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Research article

An innovative approach for microplastic sampling in all surface water bodies using an aquatic drone

Gabriel Pasquier^{a,*}, Périne Doyen^b, Nicolas Carlesi^c, Rachid Amara^a^a Univ. Littoral Côte d'Opale, CNRS, Univ. Lille, UMR 8187 - LOG – Laboratoire d'Océanologie et de Géosciences, F-62930 Wimereux, France^b Univ. Littoral Côte d'Opale, UMR 1158 BioEcoAgro, Institut Charles Viollette, USC Anses, F-62200 Boulogne-sur-Mer, France^c IADYS Immeuble LIBER 1 - N° Z09 ZA Le clos du Rocher, ZI Plaine du Caire 1, 13830 Roquefort-la-Bédoule, France

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ABSTRACT

The lack of one standardized method to evaluate microplastic pollution in different aquatic environments worldwide represent a gap to fill for the scientist's community. To help overcome this challenge, we adapted an aquatic drone, named Jellyfishbot[®], to sample microplastics. The aquatic drone has been compared with the actual most used method for sampling MPs in surface waters: the Manta net. In order to test the reliability of the aquatic drone in different environments, samples were collected in a river and coastal waters sites. The results obtained with the two methods were similar in term of MPs abundances, shapes and colors. It provides also a better reproducibility and more accurate sampling of MPs located in the surface waters mainly the lighter and smaller ones. This sampling method has the advantage of combining the benefits of Manta net sampling (i.e. a representative surface water sampling method that covers a large sampling area and volume (several tens m³) with those of pump filtration and grab sampling (easy access to confined and hard-to-reach areas). This new sampling method could be applied in different aquatic environments making it possible to compare the data and hence become a new standardized approach to evaluate microplastic pollution levels.

1. Introduction

Microplastic pollution is a growing global concern due to their presence in all aquatic environments. Thus, the sampling methodology is considered as a basic factor influencing the knowledge about the microplastics (MPs) abundance, distribution and associated environmental impacts (Hanvey et al., 2017; GESAMP 2019). This is currently hampered by the lack of robust standard sampling method that can be used in different water bodies (Prata et al., 2019; Cowger et al., 2020). This absence of standardized sampling method has for obvious consequence an issue for comparing the results of various studies using different sampling methods in the same area or in different areas around the world and therefore assess the real MPs contamination worldwide (Ryan et al., 2020; De-la-Torre et al., 2022). The development of an easy, cost- and time-effective standard sampling method that can be used in all surface water bodies is therefore imperative to advance MPs research.

The commonly used field sampling methods for MPs in aquatic environments are nets, bottles, buckets and pumps (Hung et al., 2021). Pump, buckets and bottles sampling are usually used for the collection of limited volume samples located at specific stations. Due to the high

variability of MPs spatial distribution, the use of these three sampling methods can involve a lack of representativeness of the sampled area since the volume sampled are limited and can also lead to overestimation of the MPs abundance (Desforges et al., 2014; Song et al., 2014; Tamminga et al., 2019, GESAMP 2019). Nonetheless, these sampling methods have for advantages to be relatively easy to use, may be handled by one person and be deployed in areas where classic net trawling is impossible (harbors, shallow areas and near the shore). In addition, these methods allow the sampling of the smallest particles where the mesh of a net set a lower limit on the particle's sizes sampled.

Besides these three methods, one of the widely used method for sampling surface water MPs has been the trawl nets (Hidalgo-Ruz et al., 2012; Barrows et al., 2017; Gago et al., 2019; Pasquier et al., 2022). Trawl nets can sample relatively quickly MPs in a larger volume of surface water at a certain location and give a representative sample of the area (Hidalgo-Ruz et al., 2012; Barrows et al., 2017; Gago J. et al., 2019). The Manta net is the most commonly used trawl net method for sampling MPs (Pasquier et al., 2022). Its design is inspired from the animal *Mobula birostris* (the manta ray) and the Neuston net, the original trawl for MPs sampling. It allows a certain level of stability, buoyancy and precision in

* Corresponding author.

E-mail address: gab.pasquier@gmail.com (G. Pasquier).

the water layer sampled compared to the Neuston net (Brown and Cheng 1981). However, it is often difficult to use trawl net like Manta net to sample water in some areas due to difficulty of access and trawling with a boat. Realizing replicates while sampling with a trawling net can also be difficult due to the eddies and disturbances caused by the boat, the time-consuming method and a lack of precisions during sampling with a boat (height of water sampled, transect position and sampling speed) (Gago et al., 2019; Karlsson et al., 2020; Felismino et al., 2021). The challenge of developing a new sampling method that combine both the advantage of the trawling net with the large amount of water sampled and the other sampling methods such as pump, bucket and bottles that allow sampling in difficult to access areas, is real in order to put a step forward a standardized sampling method for surface water MPs.

The current study presents an innovative approach using an aquatic surface drone tailored for water microplastic sampling that combines the

advantages of the Manta net (surface and subsurface sampling and large volume sample) and being easy to use in different water bodies, even in confined and hard-to-reach areas, in order to better assess the MPs contamination in a wider range of water bodies.

To test and validate the use efficiency of this aquatic drone, the device was compared to a classical Manta net device towed by a small boat in two different environments, a river and marine coastal waters in the Eastern English Channel (France). Furthermore, these two methods were also compared to a widely used water MPs sampling method, in closed and shallow environments, the in-situ pump filtration. The protocols used for each of these methods have been defined similarly in order to compare the three methods both on the processing and resulting parts. These data will support the interest in using the aquatic drone in order to standardize MP sampling in aquatic environments.



Figure 1. Satellite pictures of the location of the sampling sites: (a) Location of the sampling sites at a larger scale; (b) Location of the two sampling sites and the Waste Water Treatment Plan (WWTP).

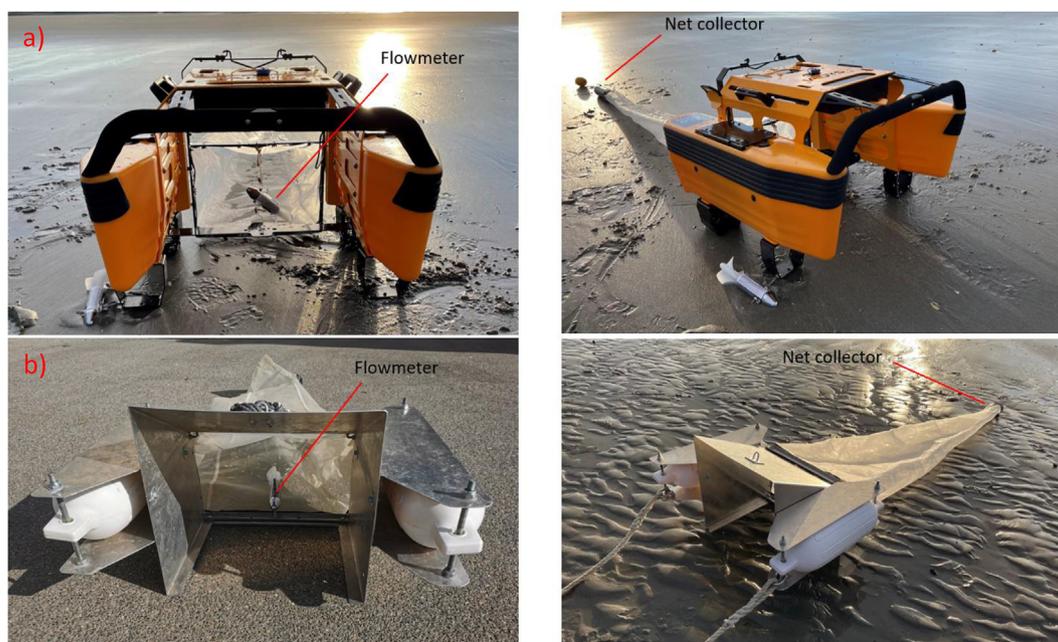


Figure 2. Pictures of the sampling devices: (a) the front and the right side of the aquatic drone sampling device adapted from the Jellyfishbot[®] equipped with a 150 or 300 μm mesh net and 2 flowmeters, one inside the opening of the net and one on the side of the drone; (b) the front and the left side of the Manta net sampling device equipped with a 150 or 300 μm mesh net and a flowmeter located in the opening mouth of the net.

2. Materials and methods

2.1. Study sites

The three different methods for sampling microplastics have been tested at two different sampling sites (Figure 1a). First, the sampling was conducted in the Liane river, which is a 38 km long river in the Pas-de-Calais department in northern France. It rises in Quesques and flows into the English Channel at Boulogne-sur-Mer. The Liane river is affected by various anthropogenic activities and by the presence of a municipal wastewater treatment plant (WWTP) that treats the wastewater of ca. 200,000 inhabitants. Sampling was conducted in June 2021 in the lower part of the river downstream the WWTP (Figure 1b). The river in this area, where the depth varies between 0.75 m and 1.25 m, is freshwater and the water flow is about 2.99 m^3/s .

The second sampling site was located in the marine coastal areas near the cities of Boulogne-sur-Mer and Wimereux (French coast of the eastern English Channel). This coastal area is characterised by high hydrodynamic activity which is mostly due to tidal currents. The tidal regime is semi-diurnal with an average tidal range of about 7 m on spring tides and 3 m on neap tides. The current can be directed either toward North while the tide is rising or toward South when the tide is falling. Sampling was conducted in October 2021 in the shallow coastal area (depth ranges from 2 to 5 m) parallel to the coast (Figure 1b). These two different sampling sites have been selected in order to demonstrate the relevance that the new sampling method can be applied in different type of aquatic environments.

Different environmental parameters have been recorded during the sampling such as water turbidity, the wind direction and speed, the tide coefficient, the river flow and the rain record of the past few days.

2.2. The aquatic drone sampling

The aquatic drone (Figure 2) is an adaptation of the Jellyfishbot[®], an aquatic surface drone developed by IADYS (Roquefort-la Bédoule, France) which looks like a little catamaran (70 cm width, 70 cm long and 50 cm height). It is a compact, easy-to-use and a handy robot operated by remote control which can deliver information such as the sampling speed, duration and distance or the exact drone position. It is equipped with two propulsors

that are located under the two floating parts and weight about 20 kg. The aquatic drone can have a top speed of 2 knots and have an autonomy of more than 2 h. The drone was tailored for MPs sampling by developing a removable metal frame (36 cm width and 25 cm height) at the back of the drone allowing the attachment of a net whose dimensions are 36 * 25 * 200 cm (length). In the present study we tested the two most common types of net mesh size: a 150 μm and a 300 μm mesh size net. The net can be easily removed and placed back. At the end of the net, a detachable “cod-ends” made of PVC with a length of 30 cm, and a diameter of 11 cm, is equipped with a window consisting of a 20 μm mesh size. Two flowmeters (General Oceanic[®], Miami, Florida, United States) were put at the collecting net opening mouth, one on the outside and another inside (Figure 2), in order to compare the filtration rate and analyze the potential net clogging. The height position of the sampling net on the drone was adapted in order to sample precisely at the water surface. Due to its catamaran shape, the drone is very stable on the water surface. Therefore, the section of the water column that is sampled stays the same during the whole process of sampling.

For the first sampling location in Boulogne-sur-Mer, a transect of 300 m in the middle of the river has been carried out and a mesh net of 150 μm has been used. For the second sampling area in the coastal waters a transect of 300 m along the coast line was performed with a mesh net of 300 μm . For both of the sampling locations, the sampling was conducted against the current during 10 min and the speed of the aquatic drone stayed around 1 knot during the whole transect. Three replicates were carried out for each of the locations. The average volume sampled was 32.31 (± 0.69) m^3 . After every sampling transect, the drone was picked up with a small boat. The collecting net was then put vertically and rinsed meticulously with environmental water from the outside in order to get all the particles trapped in the net just as described by Viršek et al. (2016). The collector attached to the net was then removed and rinsed many times with Milli-Q water in order to retrieve the particles trapped in the collector. The rinse solution was put in glass bottles and kept in a cooler at a temperature of around 10 degrees Celsius until further process.

2.3. Manta net sampling

The Manta net (Figure 2) is a device that has an opening mouth of 36 * 25 cm and the net has a length of 200 cm with a collector at the end. The net

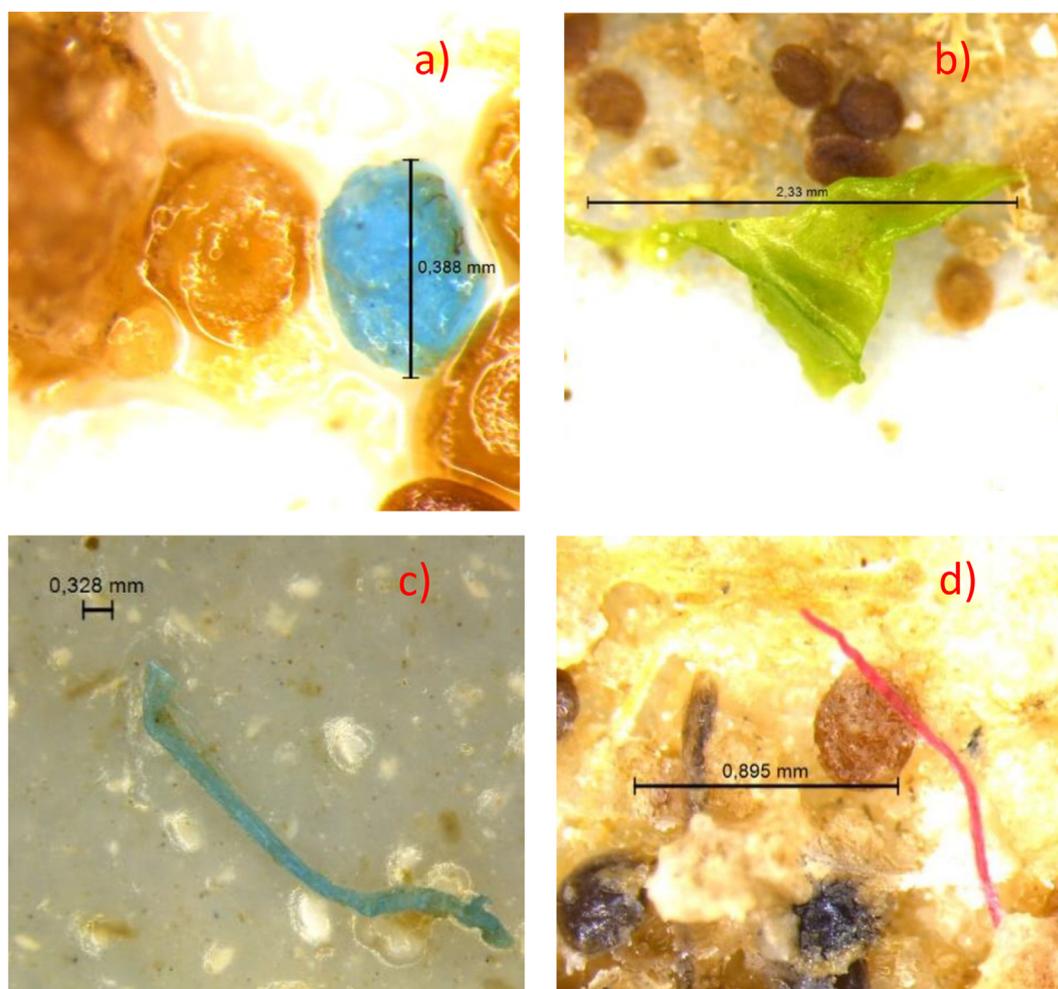


Figure 3. Pictures of different sampled microplastics with the length scale observed with a stereomicroscope on filters: (a) blue fragment; (b) green fragment; (c) blue fiber, (d) red fiber.

and collector mesh sizes were the same as for the aquatic drone. The process of sampling with the Manta net was the same as the one with the aquatic drone and these two sampling devices were used at the same time, in parallel with each other, in order to compare the two methods. Three replicates of 300 m transect were performed on the river but the last replicate has been cancelled due to an incident while doing the sampling. The Manta net was towed by a small boat and kept at a distance of 30 m behind the boat in order to avoid as maximum the turbulences created by the boat's engine. The sample duration was about 10 min and the sampling speed was around 1 knot for the whole sampling process. A flowmeter (General Oceanic[®]) was also placed inside the opening mouth of the net and the average volume sampled was $35.05 (\pm 1.41) \text{ m}^3$. The same sample recovery protocol described above was used to collect particles from the net.

2.4. In-situ pump sampling

The pump (Figure S1) sampling was carried out, in the same locations and conditions, in order to be able to compare it with the two others sampling method. The pump was put in the first 10 cm of the water column from the side of a boat following the same 300 m transect mentioned before with an average speed of 1 knot. The water was filtered on a $150 \mu\text{m}$ stainless sieve for the sampling in the river and with a $300 \mu\text{m}$ stainless sieve in the coastal waters. During the three replicates, the water flow intake was about $30\text{--}35 \text{ L min}^{-1}$ leading to an average volume sampled of $369 (\pm 6) \text{ L}$. After the transect, the sieve was meticulously rinsed with Milli-Q water and this rinse solution was preserved just as previously.

2.5. Environmental blanks

Environmental blanks have been carried out during every sampling transect. To this end, a $150 \mu\text{m}$ control Inox sieve was left uncovered during the whole sampling transect in order to check the possible atmospheric contamination. After 10 exposure minutes, every sieve was meticulously rinsed with Milli-Q water that has been collected and saved as previously until treatment.

2.6. Samples treatment

The different samples obtained were put into a proofer set at 40°C in order to dry them and maintain the integrity of the particles, this step could last up to 5 days depending on the amount of water (Treilles et al., 2020). After complete drying, 400 ml of KOH 10% (CHIMIE-PLUS) has been added to digest the remaining organic matter at 40°C under magnetic agitation (300 rpm) for 48 H (Dehaut et al., 2019). The obtained digested solution was filtered on GF/A filters (Thermo Fisher Scientific) of glass fiber (9 cm diameters and $1.3 \mu\text{m}$ mesh). Every filter was then put in a glass Petri dish until MPs characterization and analysis.

2.7. Microplastics characterization and identification using Raman spectroscopy

The obtained filters were then observed under a dissecting Stereomicroscope (Carl Zeiss, Stemi-305, Germany) equipped with AXIOCAM 105 color 5 MP. The filter was observed from left to right following a

“zigzag” pattern using visual spots to avoid the omit of particles. Pictures of the potential MPs (Figure 3) were taken and processed with Zein platform (Image Analysis software). The particles were then counted and assessed with different criteria such as their shape, color and size (Cózar et al., 2015; Kazour et al., 2019). Particles shapes were identified as fragment, fibers, balls, pellets and films and the colors were noted.

After this visual observation, a chemical identification has been carried out using a Micro-Raman Spectrometer Xplora Plus (HORIBA Scientific®, France). The Micro-Raman analysis allows a non-destructive method for analyzing MPs particles and confirm the polymer type. Different parameters have been tested in order to have the most reliable technique for identifying the polymers of the analyzed particles. The best instrument parameters that have been found for optimizing the sample detection were a laser of 785 nm with a range of 200–3,400 cm^{-1} for less risk of burning the particle compared to the 582 nm laser, using a x100 objective (Olympus) to be more precise with 12 s of acquisition and 18 accumulations. The obtained spectra were compared using the polymer identification database (KnowItAll, WILEY®) and a personal library made with specific polymers obtained from Goodfellow (France). The identification is considered correct when the HQI (Hit Quality Index) was above 70 (ranging from 0 to 100).

Due to the high time consumption, a subsample that represented 10% of random suspected plastics were characterized through the Micro-Raman (Kazour et al., 2019).

2.8. Sampling parameters optimization

The impact of net clogging while sampling MPs at the water surface with net devices has been poorly reported in the literature (Pasquier et al., 2022). In order to acknowledge the potential effect of sampling distance (or duration) and water turbidity on net clogging, a preliminary test has been carried out during this study. As already described, the aquatic drone was equipped with two flowmeters. Three sampling replicates of both 300 m and 600 m length each, corresponding to about 10 min and 20 min duration, were then carried out at two different locations with either low (8 NTU) or medium turbidity (42 NTU) conditions. The values indicated by the two flowmeters were then compared to evaluate possible net clogging and choose the best sampling distance to use.

2.9. Contamination control and quality assurance

Before the sampling, all the utensils were cleaned and rinsed with ultra-pure water. The ultra-pure water was obtained by filtering at least

three times through glass fibers filters of 1.3 μm mesh Milli-Q water in order to remove possible contamination. Sampling utensils were then kept in aluminum foil to avoid atmospheric contamination. All the laboratory equipment was rinsed at least three times with ultra-pure water in order to remove possible contamination. The experiments were conducted under laminar flow hood and the use of plastic tools was restricted to a minimum. Cotton lab coat was wearing during the whole process. Procedural controls were conducted during samples treatment with the same volume of KOH used to samples digestion in order to have a picture of the background contamination. None MPs have been found while observing the procedural controls, proving the efficiency of the prevention measures. The samples were protected under a Plexiglass hermetic box while being analyzed by the stereomicroscope. The Raman spectrometer microscope and supporting platform for the samples were cleaned with microfibers paper between two analyzes.

2.10. Statistical analysis

For every location, the particles abundance has been reported as particles/ m^3 . The results are mean values of the different replicates carried out for each location \pm standard deviation (SD). The statistical analysis has been carried out through Microsoft Excel 2021 and R Studio (RStudio, Inc) software. The differences between the mean values of the two different methods were tested through a bilateral t-test Student 2 by 2 in order to check differences between the results. The analysis of colors, shapes and sizes were expressed as percentage of the mean values of the different replicates for every method at both locations.

3. Results and discussion

3.1. Environmental conditions

During the sampling, the salinity was 0.1 PSU (practical salinity unit) at the river site and 34.5 PSU at the coastal waters. The turbidity was 7.97 NTU at the river site and 6.5 NTU at the coastal waters. There was very calm wind for both sampling locations, lower than 2 knots coming from the West for the river site and from the North at the coastal waters site. Moreover, no rain was recorded on both sampling days and for the past 7 days before the samplings. In addition, no waves were observed at the coastal waters site nor current at the river location. The river flow was 0.7 m^3/s . These very calm environmental conditions (low wind speed, low wave height and no rain) were advised for surface water MPs sampling with a trawl net (Cowger et al., 2020, GESAMP 2019).

Table 1. Advantages of the aquatic drone sampling method compared to the Manta net in term of deployment, sampling efficiency, care for contamination and cost.

Methods	Deployment	Sampling efficiency	Care for contamination	Cost
Manta Net	<ul style="list-style-type: none"> • need of a vessel and at least 3 persons • exclusively in open and large water bodies • sufficient depth for the boat (generally >2 m) 	<ul style="list-style-type: none"> • difficulty to maintain the stable net immersion depth • approximative assessment of the volume sampled • net towing influenced by weather and hydrodynamic conditions • low accuracy in controlling the speed and distance sampled • approximation of the transect exact position • complexity to achieve replicates or sampling in both directions of a same area due to boat disturbances 	<ul style="list-style-type: none"> • possible contamination from the vessel and its potential turbulences • potential modification of the MPs distribution in the water column by the wake zone 	<ul style="list-style-type: none"> • high cost due to vessel requirement and at least 3 persons aboard
Aquatic drone	<ul style="list-style-type: none"> • one sufficient person • operable in many different water bodies (marine, estuarine, river) • facilitated access to shallow waters, river banks or small aquatic areas • easy to use from the shore 	<ul style="list-style-type: none"> • a higher overall stability due to its catamaran shape • sampled water height more consistent • measurement accuracy of the volume sampled • very good control of transect exact position, speed and duration with the remote controller • easy and rapid replicate sampling 	<ul style="list-style-type: none"> • no contamination from the drone • no turbulence registered • adapted localization of drone propulsors to the collecting mouth 	<ul style="list-style-type: none"> • Relatively low cost due to one person handling it and no vessel required

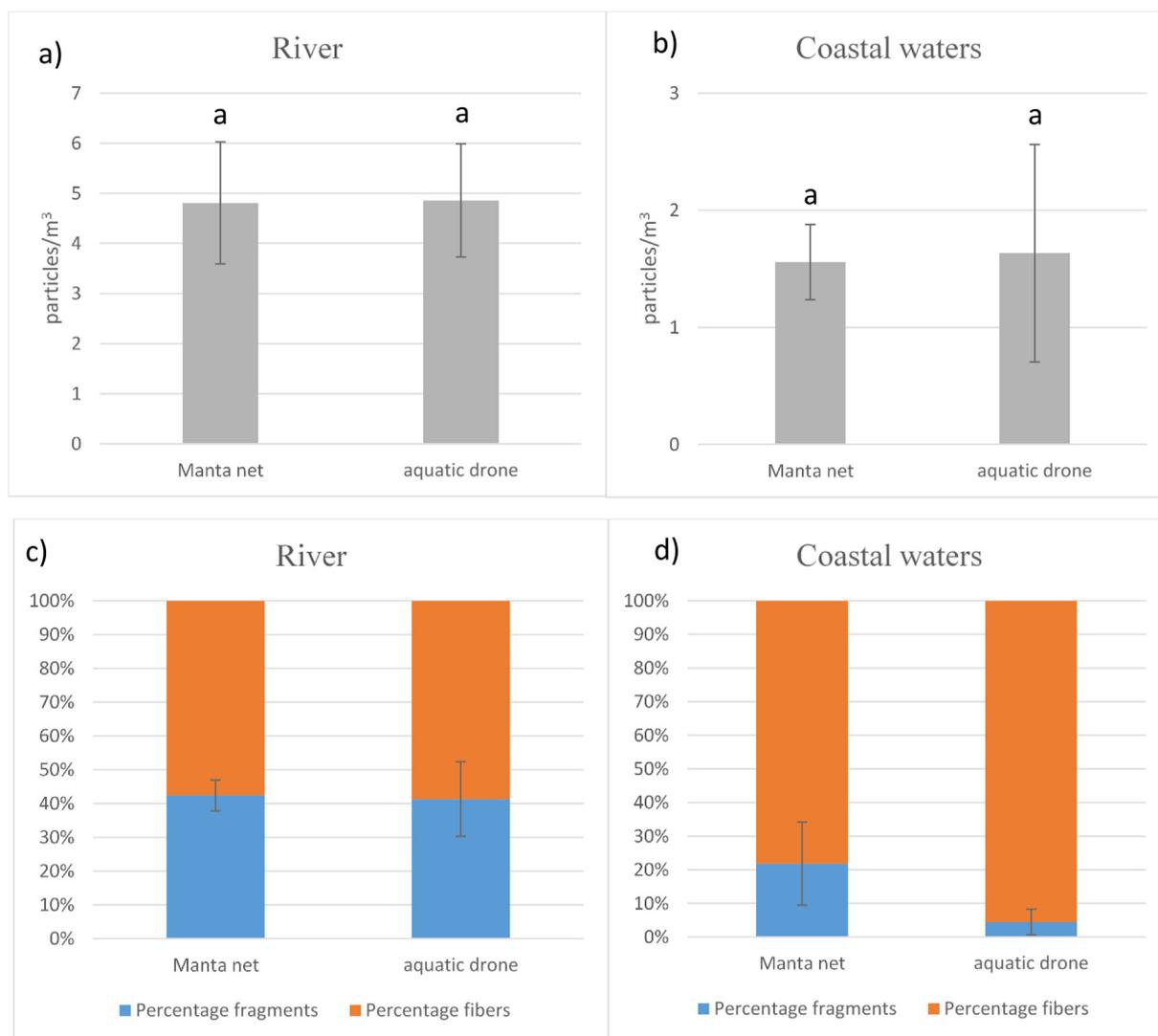


Figure 4. Microplastics abundance (particles/m³) obtained by the Manta net and the aquatic drone in (a) the river sampling site and (b) the marine coastal waters sampling site. Error bars represent the standard deviation between the replica and similarities between the methods are represented by the letters with a t-student test with 2 independents samples with $p > 0.90$ and microplastics repartition in percentage of fibers and fragments for the Manta net and the aquatic drone sampling methods at (a) the river sampling site and (b) the marine coastal waters sampling site. The error bars represent the standard deviation between the replica.

3.2. Sampling optimization

Two sampling distances, 300 and 600 m, were tested to check if the filtered volume remained constant under two turbidity conditions 8.0 and 42.2 NTU (Table 1). For the 300 m sampling distance the estimation of the decrease in the volume sampled are $6.9\% \pm 2.1$ at 8.0 NTU and $3.17\% \pm 2.1$ at 42.2 NTU. And for the 600 m sampling distance, $12.9\% \pm 2.5$ at 8.0 NTU and $14.9\% \pm 2.6$ at 42.2 NTU. The results of this sampling optimization showed a 2 to 4 times greater decrease in filtered volume with a sampling distance of 600 m compared to a distance of 300 m. These values underlined that a 600 m distance lead to a clogging of the net, which can impact to the filtration efficiency (Liedermann et al., 2018; Viršek et al., 2016). This is the reason why a 300 m distance has been chosen in the present study for the sampling transects. Furthermore, the volume measurement repeatability of the aquatic drone has proven to be significantly higher than the Manta net with a standard deviation being between 2 and 4 times lower for the aquatic drone between replicates than the Manta net. Indeed, the average volumes sampled with the Manta net were $34.6 \text{ m}^3 (\pm 1.27)$ and $35.5 \text{ m}^3 (\pm 1.53)$ whereas the aquatic drone collected $32.3 \text{ m}^3 (\pm 0.3)$ and $32.3 \text{ m}^3 (\pm 0.78)$ in the river and coastal waters sites respectively.

3.3. Comparison of particles abundance and shapes sampled with the two sampling net devices

The Manta net and the aquatic drone have been used in two aquatic environments to compare their efficiency in sampling MPs. Particles have been observed in the samples of every transect carried out at both locations with a total of 1,199 particles. In the two sites studied, there was no significant differences between the particle's abundances obtained via the Manta net and the aquatic drone samples. A bilateral statistic student's t-test has been carried out for both locations and showed that Manta net and aquatic drone samples presented more than 90% of similarity. The particles concentrations were of $4.81 (\pm 1.23)$ particles/m³ with the Manta net and $4.86 (\pm 1.13)$ particles/m³ with the aquatic drone in the river (Figure 4a), whereas in the coastal waters, they were respectively of $1.56 (\pm 0.32)$ particles/m³ and $1.63 (\pm 0.93)$ particles/m³ (Figure 4b).

The differences of particle abundance between the two sites were not related to the sampling method but only to the environment. On the one hand, the river location in an urban area, which is likely more polluted by plastic waste, can explained the higher abundance of particles. Moreover, the sampling site is located downstream a waste water treatment plant.

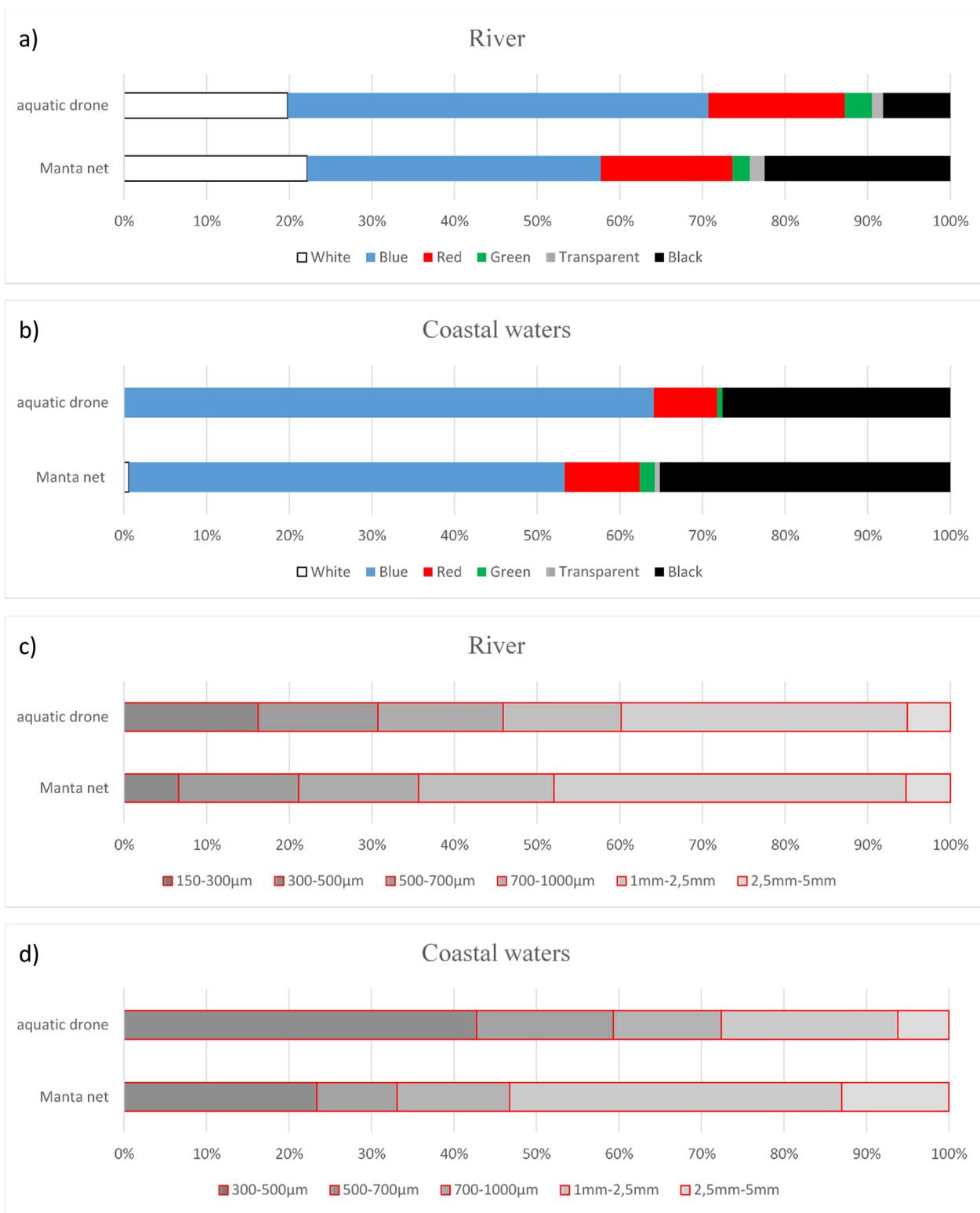


Figure 5. Microplastics colors repartition (in %) for each sampling methods the Manta net and the aquatic drone at (a) the river sampling site and (b) the marine coastal waters sampling site and size class particles repartition (in %) for each sampling methods, the Manta net and the aquatic drone at (c) the river sampling site and (d) the marine coastal waters sampling site.

Nevertheless, the abundances of particles in this river presented the same order of magnitude with those found in literature using a Manta net for MPs sampling in river, with for example 0.04 to 9.97 particles/m³ along the Rhine River (Mani et al., 2015) and 0.688 to 8.221 particles/m³ in the Pearl River estuary (Lam et al., 2020).

On the other hand, coastal waters site was an open marine environment, less subject to human activity pressure, which could explain the lower particle abundances at this site. These last remained similar with other studies using the Manta net to collect MPs in coastal waters, as for example in the southwest coast of India (1.25 ± 0.88 particles/m³) and in

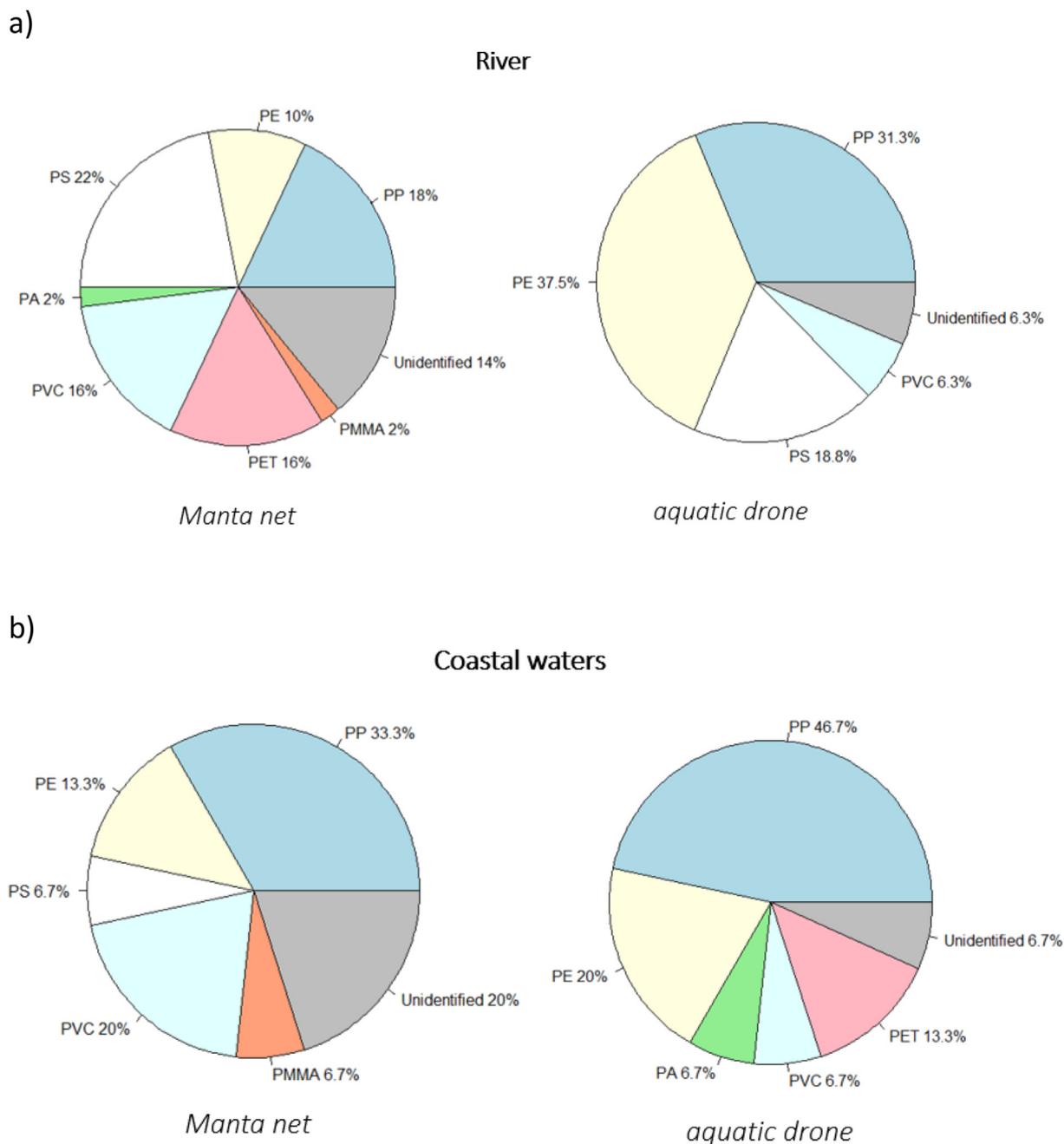


Figure 6. Repartition in percentage of the polymers identified and not identified in the particles sampled for the Manta net and the aquatic drone method at (a) the river sampling site (b) the marine coastal waters sampling site locations. Polypropylene (PP) polyethylene (PE), polystyrene (PS) polyvinylchloride (PVC), polyethylene-terephthalate (PET), polyamide (PA) and polymethyl-methacrylate (PMMA).

the central Adriatic sea (0.04 ± 0.01 to 3.42 ± 2.28 particles/ m^3), but higher than that recorded in coastal Arctic fjords (0.06 particles/ m^3) and Cilacap coast in Indonesia (0.27 – 0.54 particles/ m^3) (Robin et al., 2020; Capriotti et al., 2021; Carlsson et al., 2021; Syakti 2017).

Our results in terms of particle abundance support the fact that the drone is as effective as the Manta net in collecting particles in the water of these two environments. Other criteria about these particles must be taken into consideration to support this first observation. The shape of particles could indeed be influenced by the sampling method (Green et al., 2018). Two different shapes of particles have been detected in all the samples: fragments and fibers (Figure 4). These last were the dominant shape collected, accounting for at least 57 % of the particles. The proportion of fibers and fragments found in the river were almost similar for both of the method with 42 (± 4.5) % of fragment with the Manta net

and 41 (± 11.3) % of fragment collected with the aquatic drone (Figure 4c), contrary to the samples in coastal waters where the fragments represented respectively 21 (± 10.2) % and 4 (± 3.1) % (Figure 4d). These results were in the same vein than observations made at the level of abundance because the proportions of the two forms observed were equivalent between the two sampling methods. Indeed, the trend of a higher fiber proportion obtained with the drone compared to the manta net in coastal waters was not significant with a t-test and a confidence area of 0.90. Other studies demonstrated that fibers were predominant in coastal waters (Green et al., 2018; Frias et al., 2020), and that fragment could represent half of the total MPs sampled at some river sampling sites (Liu et al., 2020; Frank et al., 2021). This could be explained by the river trapping fragments that have less buoyancy than fibers, due to the lower current than in the coastal waters (Defontaine et al., 2020).

These first observations highlighted that in terms of collected particle abundance and shape, the aquatic drone is just as reliable as the samplings performed with the Manta net in two different aquatic environments.

3.4. Particles sizes and colors sampled with the two net devices

Six colors of particles were visualized among the samples with the range was white, black, red, green, blue or transparent (Figure 5). No significant difference of this color repartition among the samples collected with the Manta net and the aquatic drone has been highlighted. Blue particles showed the highest concentration (accounting for 36–65% of the particles sampled) compared to all the other colors whatever the method used (Figure 5), that explained by the predominance of blue fibers (accounting for 58–75%). The other important colors were black in coastal waters and white in the river. Other colors as red and green have been reported with lower concentration (16–1%) and transparent particles have been reported with the lowest concentration (less than 5%).

The particles sizes repartition is widely spread with particles ranging from 153 μm to 4862 μm with an average size of 1144 μm for the aquatic drone and range from 164 μm to 4965 μm with an average size of 1400 μm for the Manta net. The particles sizes repartition for both methods showed that the aquatic drone collected a significant higher number of smaller particles, 16.2 % of the particles between 150–300 μm compared to 6.6 % with the Manta net in the river and 42.8 % of the particles between 300 - 500 μm compared to 23.4 % with the Manta net in coastal waters (Figure 5). This loss of small-size particles when sampling with a manta net was already observed in Chinese Haihe river and of coastal waters of Sri Lanka (Liu et al., 2020; Athapaththu et al., 2020). Our results also showed that the Manta net collected a higher number of bigger particles, between 1mm - 5mm, with in the coastal waters 53.3 % of these particles sampled with the Manta net against 27.6% for the aquatic drone and in the river 48 % against 39.8 % respectively (Figure 5). The sizes of the particles found are comparable with the ones found in the literature (Du et al., 2022; Liu et al., 2020; Pagter et al., 2018).

The results of this study exhibited that the aquatic drone tended to sample more smaller particles than the Manta net, an explanation can be that sampling with a Manta net trawled by a boat generates turbulences that can lead to smaller particles being push through the mesh of the net (Vermaire et al., 2017; Mai et al., 2018). A problem that is not observed with the aquatic drone due to the fact that the propulsors are located on the side of the opening net mouth and therefore limits the turbulence.

3.5. Raman identification

10 % of the particles sampled of every replica with the Manta net and the aquatic drone were analyzed under the μ -Raman, i.e. a total of 120 particles. The particles were selected to be representative with the different colors and shapes observed previously. Among the particles analyzed by μ -Raman, 87% were identified as polymers and 13% could not provide a clear spectrum and were considered as ("unidentified"). Polypropylene (PP) particles representing 41% of all particles followed by polyethylene (PE) (13%), polystyrene (PS) (8%) and polyvinylchloride (PVC) (13%). Polyethylene-terephthalate (PET), polyamide (PA) and polymethyl-methacrylate (PMMA) were also identified with lower concentrations (Figure 6).

93% of the white fragments observed were identified as PS, explaining the high concentrations found at the river site. The proportion of PS found in the river site being equivalent for both methods. PP particles were the most common particles found in coastal waters with the Manta net (33.3 %) and the aquatic drone (46.7 %). 70 % of the blue fibers sampled were identified as PP explaining the high concentration of this type of polymer. PP and PE being the most found polymers in the water surface with a trawling net is in accordance with most of the literature (Pan et al., 2021; Hänninen et al., 2021; Cheng et al., 2021). This is due partially to the fact that PP and PE have low density, high

buoyancy, and are easy to migrate with water (Zhang et al., 2020), and thereby frequently appearing on the sea surface.

Polymers with higher density like PVC (1.25–1.45 g cm^{-3}) and PET (1.38 g cm^{-3}) were found at the river site in higher concentration with the Manta net sampling method compared to the aquatic drone. PMMA which density is also superior to 1 (1.16–1.2 g cm^{-3}) was collected only with the Manta net. This confirms the observations made on particle size and supports the hypothesis that due to the higher overall stability due to its catamaran shape, the aquatic drone more regularly samples the first few centimeters of the surface layer where the smallest and least dense particles are most abundant. Another hypothesis is that with the Manta net the smaller and less dense particles are probably more easily pushed away the net because of the turbulence generated by the ship's wake.

3.6. Economic potential of the aquatic drone

The initial cost of the aquatic drone is around 20.000 € while the Manta net is around 3000 €. However, costs applied for every use of both methods should be taken in account. The aquatic drone batteries need to be charge before any use ($240 \times 2 = 480\text{W}$), which correspond to a cost of approximately 0.08–0.11 € of electricity in the European Union. One person is sufficient to handle the drone. The median income in the European Union before tax is around 12.5 € according to The Organisation for Economic Co-operation and Development (OECD). For a sampling of approximately 6 h it corresponds to 75 €. Usually no boat is needed when sampling with the drone. In total the cost of 6 h sampling with the aquatic drone would be around 75.10 €.

When sampling with a Manta net, a boat is always required. Renting a small motorboat for the day would cost around 300 € and at least 3 persons are required so a cost of approximately $75 \times 3 = 225$ € for 6 h of sampling. In total the cost of sampling with the Manta net would be around 525 €.

In conclusion, the original investment for the aquatic drone would be around 6.7 times greater than the Manta net but sampling with the Manta net is 7 times more expensive. This shows that the aquatic drone has a better economic potential than the Manta net on the long term.

3.7. The aquatic drone as a new practical MPs sampling technique

The present study showed that for a same sampling transect, the new developed sampling technique using a tailored aquatic drone is effective in sampling MPs from surface waters. This new sampling technique reflects in a very similar way the abundance and characteristics of MPs sampled under the same conditions with a Manta net, the most popular sampling method in aquatic environment. Our results also showed that it provides better reproducibility and more accurate sampling of surface waters. Compared to the Manta net it has many advantages listed in Table 1. The main ones being operable in many different water bodies with high stability in water due to its catamaran shape, can be deployed from the shore by one person and does not require a boat thus limiting the risks of contamination and turbulence. It allows easy access to shallow waters, river banks or small water bodies such as streams or creeks which can usually only be sampled with other methods such as a pump filtration or grab sampling due to the difficulty of trawling a Manta net.

Many studies have highlighted the difficulty of comparing different MPs sampling methods (Green et al., 2018; Hung et al. 2021; De-la-Torre et al., 2022). Pump sampling is usually used in areas where classic net trawling is impossible. In this study, we compared our two net sampling methods with a pump sampling under the same conditions. At both studied sites, particle concentrations per volume of water sampled by the in-situ pump were more than 10 times higher (46.75 (± 9.24) and 23.27 (± 8.35) particles/ m^3 in the river and the marine coastal sites respectively). Furthermore, particles concentrations showed more variabilities between replicates (represented by the standard deviation). The number of MPs and sampling volume are two main factors determining the abundance (Lusher et al., 2014; Tamminga et al., 2019). In the present

study, since we used the same mesh size and that the same transect were sampled simultaneously with the other methods, only the volume sampled has varied. For the same transect and same duration of sampling, the in-situ pump sampled 354 L (± 0.006) when the Manta net sampled 35.05 m³ (± 1.4) and the aquatic drone sampled 32.3 m³ (± 0.54). MP abundance tended to decrease with increasing sample volume, suggesting that MPs with low sample volume may be overestimated (Tamminga et al., 2019; Zhang et al., 2020; De-la-Torre et al., 2022; Du et al., 2022). Quantifying MP in aquatic environments require reliable sampling methods. Compared to the trawl net method, the pump sampling doesn't allow a representative sampling of the extent of MP pollution (De-la-Torre et al., 2022). This is in line with the guideline for sea surface MP monitoring that the heterogeneous distribution of MPs in the aquatic environment makes it desirable to obtain a large sample volume for producing representative data (Michida et al., 2019; Miller et al., 2021).

However, the practicality of the pump can be discussed. As a very practical sampling device, the pump can be used in all kind of water environment such as lake, pond, river, open sea and by one person alone, regardless of the water depth (Prata et al., 2019). It does not require necessarily the use of a vessel and can be used directly from the shore. All these practical advantages are possible with the new aquatic drone sampling method developed in this study.

4. Conclusion

The aim of the study is to introduce the aquatic drone as a new sampling method for microplastics in surface and subsurface water in different water bodies, even in confined and hard-to-reach areas. This sampling method has the advantage of combining the benefits of Manta net sampling (i.e. a representative surface water sampling method that covers a large sampling area and volume (several tens m³) with those of pump filtration and grab sampling (easy access to confined and hard-to-reach areas). This new sampling method is supposed to answer the different problems that scientists face with the actual microplastics sampling methods and become a new standardized method.

Declarations

Author contribution statement

Gabriel Pasquier; Périne Doyen; Rachid Amara: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Nicolas Carlési: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

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