Curtin University

Research Report

AROUND THE PLASTIC WORLD IN 455 DAYS

a citizen science global transect quantifying microplastics in the oceans

WA-OIGC

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Abstract

Public perception of plastics in the oceans has increased over the last few decades, but only more recently has the potential harm to organisms due to ingestion of microplastics started to be recognized. The monitoring of larger plastics lends itself to Citizen Science projects but sample collection and analysis of microplastics (0.05 – 5 mm) is more challenging. In this Citizen Science project, world-renowned, single-handed yachtsman Jon Sanders (AO, OBE) teamed up with Western Australian Isotope and Geochemistry Centre (WA-OIGC) researchers at Curtin University, to raise awareness of microplastics in the oceans, and to quantify the numbers of microplastic particles present along a global transect using daily water filtration. In particular, the study aimed to provide data for remote areas of the southern hemisphere for which very little data existed previously.

The voyage was carried out by Jon Sanders on board Yacht Perie Banou II, departing Fremantle port, Western Australia, on 3rd November 2019 and returning on 31st January 2021, a total of 455 days (somewhat longer than anticipated due to the Covid-19 Pandemic) and spanning 46,100 km. Approximately 115 L of seawater was pumped per day from an inlet in the hull, close to the bow of Perie Banou II, and filtered onto stainless steel woven filters with 43 µm aperture (equivalent imperial: mesh 325). No plastic was present in the filtration system. During stopovers in ports, the filters were couriered to the WA-OIGC laboratories for processing and analyzes by Attenuated Total Reflectance (ATR) Fourier-transform infrared spectroscopy (FTIR).

A total of 177 filters were analyzed resulting in a mean count of 33 microplastics m^{-3} seawater across the entire global transect. The Pacific Ocean was found to contain the least numbers of microplastic particles with 23 and 15 microplastics m^{-3} seawater for the eastern and western sides of the Pacific transect respectively. The highest recorded numbers were 291 and 246 microplastics m^{-3} seawater for two contiguous stations south of the equator in the Atlantic Ocean, both of which were over 600 km from the Brazilian coastline. Microplastic particles found were typically close to the lower size limit defined as microplastic i.e. 50 µm and were mostly grey/black in color.

The collaboration between Jon Sanders' Citizen Science team and WA-OIGC researchers was highly successful. The study was the first global transect of microplastics in the oceans that utilized consistent sampling methods throughout. The data was consistent with other scientific surveys of remote areas of ocean and could act as a benchmark for future studies into microplastics in the oceans.

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Introduction

Public perception of plastics in the Oceans

Plastics have been making their way into the world's oceans since their use became common in the 1950s (Ostle et al. 2019). Despite being a recyclable resource, plastic products have largely been treated as throwaway items thus impacting fossil fuel reserves, climate change and environmental pollution. It has been argued (Pahl et al. 2017) that in order to change how this valuable resource is perceived and utilized we should build "intrinsic motivations for better waste management and recycling". These intrinsic motivations could derive from different sources including "pro-environmental identity, people's passion for or connectedness to the ocean, social norms, and aversion to litter's aesthetic effect on natural environments" (Pahl et al. 2017). Plastics in the environment has become one of the most pressing issues of public concern which has prompted efforts to write a global treaty negotiated by the United Nations, resulting in the Basel Convention plastic waste amendments (http://www.basel.int/Implementation/Plasticwaste/PlasticWasteAmendments/Overview/tabid/8426/Default.aspx). Such public concern has grown following the publication of photos showing massive accumulations of plastics in very remote areas of the oceans due to circular currents, referred to as gyres, and to the impacts of large pieces of plastic observed to cause suffocation of marine animals such as turtles. The ubiquitous nature of small pieces of plastic, termed microplastics (<5 mm), has been of scientific interest but until recently has been less prominent in the public consciousness. However, awareness has been growing as a consequence, at least in part, to documentary films such as David Attenborough's Blue Planet and numerous outreach projects conducted by scientists keen to share their knowledge outside of the usual peer-reviewed publications. Members of the public who have also taken a special interest in some areas of research, have furthered their involvement through citizen science movements.

Citizen science

Citizen science is a term given to scientific research conducted, in whole or in part, by amateur (or nonprofessional) scientists (Gura 2013). Citizen science projects can take many different forms but when citizen scientists partner with professional scientists to achieve specific outcomes it is perhaps at its most powerful. Yacht crews can be at sea for weeks or even months. During this time, they can become highly conscience of their environment and become very aware of contamination by visual anthropogenic inputs such as plastic garbage floating on the ocean surface. It is perhaps therefore not surprising that some yachtsmen and yachtswomen wish to initiate and contribute to citizen science projects.

Dedicated scientific voyages to sample remote regions of oceans are extremely expensive. An alternative approach has been to model where microplastics may accumulate based on studies that have measured microplastics coupled with ocean current data and known inputs etc. (e.g. Cózar et al. 2014). As with all models, their ability to reliably predict distribution improves with addition of data and ground-truthing. This provides an opportunity where citizen science can make a real contribution. In this study, a complete circumnavigation of the globe was undertaken to sample remote areas of the oceans using consistent sampling methodology throughout the voyage. Although the focus was upon remote areas of the oceans within the Southern Hemisphere where few studies had been conducted, the global transect also passed though regions previously sampled during scientific expeditions (e.g. Desforges et al. 2014) thus allowing data to be compared. Undertaking such a voyage is of course still very expensive but was possible due to crowd-funding donations and by sponsorships. This particular voyage also had extensive international media attention, something rarely received by scientific expeditions so early on. This media coverage highlighted to the public the sheer extent of ocean microplastics, brought to light globally through the involvement and leadership of world-renowned veteran yachtsman Jon Sanders in completing the entire project's sampling single-handed.

Jon Sanders (AO, OBE)

Jon Sanders is a highly experienced yachtsman who, in 2018, was inducted into the Australian Sailing Hall of Fame for his numerous accomplishments (Fame). These include:

- 3 x non-stop circumnavigations 1986-1987.
- 5 x Cape Horn roundings (one east-west & four west-east).
- 4 x roundings of the five southernmost capes.
- 1 x circumnavigation using the east-west route.
- 2 x circumnavigations using the west-east route.
- Circumnavigate non-stop via Cape Horn west-about and east-about.
- Skipper of small yacht (less than 15.5m) to complete these voyages and circumnavigations, crewed or single-handed.
- The first single-handed sailor to remain continuously at sea twice around the world.
- First single-handed sailor to round the five southernmost Capes twice on one voyage.

- First single-handed sailor to round the five southernmost Capes twice.
- Longest distance continuously sailed by any yacht: 78,070 km.
- Longest period alone at sea during a continuous voyage: 419 days: 22 hours: 10 minutes.

Having completed 10 single-handed circumnavigations of the globe, Jon Sanders had seen the quantity of plastic garbage increasing over the years. This led to further inquiry and the discovery that the visible plastic was just one aspect of the contamination and that much smaller pieces of plastic, some microscopic, lurked on and beneath the surface. From this, a citizen science project began to emerge. Having said at the end of his 10th circumnavigations "never again", Jon Sanders developed an idea for another voyage, this time to raise awareness about the microplastics in the oceans.

Rationale for sample collection system

Many of the studies into microplastics in the marine environment have made use of plankton nets, in particular Neuston nets, that filter the top few centimeters of the ocean (Barrows et al. 2017, Gago et al. 2018). It consists of a towing line and bridles with, typically, a nylon mesh net and cod end. The net is towed behind a vessel which can cause issues with microplastics derived from the vessel being captured. Hence, deploying the equipment to the side rather than immediately behind the vessel is preferred (Barrows et al. 2017, Gago et al. 2018). By slowly towing the net for typically about a kilometer, a huge volume of water can be filtered, providing a measurement for plastic quantity in potentially over a million litres of seawater each tow (Gago et al. 2018). Due to the buoyancy of most macro-sized plastics, they tend to be concentrated on or near the surface before they become encrusted with organisms and eventually sink to the ocean's depths (Kanhai et al. 2019, Porter et al. 2018).

The deployment of plankton nets was not an option for the current study due to it being undertaken by a lone yachtsman. An alternative was devised whereby a simple seawater pump was installed in the bow of the yacht with an inlet in the hull. Microplastics and other debris was then filtered from a recorded volume of water using a suitable sized mesh. This had the advantage of both being able to record the exact volume of water filtered and reducing the risk of microplastic contamination from the vessel due to its proximity to the bow. Plastic material was avoided throughout the development and use of the sampling system to ensure a high degree of confidence that the filtered seawater has not been contaminated during the sampling procedure. Such a system can be operated by a single person with negligible risk to personal safety. The seawater intake cannot be at the ocean-air interface as this would cause issues with the pumping system and therefore, was placed just below the waterline. This consequently meant highly buoyant plastics occurring at the surface were not sampled and hence the recorded microplastic numbers are likely less than if the surface water was also sampled. The major disadvantage for this system is that, only a relatively small volume of seawater can be filtered on the small yacht. During the method development for this study, it was calculated that about 100 L of seawater could be filtered within a reasonable time frame (20 minutes), which would not cause issues with the pump or force deviation from the yacht's course for an excessive period. This is potentially orders of magnitude less seawater volume than by towing a plankton net or pumped by a large scientific vessel. However, given the high concentrations of microplastics previously reported in some regions of the ocean (Desforges et al. 2014, Law et al. 2010), this volume of seawater was estimated to be sufficient to detect relatively high to moderate concentrations of microplastics present in the immediate sub-subsurface of the ocean. However, it should be noted that if no microplastics are recorded in a particular area, it does not mean there were no microplastics present moreover, the numbers were sufficiently low to miss collection in a single sample. The degree of microplastic concentration and associated threat to marine organisms is not fully understood (Anbumani and Kakkar 2018, Covernton et al. 2019, Everaert et al. 2018, Ha and Yeo 2018, Rochman et al. 2016) but it can be logically concluded that areas of high ocean microplastic concentrations would pose a greater threat than to those with lower concentrations.

Aims of study

This study was initiated as a citizen science project to highlight the presence of microplastics in the oceans. It also aimed to provide some insight into the concentrations of microplastics in previously unstudied regions, in particular remote areas of the southern hemisphere. Working with scientists at the Western Australian Isotope and Geochemistry Centre (WA-OIGC), Curtin University, the expedition team were able to construct a sampling methodology that filtered a reasonably large volume of seawater whilst minimizing risks associated with plastic contamination to samples and personal safety risks to the 80-year-old yachtsman. It should be noted that this was made possible due to the immense experience of Jon Sanders and such a voyage is not recommended for the inexperienced. The methodology developed for the voyage could be adapted for future citizen science expeditions, however is perhaps more suited to multi-crewed yachts. Most citizen scientists do not have access to sophisticated instrumentation required to reliably identify microplastics. The collaboration with Curtin University that provided gratis analyses of the samples by Fourier-transform infrared spectroscopy (FTIR), permitted this study to add valuable information to our knowledge of global ocean concentrations of microplastics.

Methodology

General comments

The voyage was carried out by Jon Sanders on board Yacht Perie Banou II, designed by Sparkman and Stephens, constructed in fibreglass, and built in 1971 by Doug Brooker (Sydney). Perie Banou II is a masthead Sloop with an overall length of 11.77 m, beam of 3.58 m and max draft of 1.98 m.

Whenever possible, seawater samples were taken daily at a similar time, typically late morning local time, but this was dependant on weather conditions and sea state or other priorities to allow safe operation of the filtration system. As rough seas may interfere with the water intake, calmer conditions were preferred whenever possible, and the yacht manoeuvred onto a point of sail to facilitate safe operation (typically avoiding 'close to the wind beating'). During extreme weather conditions, sampling was suspended. The yacht would typically be sailing at about 5 Kts and filtration lasting about 20 minutes. Consequently, the yacht would travel about 3 km during filtration. The live track of the yacht was monitored by ClientSat.com.au and is available at https://track.noplasticwaste.org/. For logistic and safety reasons, it was not possible to obtain multiple samples from the same location. Consequently, each filter represents a snapshot in time and space of the seawater that the yacht was passing through. It was therefore not possible to obtain average counts, nor the variation, for each sampling location.

Wearing of synthetic clothing was avoided whenever possible to minimise risk of contamination during handling of filters.

Plate 1 Jon Sanders during field testing of water filtration system.

Daily filtration using stainless steel cloth filters

Following testing of prototype filtration systems, a stainless steel housing and filter system was constructed and field tested (Plate 1). Stainless steel cloth, twill weave, with aperture 43 µm and wire diameter 35 µm (equivalent imperial: mesh 325) was supplied by Inter-Screen (Canning Vale, WA, Australia). Discs of cloth (142 mm diameter) were used as water filters within a Millipore 142 mm stainless steel filter housing (Merck Burlington, MA, USA). Seawater was pumped (Parmax 4, Jabsco, Brookvale, Australia) at a rate of ~5 L min $^{-1}$ from below the water line through the filter. All hoses were silicone with brass fittings to avoid plastic contamination prior to filtration. The volume of seawater filtered was measured at the outflow using a Flomec water meter (Trimec Industries PTY LTD, Boronia, VIC, Australia).

The filtration system was flushed through with seawater by running the pump for a few minutes. A stainless steel cloth filter was then placed within the filter housing and the position of the yacht recorded by Global Positioning System (GPS) prior to commencement of filtration. The filtration system was operated for ~20 minutes to filter ~100 L of seawater. The position of the yacht at the end of filtration was recorded along with descriptions of sea state, water clarity, shipping activity etc. The stainless steel filter was wrapped in grease-proof paper and placed in a pre-labelled plastic bag (the filter did not come into contact with the bag at any time). A schematic of the filtration system is provided in Figure 1. The stainless steel filters were sent by courier to WA-OIGC laboratories at Curtin University in Perth, Australia, for processing and analyses.

Processing of stainless steel filters

On arrival, the 43 µm aperture stainless steel filters were carefully unwrapped from the protective paper and inspected with a ×10 magnifying glass and under a microscope with 50x magnification if required. The filters were photographed then placed in 156 mL volume cylinder glass jars (this required furling of the cloth filter using stainless steel forceps). In order to minimise the quantity of natural organic material such as algae and animal tissues, a strong base digestion was employed based on previous studies that have reported minimal impact on plastics (e.g. Covernton et al. 2019, Kuhn et al. 2018, Piarulli et al. 2019, Rochman et al. 2015). The jars containing the filters were filled with 10 % potassium hydroxide (KOH) solution (filtered Whatman GF/C 1.2 µm), shaken vigorously, then sonicated for 15 minutes to help dislodge microplastics and other material from the stainless steel cloth. The jars were again shaken vigorously then incubated at 60 °C (24 h). The digest was filtered under a vacuum system (Millipore) through 47 mm Whatman Grade 4 qualitative 20-25 µm cellulose filters to retain particles and fibres large enough for FTIR analysis. This was conducted within a fume cupboard to minimise risk of contamination. The stainless steel cloth filters and glass jars were rinsed with 3× jar volume (filtered Whatman GF/C 1.2 µm) deionised water. The cellulose filters were inspected and photographed then stored in glass petri dishes with lids until further inspection and analyses. The stainless steel cloth filters were re-examined under magnification to check for any material remaining on the filter. Full procedural blanks using unused stainless cloth, plus additional water blanks were performed for each batch processed. In addition, a positive control was created using weathered plastics collected at local Perth beaches. This was subject to the full procedure to ascertain if microplastics were successfully transferred from the stainless steel filters to the cellulose filters and that their FTIR spectra were unaffected. A schematic of the processing procedure is shown in Figure 2.

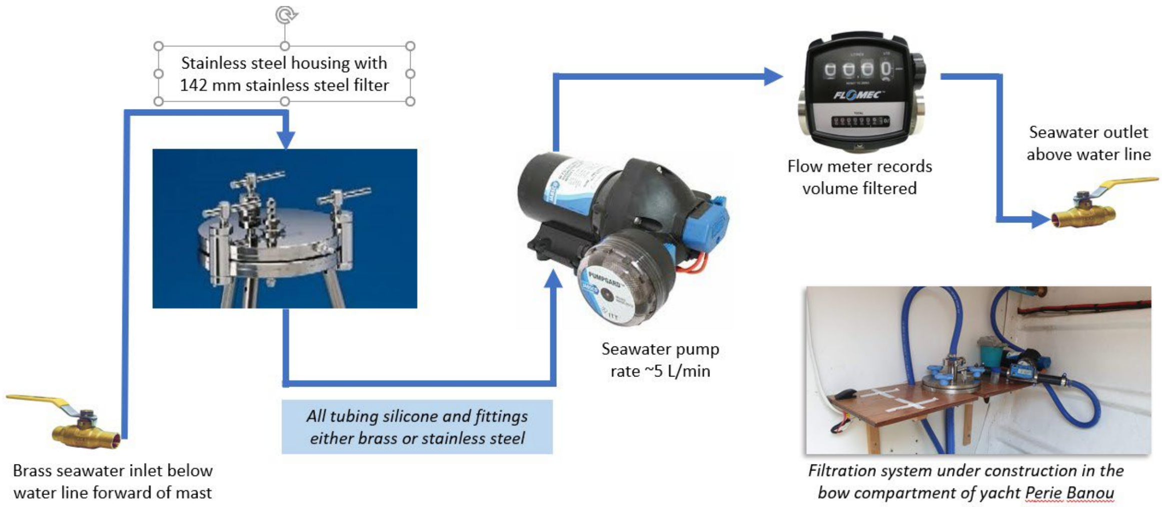

Figure 1 Schematic of seawater filtration system on board Yacht Perie Banou II

Fourier-Transform-Infrared (FTIR) analysis

Particles and fibres retained on the cellulose filters were analysed by FTIR using a Nicolet iN™10MX imaging microscope (Thermo Fisher Scientific, Waltham, MA, USA) fitted with a mercury-cadmium-telluride detector cooled by liquid nitrogen. Measurements were performed using a slide-on Attenuated Total Reflectance objective, equipped with a conical germanium crystal, in the range 4000-675 cm^{-1} with a spectral resolution of 4 cm^{-1}. Due to time limitations, most of filters were examined in detail over 25% of their area with a smaller number of filters examined over their entire area. Measurements and analysis were operated by OMNIC Picta™ (Thermo Fisher Scientific, Waltham, MA, USA). Spectra were compared with in-house libraries and literature data to identify and assign types of plastic. Re-examination of a sub-sample of filters by a second operator was employed for quality assurance purposes. In order to aid comparison with literature data, the number of microplastics observed were converted to numbers per cubic meter of seawater.

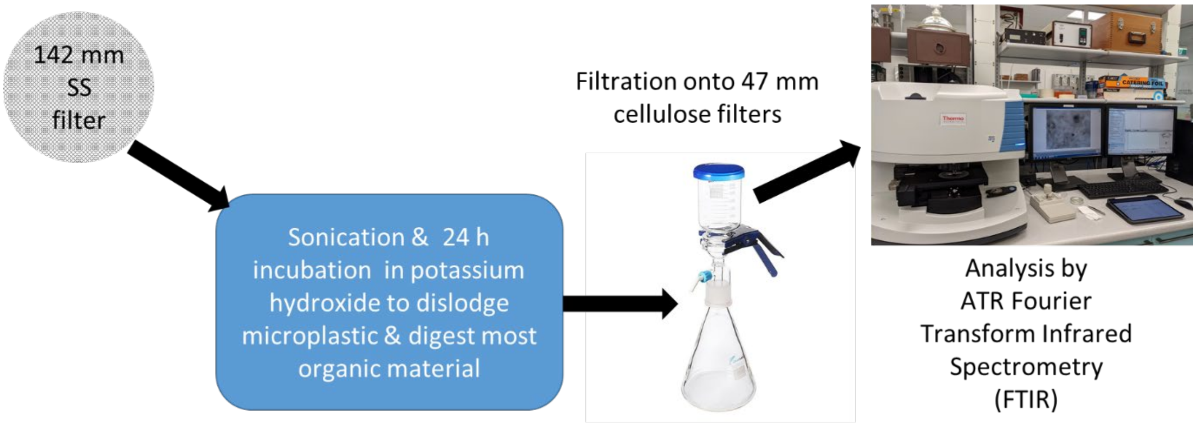

Figure 2 Schematic of laboratory processing of stainless steel (SS) filters.

Plate 2 Jon Sanders on board Perie Banou II departing Fremantle port on 3rd November 2019.

Plate 3 Perie Banou II returning to Fremantle port on 31st January 2021.

Results

General observations

The voyage began on 3rd November 2019 from Fremantle port with a large audience onshore and on an array of water craft (Plate 2) and ended on 31st Jan 2021 on return to Fremantle port to a massive reception (Plate 3), a total of 455 days, sailing 46,100 km. The anticipated length of the voyage was greatly extended due to much of the voyage being undertaken during the Covid-19 pandemic. This caused Jon Sanders to have to quarantine on multiple occasions and have to spend extended periods in port awaiting clearance to depart. It also meant that the support crew were unable to visit Jon at various locations as planned. Consequently, of the 455 days of the circumnavigation, a large number were spent at anchor or in port during which seawater was generally not sampled. The route of the voyage is shown in Figure 3. The impact of the Covid-19 pandemic was also felt at Curtin University. Lock-downs and laboratory access restrictions caused lengthy delays in the processing and analysis of filters. This was exacerbated by the inability to acquire spare parts and repair instruments.

During the voyage, a total of 20274 L seawater was filtered using 177 stainless steel filters, a mean of 114.5 L/filter (standard error = 1.2 L. The minimum and maximum filtered per day was 81.0 L and 188.4 L, respectively. Samples were mainly taken at around 11 AM local time with filtration usually taking around 20 minutes.

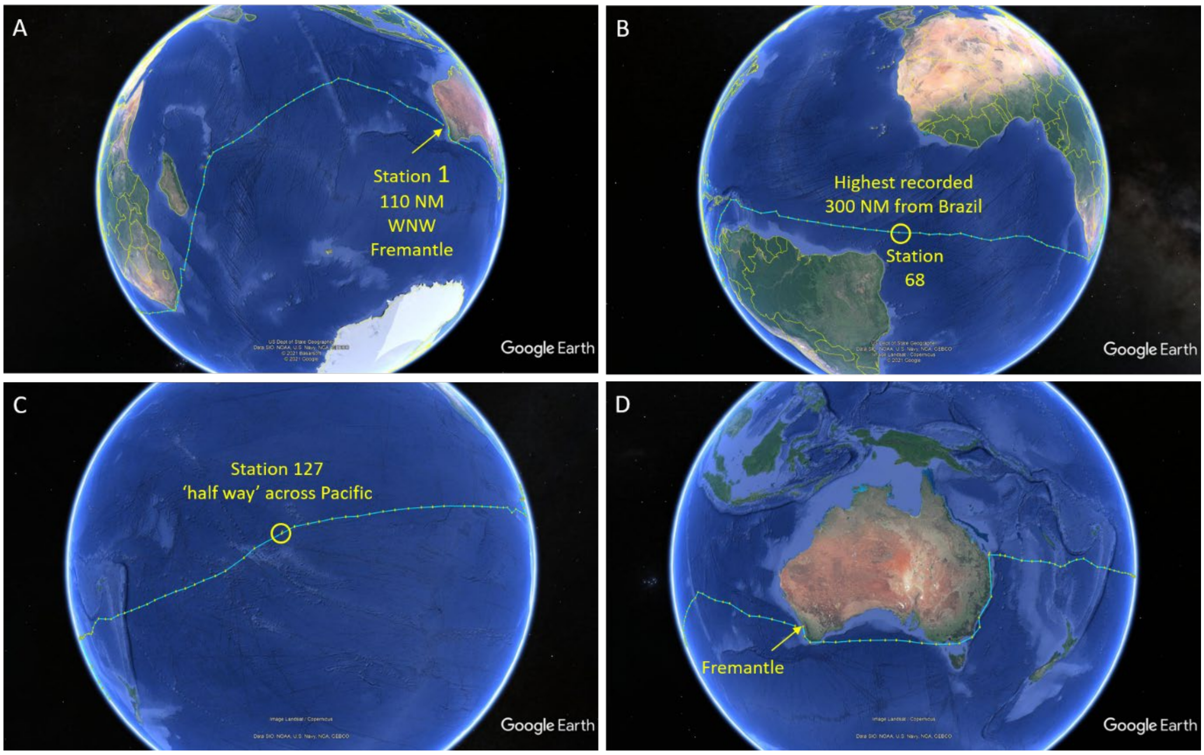

Figure 3 Route taken by Jon Sanders with sampling stations shown as yellow pins. Panel A shows the route crossing the southern Indian Ocean from Fremantle, Australia, eastwards to Cape Town, S. Africa, via Mauritius. Panel B shows the route across the Atlantic Ocean and Caribbean Sea with station 68 off of the coast of Brazil highlighted. Panel C shows the route across the Pacific Ocean from the Gulf of Panama with station 127 highlighted as close to the 'halfway point' across the ocean. Panel D shows the route from the western Pacific Ocean to Bundaberg and then onwards around the eastern and southern seaboards of Australia returning to Fremantle.

Examination of the stainless steel cloth filters generally revealed no obvious plastic particles. Some filters had considerable amounts of organic material such as plankton. Following digestion of the organic material and filtration onto smaller cellulose filters there remained considerable amounts of material on some filters including a few particles visible with the naked eye but no obvious microplastics were observed. With magnification, large numbers of very small particles and fibers could be seen.

Most particles when observed under the microscope, both plastic and natural, were dark colored and typically close to the 50 µm size threshold below which are deemed to be nanoplastics rather microplastics. When analyzed by FTIR, many of the observed particles were found to be of natural origin, typically wood (Figure 4). Very few particles were brightly colored. Of the blue particles (e.g. Figure 5 top), many were too small to obtain spectra and were not counted as microplastics. Yellow particles were very visible but extremely rare, (e.g. Figure 5 bottom). Some relatively large particles were virtually transparent, many others were difficult to observe (e.g. Figure 6). There was no particular association between the color of a particle and the type of plastic.

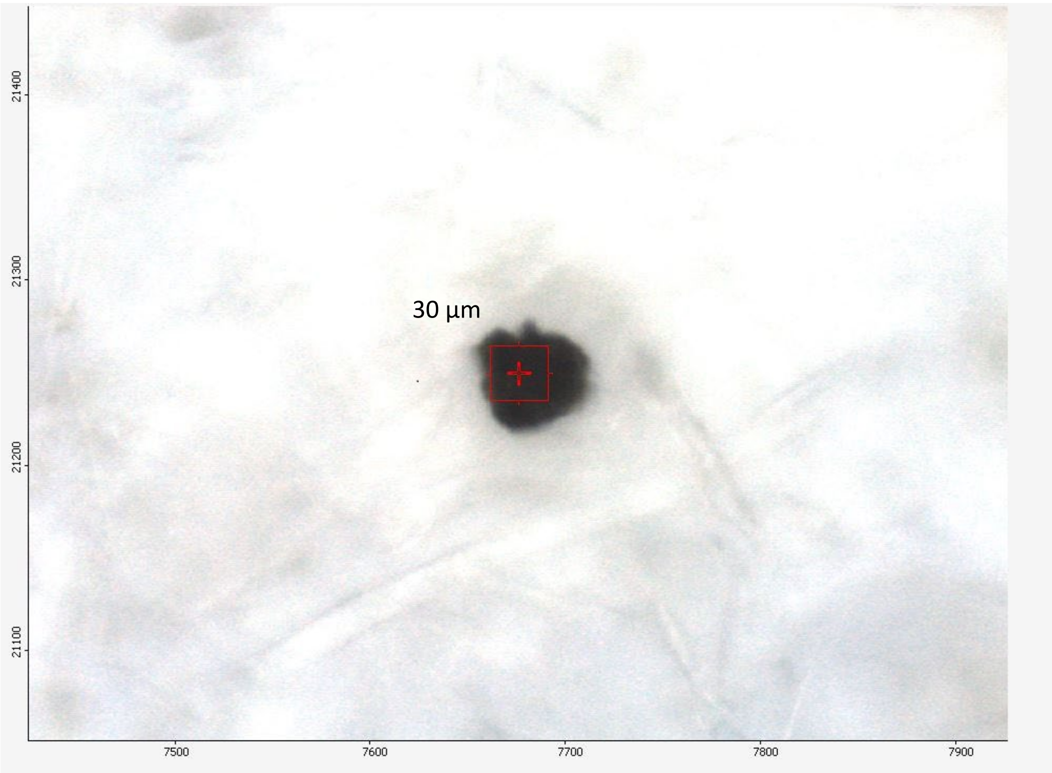

Figure 4 Photograph of typical particle found on many cellulose filters when analysed by FTIR. This particle produced a spectrum consistent with wood. The red box has sides of 30 µm and represents the centre of the FTIR analysis.

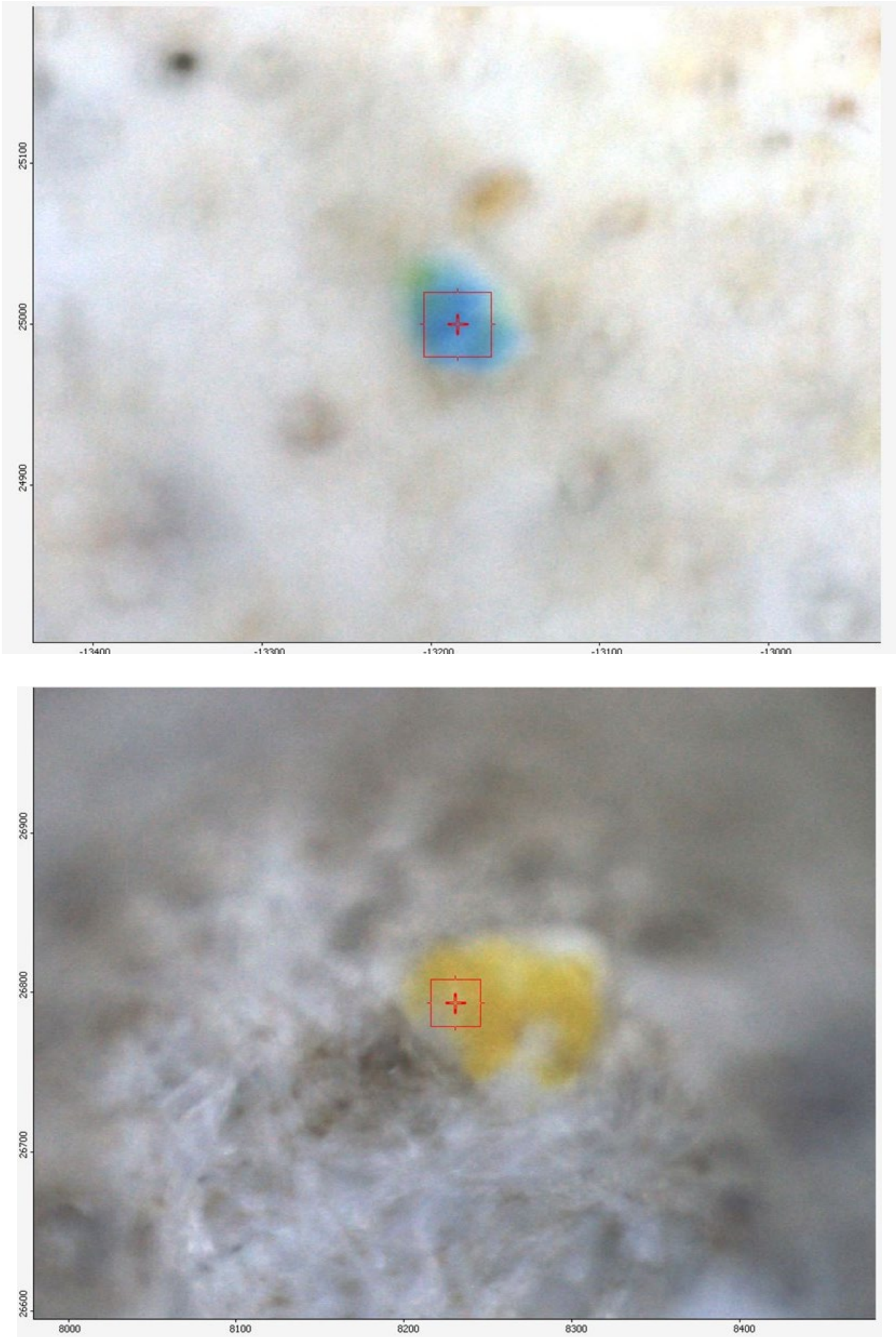

Figure 5 An example of a blue particle (Top) and a relatively large yellow particle (Bottom). When analysed by FTIR, these particles produced spectra consistent with polyethylene. Some smaller blue particles were observed but could not be analysed by the instrument used. The red box has sides of 30 µm and represents the centre of the FTIR analysis.

As well as particles, fibers of various lengths and widths were observed. Many of these were very narrow, typically <10 µm, and difficult to obtain spectra. The majority of fibers were grey/silver and were also observed in the procedural blanks. These did not produce FTIR spectra consistent with plastic or any other organic material and were most likely derived from the stainless steel filters. Other fibers, some colored or black, produced spectra consistent with natural products such as cotton (Figure 7). Consequently, it was not justifiable to count fibers as microplastics unless confirmed by FTIR.

It is likely that some of the fibers and small particles were plastic but were not counted as such. This means that the number of microplastics recorded is probably an underestimate. However, the number of undesignated particles and fibers that would fall within the definition of microplastics is relatively low, so the true numbers are unlikely to be significantly greater than those reported.

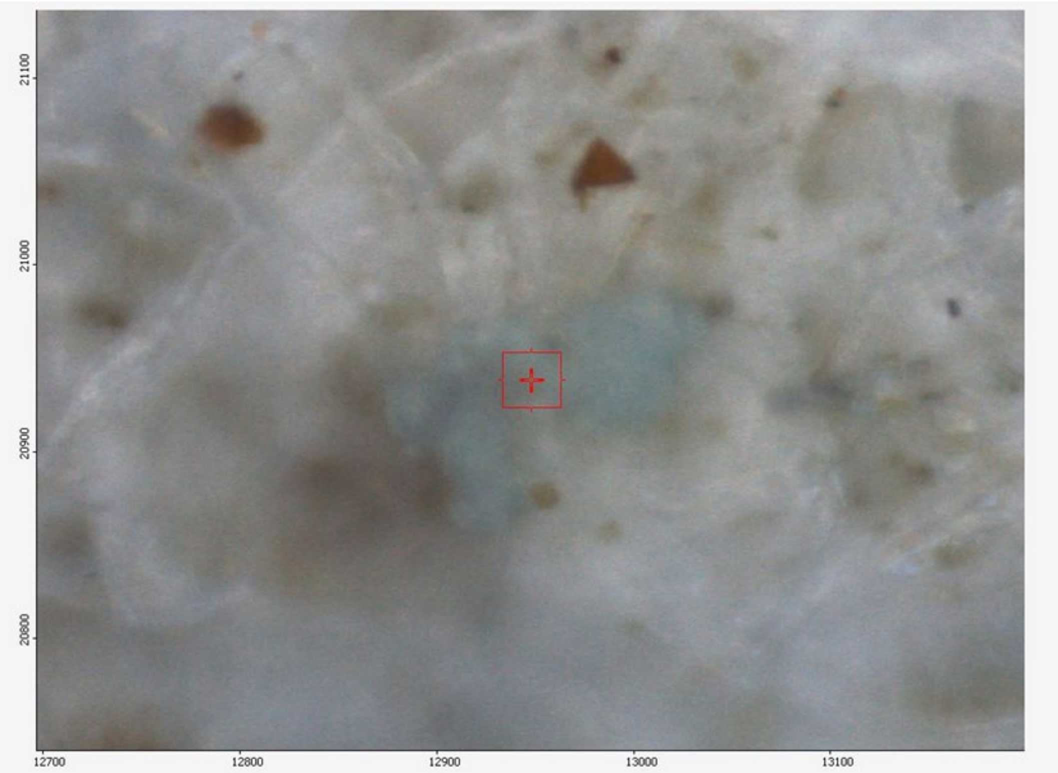

Figure 6 An example of a relatively large almost transparent particle. When analysed by FTIR, this particle produced a spectrum consistent with polypropylene. The red box has sides of 30 µm and represents the centre of the FTIR analysis.

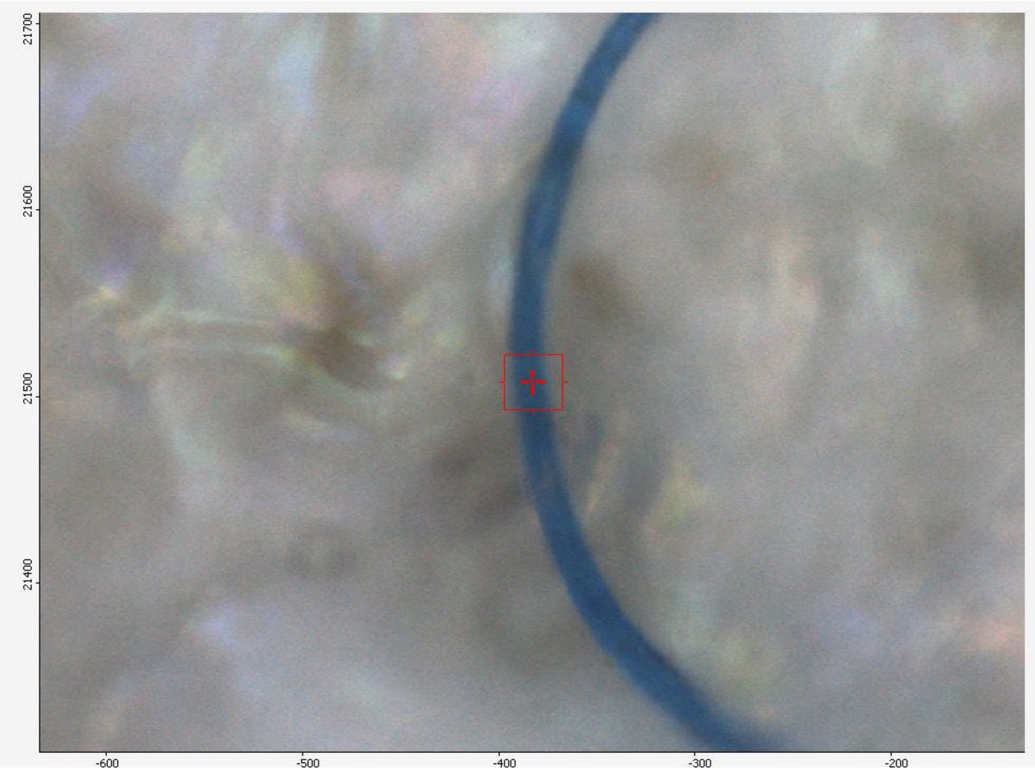

Figure 7 An example of a coloured fibre. When analysed by FTIR, this particle produced a spectrum consistent with cotton. The red box has sides of 30 µm and represents the centre of the FTIR analysis.

Quantification of microplastics in the Indian Ocean

The first leg of the voyage was an east to west crossing of the Indian Ocean from Fremantle to Mauritius (Figure 3A). The first sampling station was at latitude 31° 30.7' S (~110 NM WNW of Fremantle) and then tracked in a northerly and westerly direction reaching the most northerly point at station 12 at latitude 18° 14.0' S. This was just past the highest recorded count for the Indian Ocean of 198 microplastics/m^3 at station 11 (Figure 8A). Most of the filters from the 1st leg contained microplastics although there was a notable gap at stations 19-22 (Figure 8A). Jon Sanders had noted more shipping activity along his route during the 2nd leg from Mauritius to Cape Town but fewer microplastics were measured during this leg which suggests that the microplastics found were not originating from localized jetsam. Numbers were generally very low throughout the route from Fremantle to Cape Town although six filters contained >100 microplastic particles m^{-3} seawater (Figure 8A). A mean count of 47 microplastics m^{-3} seawater was calculated.

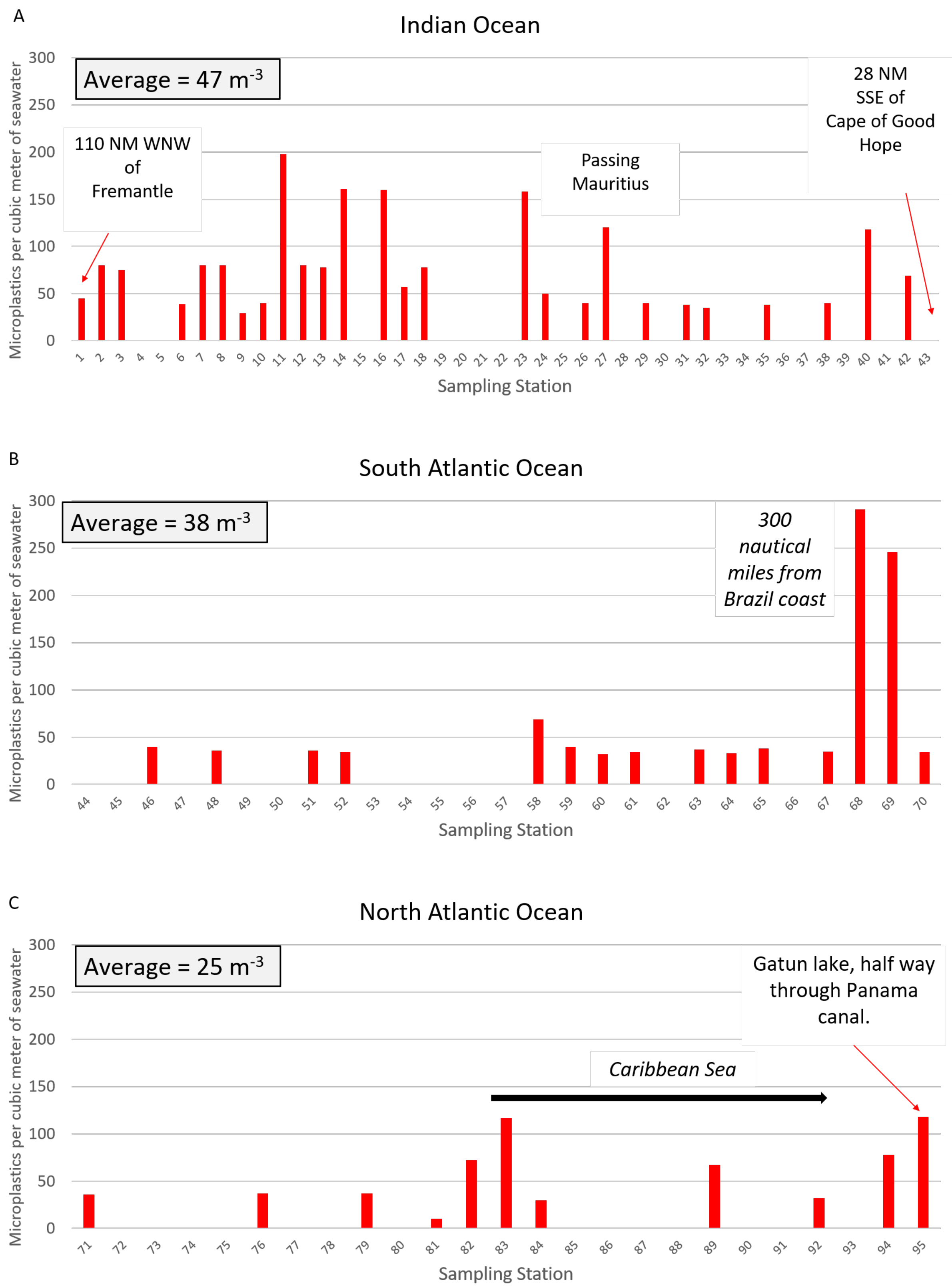

Figure 8 Numbers of microplastics per cubic meter recorded at sampling stations across the Indian Ocean (A), the South Atlantic Ocean (B) and the North Atlantic and Caribbean Sea into the Panama Canal (C).

Quantification of microplastics in the Atlantic Ocean and Caribbean Sea

The third leg of the circumnavigation from Cape Town, South Africa, to St Maarten in the Caribbean Sea covered a huge distance of over 10,000 km (Figure 3B). Microplastics were found on most filters but numbers were generally very low (Figures 8B and C). The exceptions were two filters obtained from just south of the equator, stations 68 and 69, where considerably higher numbers, 291 and 246 microplastics m^{-3} seawater respectively, were recorded (Figure 8B). These stations were over 600 km from the Brazilian coast. Jon Sanders provided observations along the route such as the presence of nearby fishing fleets but nothing was recorded that might explain the elevated numbers at stations 68 and 69 south of the equator in the Atlantic Ocean. In contrast, there were areas of both the South and North Atlantic, and even the Caribbean Sea that had several contiguous stations with no observed microplastics (Figures 8B and C). Consequently, the mean counts were 38 and 25 microplastics m^{-3} seawater for the South and North Atlantic/Caribbean Sea, respectively. The highest latitude seawater samples were taken during the entire voyage was at 17° 20.8' N (station 85).

Travel restrictions due to the Covid-19 pandemic prevented Jon Sanders' support team joining him to navigate the Panama Canal. It had been planned to take some samples in Panama Canal to likely provide highly contaminated water to compare with the remote ocean waters. Despite the logistic problems associated with the lack of support crew, Jon Sanders was able to take a sample in Gatun Lake (station 95) which is about half way through the Panama Canal. This was the only fresh water sample taken throughout the voyage. Although this station had the highest number of microplastics in the North Atlantic/Caribbean Sea, it was not exceptionally high (118 microplastics m^{-3} seawater) and similar to station 83.

Quantification of microplastics in the Pacific Ocean

The first sampling location for the huge Pacific Ocean crossing was in the Gulf of Panama (Figure 9A). Although the numbers of microplastics were generally below 70 m^{-3} seawater, all of the first eight stations contained some microplastics but as Perie Banoe II tracked westwards, frequency of microplastics declined with none recorded off of the Galapagos Islands (station 105 between Marchena and the live volcano Pinta). For large areas of ocean, no microplastics were observed such that the first half of the ocean crossing, deemed the 'eastern' Pacific had a mean count of 23 microplastics m^{-3} seawater (Figure 9A). Continuing further west passing the Tuamotu archipelago of Polynesia, further contiguous stations recorded no microplastics (Figure 9B) resulting in a mean count for the 'western' Pacific of just 15 microplastics m^{-3} seawater.

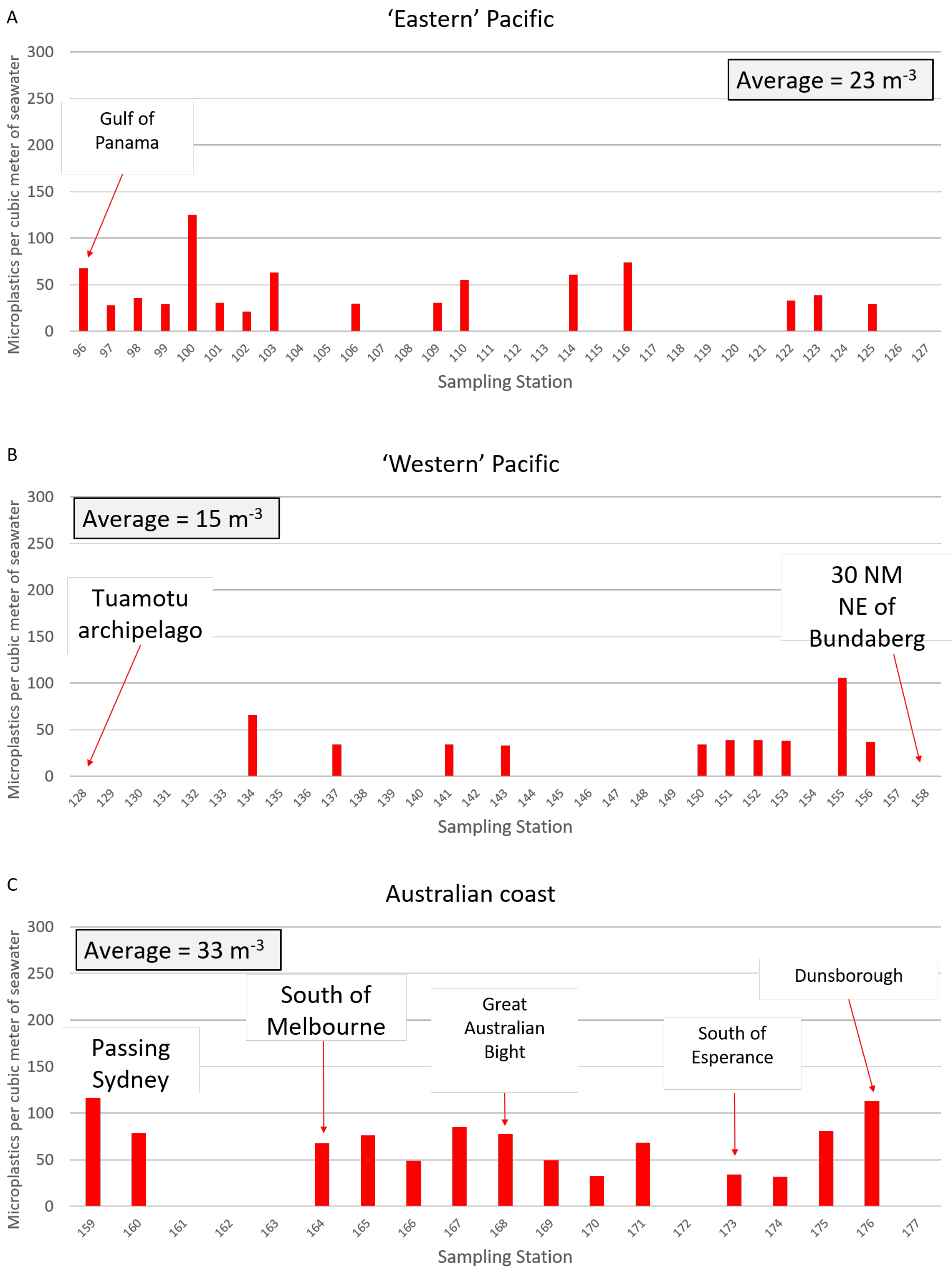

Figure 9 Numbers of microplastics per cubic meter recorded at sampling stations across the Indian Ocean (A), the South Atlantic Ocean (B) and the North Atlantic and Caribbean Sea into the Panama Canal (C).

During the final leg of the voyage from Bundaberg in Queensland, down the coast of Australia, then along the southern coast and across the Great Australian Bight and up the western seaboard to return to Fremantle, microplastics were found on the vast majority of filters (Figure 9C). However, there were only two locations where numbers exceeded 100 microplastics m^{-3} seawater and these were whilst passing Sydney and whilst at anchor off the coastal town of Dunsborough in SW Australia. The mean count for the Australian leg was 33 microplastics m^{-3} seawater.

Global transect

Viewing the data as a global transect (Figure 10), it is clear that microplastics are present along much of the route taken by Jon Sanders in Perie Banoe II, at concentrations sufficient to be detectable in relatively small water samples. Sampling station locations with associated microplastics concentrations can be viewed on Google Earth via a downloadable file or as an online Google Map available on the WA-OIGC Ocean Microplastics webpage.

The mean count of 33 microplastics m^{-3} seawater is likely to be an underestimate as discussed above. Some areas of all the oceans were found to contain no detectable microplastics. Although due to the limitations of the study, it cannot be ruled out that the snapshot sampling simply missed the microplastics which are unlikely to be evenly distributed in the water column, the occurrence of multiple contiguous stations without detectable plastics suggests that there are still areas of ocean with relatively few microplastics in the near surface waters. Several types of microplastic were observed including polycarbonate, polyethylene, polypropylene, polyethylene terephthalate, polyvinyl chloride, and synthetic rubber, with some particles providing more difficult identification due to being a mixture of types. Reference spectra obtained by ATR FTIR for a large number of plastic polymers are provided by Jung et al. (2018). No trends were observed in the type of plastic for any particular geographic area.

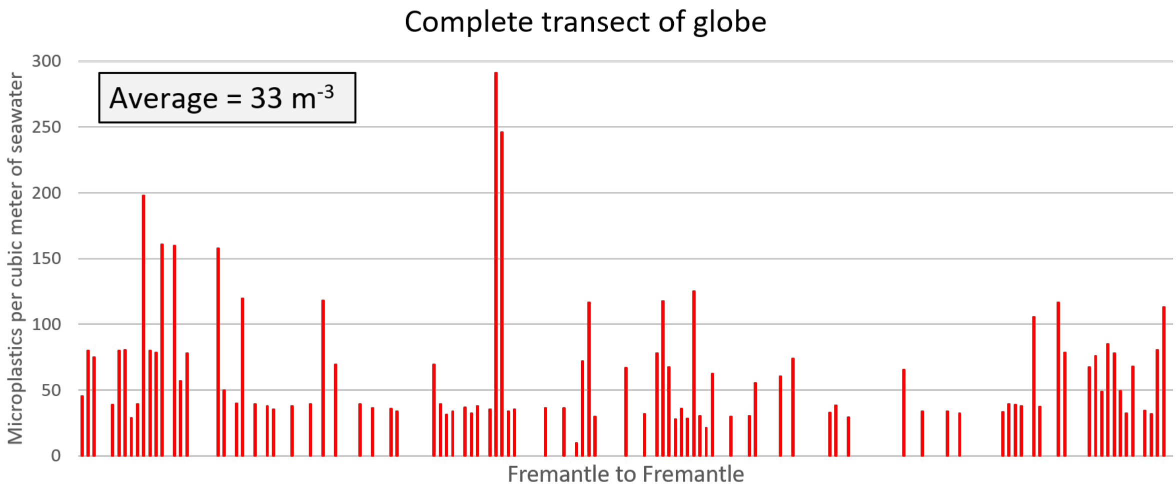

Figure 10 Numbers of microplastics per cubic meter recorded at sampling stations across the entire global transect sailed by Jon Sanders on board Yacht Perie Banou II.

Discussion

The completion of a single-handed circumnavigation of the globe at the age of 80 is a tremendous achievement in itself, not to mention the world's first ever global transect of microplastic contamination. This is a remarkable journey and with seawater samples being taken with incredible precision on nearly every day of the voyage, it could have only been possible due the experience, skills and seamanship of Jon Sanders. Worldwide media coverage of the project greatly helped in achieving the goal of raising awareness of microplastic contamination, with many articles written throughout the journey, e.g. https://www.theguardian.com/australia-news/2021/feb/06/anything-but-ordinary-octogenarian-sailors-11th-circumnavigation-highlights-plastic-pollution. Another aim of the project was to quantify the number of microplastics in the oceans, especially in remote regions of the southern hemisphere. This was also achieved as it was found even in some of the most remote areas of the oceans contained microplastics, although there were areas in which none were recorded (Figure 10). Most of the previous studies into microplastics were carried out in the northern hemisphere with high shipping traffic although some very recent studies have also included remote areas including the Arctic (Ross et al. 2021).

In a major review of microplastics in the marine environment measured using surface-trawling plankton nets, coupled with ocean circulation models, van Sebille et al. (2015) reported that large areas of both the North Atlantic and North Pacific Oceans can have concentrations of over 10 million particles per km^2. Data was scarce for the southern oceans but counts of up 10^6 km^{-2}, i.e. 1 m^{-2}, were reported. Although it is difficult to compare surface-trawled microplastics data reported as particles per km^2 with that of present study where volume is recorded, i.e. global average of 33 m^{-3} seawater, the numbers would appear to be similar. It was noted by van Sebille et al. (2015) that large areas of ocean had very little data, in particular: much of the Indian, South Pacific and Southern oceans; an area from the southern tip of Africa to the Caribbean; and, from the equator to northern Australia. These areas now have data following the present study with an average of 47 particles m^{-3} for the Indian ocean (Figure 8A), 38 m^{-3} and 25 particles m^{-3} for the South and North Atlantic respectively (Figures 8B and C), and 15 particles m^{-3} for the for the eastern side of the South Pacific (Figure 9), whilst the Great Australian Bight, at the northern edge of the Southern Ocean, averaged 33 particles m^{-3}. Using a very different sampling method from van Sebille et al. (2015), Desforges et al. (2014) also reported large numbers of microplastics in the NE Pacific Ocean in and around coastal British Columbia, Canada. In the latter study, rather than use plankton nets, seawater was collected from 4.5 m below the surface via the saltwater intake system of the vessel and was filtered through sieves of diminishing pore size. This system can be viewed as a more sophisticated version as that used on board Perie Banou II but it should be noted that the water was sampled from a much greater depth. Concentrations of microplastics varied from 8 to 9180 particles m^{-3} seawater although offshore sampling stations mostly recorded <500 particles m^{-3} seawater (Desforges et al. 2014). The microplastics were identified by observation under a microscope rather by spectroscopic means which may have led to an underestimate of fragmented microplastics or an overestimate of fibers based on a study by Song et al. (2015).

Recent studies that were published during or following Jon Sanders' voyage include a study reporting microplastic particles in the Arctic Ocean (Ross et al. 2021). This used a pumping and filtration system with sampling at a depth of 4 – 9 m. The study reported an average of 49 particles m^{-3} seawater which is similar to that reported herein for remote areas. This suggests that despite the limitations of the sampling system employed for the Citizen Science Global Transect, the numbers of particles found were in agreement with more sophisticated sampling studies. However, another recent study that utilized a pump/filtration system found far higher numbers of microplastics in the Atlantic Ocean (Pabortsava and Lampitt 2020). This study sampled at even greater depth (10 – 270 m) and reported an average of ~2800 particles m^{-3} seawater at 10 m and similar numbers at 50 – 170 m. These are far greater numbers than recorded from the Citizen Science Global Transect and suggests that much of the Ocean's microplastics are to be found at a much greater depth than sampled from Perie Banou II. Indeed, a surface study utilizing a plankton net (Alfaro-Nunez et al. 2021) to sample an area of the Eastern Pacific/Galápagos reported only 0.2 particles m^{-3} seawater, which is more consistent with data from the current study for the same region (Figure 9A).

Future work

Several yacht owners have expressed an interest in undertaking voyages to sample new areas of ocean or to resample areas which were covered by the current study. Both would be useful, especially if the methodology could be replicated. The amount of time required to analyze the filters by FTIR severely restricts the number of filters that can be analyzed in a reasonable time frame and cost. A study at Curtin University led by Mark Hackett has developed an automated FTIR analysis method which may help to improve efficiency and reduce costs.

Conclusions

This Citizen Science collaborative project undertaken by lone single-handed yachtsman Jon Sanders and WA-OIGC researchers at Curtin University was highly successful despite the logistical problems and delays caused by the Covid-19 pandemic. The sampling strategy and methods proved to be robust and reliable so could be adopted by future Citizen Science projects. The only expensive apparatus deployed on the yacht was the stainless steel filtration housing, the cost of which may be an obstacle for future projects.

Seawater was filtered on 177 days of the voyage, representing a global transect of the World's Oceans, predominantly in the Southern Hemisphere. The vast majority of the filters were found to contain microplastics but some areas of ocean, particularly the Pacific, had several contiguous sampling stations without any microplastics observed. Two sampling stations, approximately 600 km off the coast of Brazil, recorded relatively high numbers (~250 particles m^{-3} seawater) of microplastics, otherwise there were no 'hot spots' of contamination. Although several types of microplastic were observed including polycarbonate, polyethylene, polypropylene, polyethylene terephthalate, polyvinyl chloride, synthetic rubber and mixtures thereof, no particular type of plastic dominated. The size of particles observed and confirmed by FTIR was typically close to the lower size limit defined as microplastic i.e. 50 µm and were mostly grey/black in color. Many observed fibers had diameters too small to be able to obtain a FTIR spectra and therefore the numbers reported are likely to be an underestimate of the actual number of microplastics present in the oceans. The global average recorded of 33 particles m^{-3} seawater is consistent with other studies of remote areas of ocean but other studies suggest that there are far greater numbers of microplastics present at a greater depth than sampled during the present study.

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References

Alfaro-Nunez, A., Astorga, D., Caceres-Farias, L., Bastidas, L., Villegas, C.S., Macay, K. and Christensen, J.H. (2021) Microplastic pollution in seawater and marine organisms across the Tropical Eastern Pacific and Galapagos. Scientific Reports 11(1).

Anbumani, S. and Kakkar, P. (2018) Ecotoxicological effects of microplastics on biota: a review. Environmental Science and Pollution Research 25(15), 14373-14396.

Barrows, A.P.W., Neumann, C.A., Berger, M.L. and Shaw, S.D. (2017) Grab vs. neuston tow net: a microplastic sampling performance comparison and possible advances in the field. Analytical Methods 9(9), 1446-1453.

Covernton, G.A., Pearce, C.M., Gurney-Smith, H.J., Chastain, S.G., Ross, P.S., Dower, J.F. and Dudas, S.E. (2019) Size and shape matter: A preliminary analysis of microplastic sampling technique in seawater studies with implications for ecological risk assessment. Science of the Total Environment 667, 124-132.

Cózar, A., Echevarría, F., González-Gordillo, J.I., Irigoien, X., Úbeda, B., Hernández-León, S., Palma, Á.T., Navarro, S., García-de-Lomas, J., Ruiz, A., Fernández-de-Puelles, M.L. and Duarte, C.M. (2014) Plastic debris in the open ocean. Proceedings of the National Academy of Sciences 111(28), 10239.

Desforges, J.-P.W., Galbraith, M., Dangerfield, N. and Ross, P.S. (2014) Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. Marine Pollution Bulletin 79(1), 94-99.

Everaert, G., Van Cauwenberghe, L., De Rijcke, M., Koelmans, A.A., Mees, J., Vandegehuchte, M. and Janssen, C.R. (2018) Risk assessment of microplastics in the ocean: Modelling approach and first conclusions. Environmental Pollution 242, 1930-1938.

Fame, A.S.H.o. Jon Sanders AO OBE CitWA.

Gago, J., Filgueiras, A., Pedrotti, M.L., Caetano, M. and Frias, J. (2018) Standardised protocol for monitoring microplastics in seawater. JPI-Oceans BASEMANproject.

Gura, T. (2013) Citizen science: Amateur experts. Nature 496(7444), 259-261.

Ha, J. and Yeo, M.K. (2018) The environmental effects of microplastics on aquatic ecosystems. Molecular & Cellular Toxicology 14(4), 353-359.

Jung, M.R., Horgen, F.D., Orski, S.V., Rodriguez C, V., Beers, K.L., Balazs, G.H., Jones, T.T., Work, T.M., Brignac, K.C., Royer, S.-J., Hyrenbach, K.D., Jensen, B.A. and Lynch, J.M. (2018) Validation of ATR FT-IR to identify polymers of plastic marine debris, including those ingested by marine organisms. Marine Pollution Bulletin 127, 704-716.

Kanhai, L.K., Johansson, C., Frias, J., Gardfeldt, K., Thompson, R.C. and O'Connor, I. (2019) Deep sea sediments of the Arctic Central Basin: A potential sink for microplastics. Deep-Sea Research Part I-Oceanographic Research Papers 145, 137-142.

Kuhn, S., van Oyen, A., Booth, A.M., Meijboom, A. and van Franeker, J.A. (2018) Marine microplastic: Preparation of relevant test materials for laboratory assessment of ecosystem impacts. Chemosphere 213, 103-113.

Law, K.L., Morét-Ferguson, S., Maximenko, N.A., Proskurowski, G., Peacock, E.E., Hafner, J. and Reddy, C.M. (2010) Plastic Accumulation in the North Atlantic Subtropical Gyre. Science 329(5996), 1185.

Ostle, C., Thompson, R.C., Broughton, D., Gregory, L., Wootton, M. and Johns, D.G. (2019) The rise in ocean plastics evidenced from a 60-year time series. Nature Communications 10.

Pabortsava, K. and Lampitt, R.S. (2020) High concentrations of plastic hidden beneath the surface of the Atlantic Ocean. Nature Communications 11(1).

Pahl, S., Wyles, K.J. and Thompson, R.C. (2017) Channelling passion for the ocean towards plastic pollution. Nature Human Behaviour 1(10), 697-699.

Piarulli, S., Scapinello, S., Comandini, P., Magnusson, K., Granberg, M., Wong, J.X.W., Sciutto, G., Prati, S., Mazzeo, R., Booth, A.M. and Airoldi, L. (2019) Microplastic in wild populations of the omnivorous crab Carcinus aestuarii: A review and a regional-scale test of extraction methods, including microfibres. Environmental Pollution 251, 117-127.

Porter, A., Lyons, B.P., Galloway, T.S. and Lewis, C. (2018) Role of Marine Snows in Microplastic Fate and Bioavailability. Environmental Science & Technology 52(12), 7111-7119.

Rochman, C.M., Browne, M.A., Underwood, A.J., van Franeker, J.A., Hompson, R.C.T. and Amaral-Zettler, L.A. (2016) The ecological impacts of marine debris: unraveling the demonstrated evidence from what is perceived. Ecology 97(2), 302-312.

Rochman, C.M., Tahir, A., Williams, S.L., Baxa, D.V., Lam, R., Miller, J.T., Teh, F.-C., Werorilangi, S. and Teh, S.J. (2015) Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Scientific Reports 5, 14340.

Ross, P.S., Chastain, S., Vassilenko, E., Etemadifar, A., Zimmermann, S., Quesnel, S.A., Eert, J., Solomon, E., Patankar, S., Posacka, A.M. and Williams, B. (2021) Pervasive distribution of polyester fibres in the Arctic Ocean is driven by Atlantic inputs. Nature Communications 12(1).

Song, Y.K., Hong, S.H., Jang, M., Han, G.M., Rani, M., Lee, J. and Shim, W.J. (2015) A comparison of microscopic and spectroscopic identification methods for analysis of microplastics in environmental samples. Marine Pollution Bulletin 93(1), 202-209.

van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., van Franeker, J.A., Eriksen, M., Siegel, D., Galgani, F. and Law, K.L. (2015) A global inventory of small floating plastic debris. Environmental Research Letters 10(12).