (25).

[4] The sampling was carried out with the help of the Percy FitzPatrick Institute of African Ornithology (University of Cape Town, South Africa), and namely Peter Ryan, Ben Dilley, Delia Davies, George Swain and Julian Repetto.

<u>Figure 26 :</u> Sampling performed on Tristan da Cunha (B. Dilley pictures).

5. Conclusion

This study provides a momentary snapshot of the marine debris pollution on shorelines selected for their proximity to oceanic gyres. This kind of intermittent survey on a large scale has the advantage of providing consistent and comparable data to establish pollution baseline levels. Nonetheless, the intermittent nature of this monitoring does not allow an identification of the potential bias with certainty. In this case, macrodebris concentrations monitored during this study can suffer from site-specific influences (such as the popularity and tourist numbers, as well as the clean-up frequency). By contrast, microplastic concentration on the shorelines is a much more reliable and robust indicator of the plastic pollution levels. In fact, microplastics are not collected during clean-up campaigns and do not result from local mismanagement of waste. Sampled according to a depth gradient (and in an appropriate substrate), microplastic concentrations can probably also provide a historical record of the plastic contamination evolution, taking into account weather events (26).

However, certain macrodebris concentrations monitored during this Odyssey can be considered as relevant. This applies in particular to the maximum reached in Kamilo Point (Hawaii) with more than 35,000 macrodebris per 100 m^2, as well as the minimum recorded on Runaway beach (Tristan da Cunha) with two macrodebris per 100 m^2. Except for certain sampled sites completely free from microplastics in Palau, microplastic maximum and minimum levels were reached on the same geographical areas with more than 94,000 per m^2 in Kamilo Point and none in Hottentot Point (Tristan da Cunha). This seems to confirm the extremes. Looking more closely at microplastics, it is worth considering the average contamination level reached over Hawaii (Northeast Pacific) with more than 35,000 microplastics per m^2, and over Easter Island (South Pacific) with more than 11,000 per m^2. Indeed, these concentration levels are significantly higher than other sampled spots during this Odyssey with five digit values per m^2, whereas Azores (Northeast Atlantic) reaches four digits per m^2, and Mascarene (Indian Ocean), Bermuda (Northwest Atlantic) or Mariana (Northwest Pacific) reach three digits per m^2. These results confirm that marine debris accumulations in the Pacific Ocean close to Hawaii are of the greatest concern, followed by those of the South Pacific.

Beyond the predominance of hard plastic fragments resulting from the physiochemical and biological degradation of various type of bigger debris, collected debris categories show a pattern of interesting trends, such as the significant presence of ropes and fishing lines in Bermuda. In the Chagos, foams are largely predominant, whereas in Easter Island the shorelines are strongly affected by pellets. Lastly, even if they were collected almost on every geographical area in significant quantities, plastic bottle caps concentrations were even higher in areas located in close proximity to Asia (Mariana, Palau and Mascarene). Plastic bottles followed the same trend with particularly affected sites over Palau and Chagos.

Apart from these results, the 2015 Odyssey resulted in an essential experience to meet, to listen and to understand those men and women facing the degradation of the local environment on a daily basis, which - despite their efforts to raise awareness and clean-up their shorelines – is worsening. As much as a quantified overview of the world's ocean plastic pollution, such experience sharing and discussions allow to account for the rapid and unprecedented contamination of the marine environment in general, and the world's oceans and shorelines. From there, giving a voice to these people and allowing younger generations to grasp the issues of this pollution throughout scientific and educational projects aboard a larger navigating platform, such as the solar vessel, has become an evidence for the *Race For Water* Foundation.

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We would like to thank all the people listed below very warmly, especially for their useful guidance in selecting and sampling the beaches during the 2015 *Race For Water* Odyssey. Beyond the help they provide us and the fruitful discussions we had together, we wish to acknowledge their individual and/or collective actions to raise awareness, clean, prevent and manage the plastic marine pollution that affect them on a daily basis with an increasing magnitude.

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- Henrique Ramos, CEO at *SeaExpert*, Fisheries and Services, Azores, Horta, Portugal;
- Victor Monteiro, *Surfrider Foundation Europe* Azores, Horta, Portugal;
- Paulo de Melo, Manager at *Surfrider Foundation Europe* Azores, Ponta Delgada, Portugal.

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- Brenda Ann Atalig, Watershed Coordinator at *Guam Coastal Management Program*, Guam, USA;
- Denise Reyes, Teacher at *Guam Home School Association*, Guam, USA;
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- Henrick Bowman, Professor at *North West University, Unit for Environmental Science,* South Africa;
- Dr. Peter Ryan, Director and professor at *Percy FitzPatrick Institute of African Ornithology*, Cape Town, South Africa;
- Ben Dilley, Delia Devies, George Swain and Julian Repetto, scientists at *Percy FitzPatrick Institute of African Ornithology*, Cape Town, South Africa.

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Appendices

Appendix 1 : Relevant characteristics of the region and weather-related factors affecting marine debris deposition

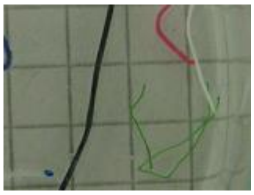
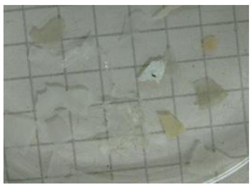
ARCHIPELAGO	AZORES	BERMUDA	EASTER ISLAND	HAWAII		MARIANA	PALAU			CHAGOS (BIOT)	MASCARENE	TRISTAN DA CUNHA
VISITED ISLANDS	**Faial**	**Bermuda**	**Easter Island**	**Oahu**	**Big Island**	**Guam**	**Ulong**	**Ngerong**	**Helen Reef**	**Diego Garcia**	**Rodrigues**	**Tristan da Cunha**
ocean surface current	North Atlantic Subtropical Gyre		South Pacific Subtropical Gyre	North Pacific Subtropcial Gyre			North-Equatorial Current of the North Pacific Ocean			South-Equatorial Current of the Indian Ocean	Indian Ocean Subtropical Gyre	South Atlantic Subtropical Gyre
direction of prevailing winds	northeast trade wind	northeast trade wind	southeast winds in summer northerly winds in winter	northeast trade wind in summer south wind in winter		northeast trade wind	east winds			monsoon	southeast winds	persistent western winds
number of inhabitant	250 018 in 2014	65 024 in 2013	5 761 in 2012	953 207 in 2014	186 738 in 2011	165 124 in 2013	20 198 in 2013		0	4 000 in 2004	41 669 in 2014	266 in 2016
date of survey	from 19/03/2015 to 22/03/2015	from 30/03/2015 to 03/04/2015	from 21/05/2015 to 22/05/2015	from 20/06/2015 to 25/06/2015		from 14/07/2015 to 16/07/2015	from 22/08/2015 to 28/08/2015			from 15/12/2015 to 22/03/2016	from 24/09/2015 to 30/09/2015	06/03/2016
extreme weather events (just before sampling)	spring tide of the century (21/03/2015)	2 hurricanes Fay and Gonzalo (12-17/10/2014)	no recent storms	2 hurricanes Iselle and Ana (08-10/2014)		2 typhoons Chan-hom (05/07/2015) and Dolphin (15/05/2015) + tropical storms (9-10 /07/2015)	2 typhoons passed north of the archipelago (end of wet season)			no recent storms	tropical storm Bansi (15/01/2015)	no recent storms

Appendix 2 : Relevant local characteristics affecting marine debris deposition

ARCHIPELAGO	AZORES			BERMUDA			EASTER ISLAND		HAWAII					MARIANA			PALAU					CHAGOS (BIOT)				MASCARENE		TRISTAN DA CUNHA		
VISITED ISLANDS	Faial			Bermuda			Easter Island		Oahu			Big Island		Guam			Ulong		Ngerong		Helen Reef	Diego Garcia				Rodrigues		Tristan da Cunha		
BEACH	Porto Pim	Do Norte	Conc-eiçao	Well Bay	Grape Bay	Somerset Long Bay	Anakena	Ovahe	Kahuku	Makapu	Kahana	Kawa Bay	Kamilo	Ipan	Tanguisson	Pago Bay	Ulong sand bank	Ulong	Ngerong sand bank	Ngerong	Helen Reef	Diego Garçia 1*	Diego Garçia 2*	Diego Garçia 3*	Gravier	Anse Ally	Gombrani	The Bluff	Runaway	Hottentot
exposure 1- facing the wind 2- lee shore / sheltered 3- accumulation area 4- offshore eddies (waves) 5- strong slope (cliff) 6- lagoon side	3	5	2	3	1	2	2	1	1;4	1;4	2.4	1;4	1;3	2	2;4	3	2	2	1	1	1	2	2	6	1;4	1	2;3	1;5	1;5	1
aspect	W	NW	S	S	S	NW	N	E	NE	E	NW	SE	E	E	W	E	W	W	S	S	E & W	SE	SW	NE	SE	E	E	W	W	W
substratum type 1- fine sand 2- volcanic sand 3- coral sand	1	2	1	1	1	1	1	1	1	1	1	2	1	1	1	2	1	1	3	3	3	1	1	1	1	1	3	2	2	2
Local pollution sources 1- river / creek input to beach 2- strong rain input 3- landfill / open-air dump 4- recreation area 5- none of the above	1	3	4	5	5	4	5	5	5	5	1	5	5	1	5	1	5	5	5	5	5	5	5	5	2	2	5	2	2	2
clean-up operations 1- very regular (once a day /week) 2- regular (once a month) 3- little regular (once or twice a year) 4- unknown frequency / none	1	3	2	2	4	2	1	1	3	2	2	2	2	3	2	2	2	1	4	4	4	2	4	4	2	1	3	4	4	4
tourist popularity of the beach *** strong (especially in summer) ** low (private beach/ remote) * very low (nonexistent)	***	**	***	***	**	***	**	**	**	**	**	**	*	**	***	**	**	**	**	**	*	*	*	*	**	***	**	*	*	*
access *** very easy ** easy * difficult o only boat access	***	**	**	**	**	***	**	**	**	***	***	**	*	**	**	**	o	o	o	o	o	*	*	*	**	**	o	*	**	**

* GPS coordinates
Diego Garcia 1 (72'27.2316 E; 07'24.8304 S)
Diego Garcia 2 (72'25.6401 E; 07'22.3832 S)
Diego Garcia 3 (72'22.6243 E; 07'15.9675 S)

Appendix 3 : Microplastics categories and potential usages

Types	Possible usages/origins	Examples
Hard plastic fragments	Unspecified plastics / Degradation of bigger debris	
Pellets	Pre-production, raw material / Industrial	
Beads (Microbeads)	Cosmetic	
Fishing lines	Fishing sector	
Fibres	Fabrics	
Thin films (transparent)	Packaging	
Foams	Expanded or solidified polystyrene / Construction and Food sectors