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WASTE CHARACTERIZATION IN THE URBAN CANAL NETWORK OF PADOVA (ITALY) TO MITIGATE DOWNSTREAM MARINE PLASTIC POLLUTION

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ABSTRACT
Concerns over plastic pollution in coastal wetlands, seas and oceans have risen exponentially in recent years. The majority of waste found in the environment has a land-based origin and is transported toward coastal-marine ecosystems along rivers and canals. Accordingly, waste collection in watercourses flowing through urban areas has a great potential to mitigate plastic pollution in local and coastal water bodies. In this paper, authors describe the results of three waste collection campaigns performed throughout 2021 (early summer, late summer and autumn) in three representative points of the canal network of the historical center of the city of Padova, Italy, where restoration of the urban stream ecosystems is currently ongoing. The collected waste was analyzed both in terms of size and material type. A total of 418 kg of waste was collected: the coarse fraction was prevalent (59% of the material intercepted by a 100 mm side mesh sieve), with plastic being the most widely represented waste category (47% by weight). The total amount of litter produced in one year from the canal network of the city of Padova was estimated, with those obtained from the canal banks found to be much higher than, or at least comparable to, those collected from the water, a finding which highlights the importance of planning waste collection together with riparian vegetation management to reduce plastic pollution. These findings provide a baseline for assessing the possibility of valorizing waste collected from the city waterways using processes other than landfilling and incineration.

1. INTRODUCTION

In the same way as all natural systems, inland surface water bodies support biodiversity and provide multiple benefits, known as ecosystem services, to humans (Millennium Ecosystem Assesment, 2005). These services may include recreational opportunities, navigation routes, water for hydropower, industries, irrigation or drinking, floodwater storage, fishery resources, nutrient abatement, carbon storage, as well as biodiversity support through the provision of habitats and ecological connectivity. On the other hand, inland surface water bodies are affected by multiple human pressures which produce a negative impact on the environment, ecosystem service provision and human society, including eutrophication, pollution, water abstraction, and morphological alterations.

In particular, the phenomenon of waste littering in water is a widespread problem worldwide. It causes numerous issues, such as the death of aquatic animals from entrapment or ingestion of waste, and bioaccumulation of microplastics in the food web (Arcangeli et al., 2018; Cincinelli et al., 2019; GESAMP, 2019; Schmid et al., 2021a, 2021b; Zeri et al., 2018) with potential risks for human health and unpredictable long term effects on aquatic biodiversity and the services it provides (Arcangeli et al., 2018; Schmid et al., 2021a). Waste abandoned in the environment by humans is transported by atmospheric events, potentially reaching as a final destination watercourses, such as rivers and canals, which act as waste "highways", transporting trash from the land to the sea: approximately 80% of marine plastic pollution derives from terrestrial litter (Canal & River Trust and Research Centre Agroecology Water and Resilience - Coventry University, 2019; Jambeck

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et al., 2015; Munari et al., 2021; Schmid et al., 2021b). It is moreover a well-known fact that plastics are the main problem related to waste abandonment, representing up to 80% of the total marine litter found in surveys (GESAMP, 2019; UNEP, 2016).

In recent years, several models have been set up to estimate the plastic waste load that reaches the marine environment every year from riverine ecosystems, varying from 0.48 to 2.75 X 10^6 t/y (Lebreton et al., 2017; Schmidt et al., 2017). These models are largely based on the assessment of mismanaged plastic waste, with scarce data deriving from field observations. Moreover, small sized plastic fragments (< 5 mm) are generally included in these models, although macro-plastics are considered secondary sources of microplastic formation due to degradation processes (Castro-Jiménez et al., 2019), thus creating a bias towards microplastics (González-Fernández et al., 2021).

Recent studies also have changed the paradigm according to which a small number of rivers are responsible for 80% of the plastic flow into seas and oceans (Lebreton et al., 2017): indeed, Meijer et al., (2021) reported how more than 1,000 rivers account for 80% of global riverine plastic emissions, while González-Fernández et al., (2021) affirmed that the majority of macro-litter in Europe is transported towards the coasts through small-sized drainage basins (<100 km^2). These studies highlighted the importance of field studies in small river basins situated close to the coastlines, in view of the calibration and validation of plastic load models (Tramoy et al., 2022).

It is of course easier, more effective, cheaper and less time consuming to intercept and collect wastes inland, before they reach the marine environment. According to a study conducted by Coventry University in collaboration with the Canal and River Trust – a charity that cares for 2,000 miles of waterways in the UK – it is possible to modify the marine plastic pollution situation by acting at a local level, including daily actions carried out by individuals to prevent the dispersion of plastic into the environment (Canal & River Trust and Research Centre Agroecology Water and Resilience - Coventry University, 2019).

Local actions to mitigate the global problem of waste and plastic loads in the oceans appear particularly strategic in cities. Indeed, on a local, regional and global level, urban areas are key drivers of environmental change linked to modification of land use, material and energy demand of human activities and associated emissions, including plastics, and impacts. Therefore, waste collection from watercourses flowing through urban areas has a significant potential to mitigate the impact of plastic pollution on local and coastal water bodies, also constituting an effective means of communication, particularly as a high percentage of the human population is now concentrated in cities (Grimm et al., 2008).

This paper focuses on the presence of litter and its removal from the ancient canal network of the historical centre of Padova. In this city, located in a densely inhabited and heavily industrialized and cultivated floodplain in north-eastern Italy, restoration works on the urban watercourse ecosystems have been ongoing since 2018 through several projects co-funded by the city administration, such as the project "Padova e i suoi canali" (i.e., "Padova and its canals"). This project is aimed at regularly removing abandoned, floating and submerged waste from the banks and beds of the canals flowing through Padova, and carrying out routine vegetation management (e.g. removal of weed plants, pruning), in both cases adopting biodiversity-friendly techniques (Padovanet, 2021). Both tasks are also accomplished by focusing on canal stretches which are hard to access by means of large landed mechanized means, thus highlighting how soft interventions based on manual labour and the use of boats are the only cost-effective approach. The overall goal of this project is to demonstrate the environmental, social (e.g., in terms of creation of green jobs) and economic advantages of regular maintenance of city canals, a fundamental precondition to improving environmental quality and revitalizing these long-neglected historical watercourses perceived as degraded by the inhabitants. Waste removal tasks envisaged by the project, carried out by a social cooperative, prevent waste from polluting the ecosystems of the rivers Bacchiglione and Brenta, which would ultimately transport waste to the Adriatic Sea, a marine ecosystem heavily impacted by human factors such as fisheries and river emissions, with the latter causing issues such as eutrophication (Artioli et al., 2008; Barausse et al., 2011; Valdemarca et al., 2016). Indeed, the Adriatic Sea receives approximately one third of the freshwater flowing into the Mediterranean Sea, mainly from the Po (the largest Italian river), but also from many smaller rivers that run through one of the most industrialized, inhabited and cultivated areas of Northern Italy (Schmid et al., 2021b; Zeri et al., 2018). Liubartseva et al., (2016) estimated that 40% of marine litter enters the Adriatic basin via rivers, a further 40% through coastal urban populations, and the remaining 20% through shipping activities, providing percentages in line with the abovementioned 80% in-land source for marine litter generation. Moreover, the Adriatic basin is frequently indicated (Arcangeli et al., 2018; Munari et al., 2021; Schmid et al., 2021b; Zeri et al., 2018) as the preferential region within the Mediterranean Sea for plastic litter accumulation, particularly along the Northern coast (Liubartseva et al., 2016; Munari et al., 2021, 2016), focus of this study.

The importance of marine litter is also recognized by the EU's Marine Strategy Framework Directive (MSFD, 2008/56/EC), mandating a "Good Environmental Status (GES)" for marine waters by 2020 through the use of 11 descriptors (European Commission, 2008), with descriptor 10 (D10) reading "Properties and quantities of marine litter do not cause harm to the coastal and marine environment" (European Commission, 2008). Although the deadline for achievement of the GES has passed, the Directive is still being implemented and its aims were included in the objectives of the EU's Biodiversity Strategy for 2030. Starting from the MSFD, the topic of litter in marine ecosystems was thoroughly investigated, in contrast to riverine environments (Cesarini and Scalici, 2022).

In this study, three different waste collection campaigns were performed in 2021 along three stretches of the urban canals of Padova, with a subsequent characterization of the collected waste in terms of size (granulometric analysis) and composition (compositional analysis). The aims of the study were:

- To characterize the spatial variation in waste size and composition, through a comparison between waste characterization analysis in the different canal stretches;
- To understand the temporal variation in waste size and composition, by comparing the three waste collection campaigns held in early summer, late summer and autumn;
- To estimate the amount of waste per year produced by the canal network of the city, to investigate whether the collected wastes can be valorized through processes other than landfilling or waste-to-energy, such as recovery or recycling.

The latter information is relevant globally to contribute data and concrete management experiences to the research on plastic pollution in water bodies, and locally to inform and plan the future management of the canals of the city of Padova.

2. MATERIALS AND METHODS

Three different waste collection campaigns were performed in 2021, in early summer, late summer and late autumn, along three different canal stretches within the city of Padova, namely the Tronco Maestro (A), Scaricatore (B) and Roncajette (C) canals (Figure 1, Figure 2).

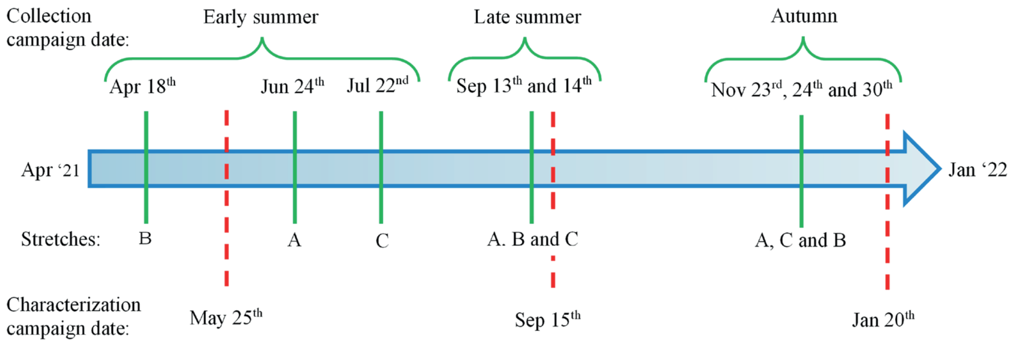

FIGURE 1: Schematic representation of the timeline of monitoring activities. Collection days in the three experimental campaigns are indicated with green lines and related to the canal stretches on which the campaigns were performed. The corresponding characterization campaigns are indicated with dashed red lines.

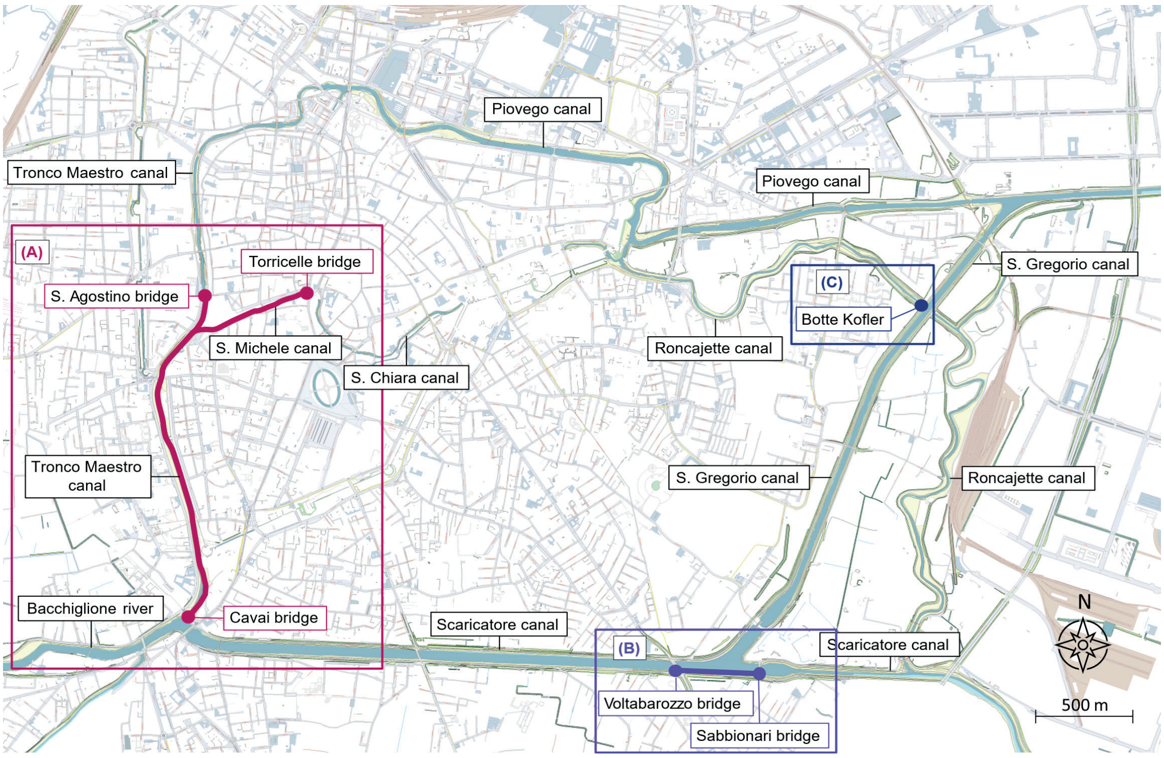

FIGURE 2: Map of the canal network of the city of Padova, highlighting the three canal stretches along which the collection campaigns were performed: Tronco Maestro and S. Michele canals in purple (A), Scaricatore canal in violet (B) and Roncajette canal in dark blue (C).

The choice of the three canal stretches was made on the basis of their representativeness of the different situations encountered in the city of Padova:

- Tronco Maestro canal stretch (A) is representative of the canal system in its initial stretch through the city; here the totality of waste found in water was collected;
- In the Scaricatore canal stretch (B) the totality of waste found on the right canal bank was collected. A decision was made to focus on the banks because people regularly congregate at this location for recreational purposes, such as running and cycling along the embankments or meeting and drinking at the bars and cafes in the area;
- In the Roncajette canal stretch (C) collection concerned a single location of the canal, Botte Kofler, an inverted canal siphon which is an accumulation point for wastes. Here, due to the high amount of waste accumulated during a hard-to-estimate period, only part of the total amount of waste was collected. In this location, only the floating waste present in water was included in collection campaigns.

The collection campaigns were performed with the support of a boat and pontoon according to the depth of the canal stretch under investigation (Figure 3).

Wastes were collected manually for all the canal stretches (A, B and C) of this work, using small instruments such as pliers and nets (Figure 4), to minimize the environmental impact of collection on the flora and fauna and avoid the need for mechanical collection that generally increases the risk of waste shredding, thus contributing to the fragmentation of waste and formation of microplastics. When the collection was performed in water (A, C) both nets and pliers were used, while for the collection executed on the bank system (B) only pliers were used. The mesh size of the nets was 2 mm. However, it is important to underline that only litter items visible from a standing position (on the boat or on the bank) were removed.

Table 1 reports the amount of waste collected in each campaign and canal stretch.

After each collection campaign, a characterization of the collected waste was performed. The characterization analyses followed a methodology developed by the Laboratory of Environmental Engineering of the ICEA department (University of Padova). The waste was characterized by size (granulometric analysis), by distributing it over a system of sieves (with 200, 100, 80, 50 and 20 mm side meshes; Figure 5) and by composition (compositional analysis), through a manual sorting into six macro-categories (cellulosic material, plastics, metals, glass and inert material, others, and undersieve). In turn, some of the macro-classes were classified into more specific categories, and in particular: plastics were divided between PET, PE (HDPE and LDPE), PP and PS, PVC and other types of plastic, metals were divided between aluminium and other metals, and finally glass and inert materials were divided between glass and inerts. The percentage by weight of each waste category was then calculated.

Following characterization analysis, the waste was disposed of in line with the separate collection scheme of the city of Padova, diverting it from the unsorted waste management options.

3. RESULTS AND DISCUSSION

With regard to the size of the waste collected in the three different stretches of the Padova canal network (Figure 6), the coarse fraction, composed of material with relatively large size (on average, 59% of the material was intercepted by the 100 mm sieve side mesh) was prevalent, whilst the fine fraction was essentially non-existent in terms of weight (less than 3% of the material passed through the 50 mm sieve side mesh), likely being difficult to intercept by a manual collection system and more easily transported by water currents (Castro-Jiménez et al., 2019). Accordingly, the results of this study are probably biased when comparing small and larger items, with underestimation of the small fraction of litter. However, variations related to the investigated canal stretch are detectable: in the Scaricatore and Roncajette canals, the resulting fraction was generally

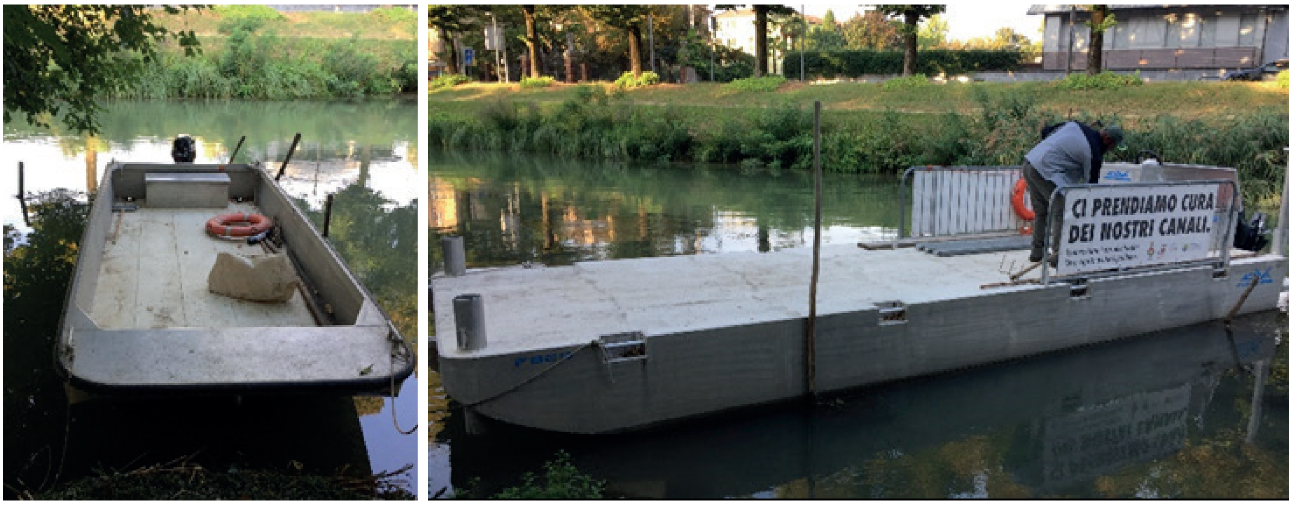

FIGURE 3: The boat and pontoon used for the different collection campaigns.

FIGURE 4: Some of the instruments used for the manual collection method applied in the collection campaigns.

TABLE 1: Amount of collected waste [kg] per collection campaign and per canal stretch. The total amount of the collected waste is also reported.

Collection campaign and date	Canal stretch	Amount of collected waste [kg]
Early summer – 18/04/2021	Scaricatore canal (B)	81.02
Early summer – 24/06/2021	Tronco Maestro canal (A)	22.16
Early summer – 22/07/2021	Roncajette canal (C)	39.10
Late summer – 13/09/2021	Scaricatore canal (B)	58.97
Late summer – 13/09/2021	Tronco Maestro canal (A)	17.23
Late summer – 14/09/2021	Roncajette canal (C)	46.29
Autumn – 23/11/2021	Tronco Maestro canal (A)	44.22
Autumn – 24/11/2021	Roncajette canal (C)	28.54
Autumn – 30/11/2021	Scaricatore canal (B)	80.73
		418.26

higher than in the Tronco Maestro canal stretch, meaning that the waste collected in the latter was larger than waste collected in the other stretches. This finding may be explained by the relative ease of collecting smaller objects on the banks or in an accumulation point rather than from the water during navigation.

With reference to the composition of the collected waste, the compositional analysis highlighted several differences according to the canal stretch in which collection took place (Figure 7):

- In the Tronco Maestro canal (A), most of the collected waste was comprised in the 'others' fraction, with an average value by weight of 37%, followed by glass/inerts and plastics with an average value by weight of 28% and 20%, respectively. The high value obtained for the category 'others' was due to the large amount of textiles, such as blankets and clothes, found, probably abandoned by homeless people and fishermen. This is the only canal stretch in which the percentage of plastic materials was not predominant, likely as plastic items are easily transported by the current due to their low specific weight, until an obstacle is encountered (an accumulation point such as a hydraulic structure or riparian vegetation);
- In the Scaricatore canal (B), plastics accounted for an average value by weight of 45% of total collected waste, followed by glass/inerts and 'others' (average values by weight of 26% and 18%, respectively);
- In the Roncajette canal (C), plastics accounted for an average value by weight of 67% of total collected waste, followed by glass/inerts (average value by weight equal to 23%). In this location, plastics were present in

FIGURE 5: System of sieves of different side mesh (200, 100, 80, 50 and 20mm) used for granulometric analysis.

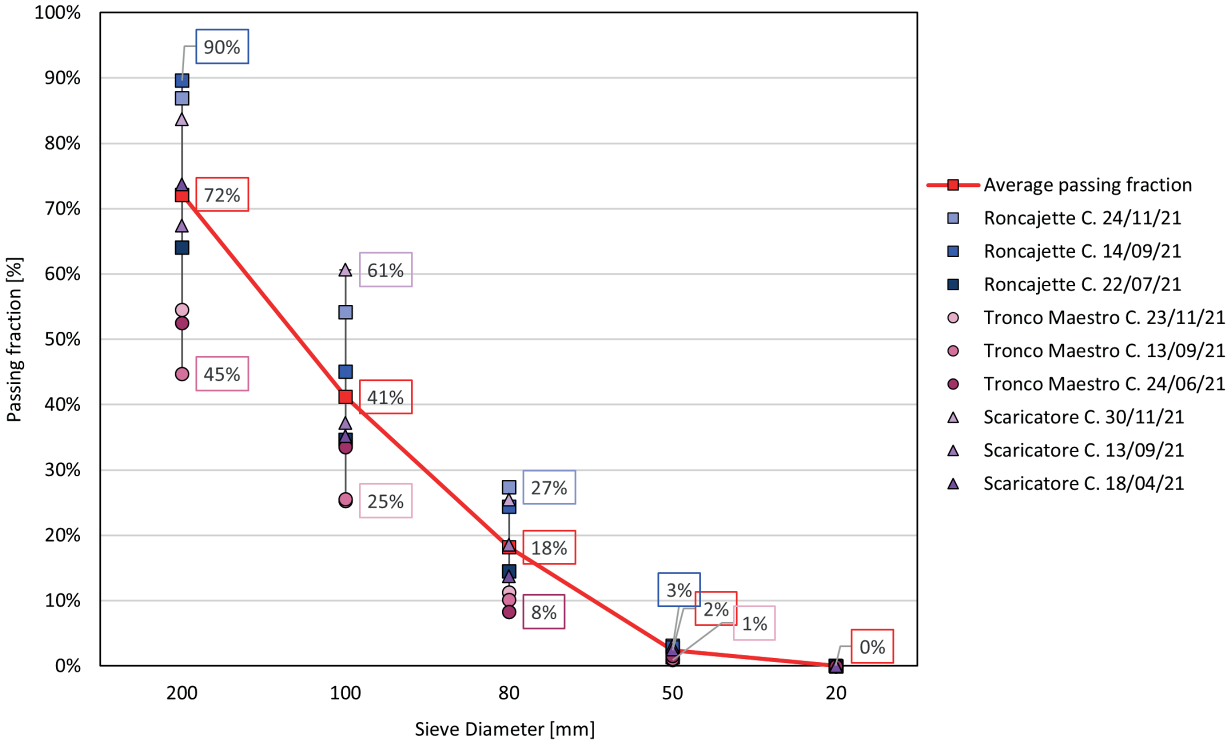

FIGURE 6: Graphic representation of the results of granulometric analysis in the three canal stretches (Tronco Maestro, Scaricatore, and Roncajette) for the three different collection campaigns (early summer, late summer and autumn). The red line represents the average for a given sieve diameter of the three collection campaigns and the three canal stretches.

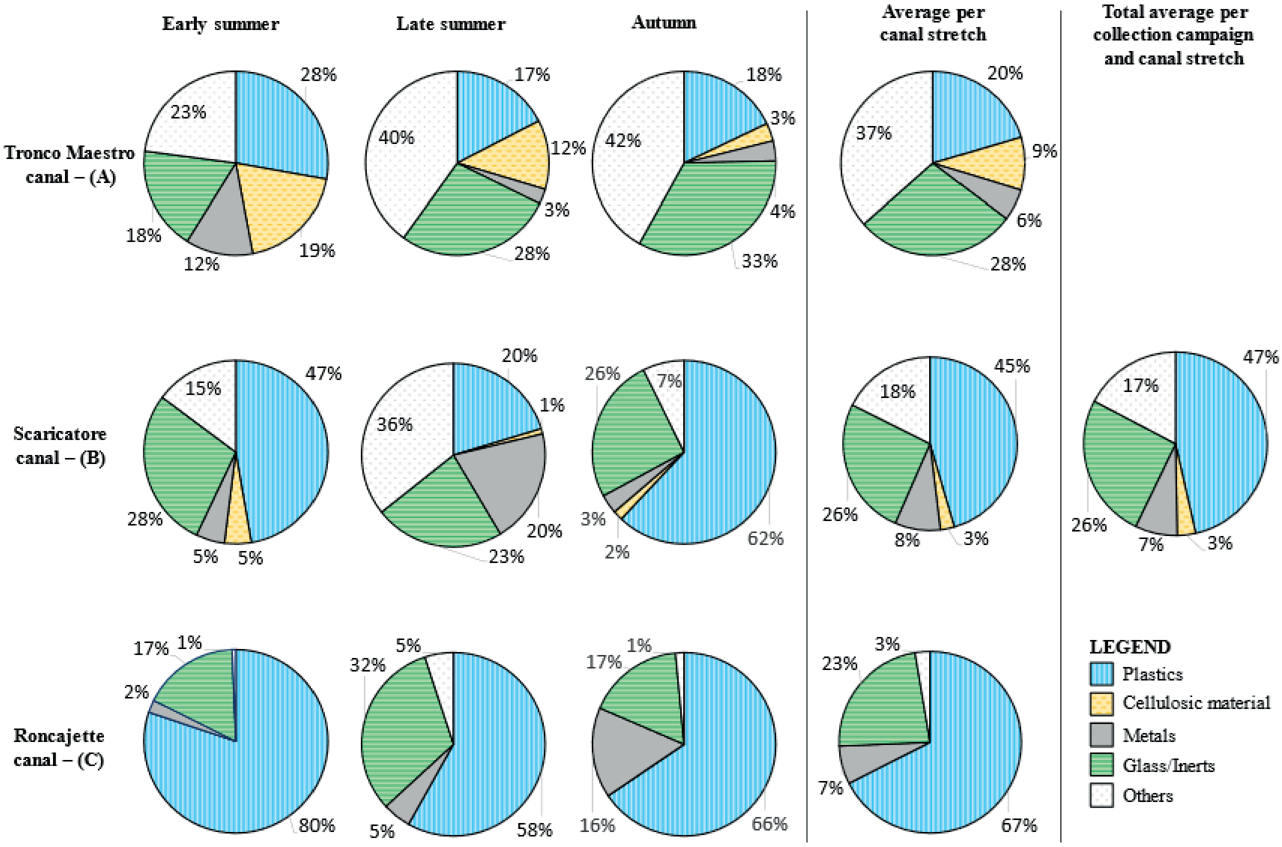

FIGURE 7: Compositional analysis results in the three canal stretches analysed (Tronco Maestro – A, Scaricatore – B, and Roncajette – C) for the three different collection campaigns (early summer, late summer and autumn). The results are also given as the average per canal stretch and as the total average per collection campaign and canal stretch. Percentages are in weight.

a much higher percentage compared to the other canal stretches. This was probably due to the fact that litter in canals may either float or sink and, if it floats, continues to move with the prevailing flow until it reaches the sea or until it encounters an obstacle, as was the case here: Botte Kofler is, in fact, an accumulation point for waste, due to the presence of hydraulic works. Moreover, at this point, heavy wastes – such as metals and glass – have the time to sink, unlike plastics which continue to float.

As expected, plastic was the most widely detected waste fraction during the collection campaigns (with an average value by weight of 47%): indeed, plastics are generally found in disposable products that are readily discarded, such as bottles, bags, packaging and food wrappers; plastics are moreover light and therefore highly mobile and easily transported by wind and water.

These findings are in line with those obtained in other similar field studies. For example, in a study conducted by the Coventry University and the Canal and River Trust in 2019 to assess waste littering in canals and rivers in the UK, the single largest category of litter found along the canals was plastics, with 14 million out of a total of 24 million items being dropped into waterways annually (59%) (Canal & River Trust and Research Centre Agroecology Water and Resilience - Coventry University, 2019). Similarly, Castro-Jiménez et al., (2019) found that the floating macro-litter in Rhone river (France) represented 77% of identified items, while Tramoy et al., (2022) obtained a percentage of 83 plastic items of the total collected items in Huveaune river (France). González-Fernández et al., (2021) obtained a similar value for European rivers, obtaining a total of 82% of plastic items. In Italian rivers, the situation is similar to that observed at European level, with plastics representing the majority of waste found in the riverine environment. This is supported, for example, by the study of Cesarini and Scalici, (2022), in which the riparian zone of 8 central Italian rivers was investigated, with a frequency of plastic items corresponding to 81% of all items found. However, in Italy, studies investigating waste littering in rivers are scarce, highlighting the importance of novel data such as those provided by this work, although the topic has been thoroughly investigated in the marine environment (Cesarini and Scalici, 2022). Focusing on the Adriatic Sea, which receives the waters of the canal network under investigation, studies on floating sea floating, mainly consisting in visual observations (through naked eyes or binoculars), revealed how the majority of waste is made up of plastics, with percentages exceeding 90% by item number (Schmid et al., 2021b). In all the above-mentioned studies, the percentage of plastics is slightly higher than the results obtained in this study, likely as they considered the number of items rather than weight of the litter: plastics have a low specific weight compared to other waste categories. In this study, focus on total weight of litter was considered the most appropriate approach, in order to understand the magnitude of pollution and to investigate the applicability of recovery and recycling strategies (Schmid et al., 2021b).

Among plastics, PET (mainly composed of bottles) was the most copious fraction in Padova, followed by PS and PP, PVC and others, and PE (39,52%, 23,05%, 23,05% and 14,39% in weight, respectively). These results are not completely in line with the findings of other studies: Schmid et al., (2021b), in a critical review of marine litter found in the Adriatic sea, reported how the most abundant polymers by number of items in all studies were PE (from 26% to 88%) and PP (from 5% to 30%). The results obtained for the Po, the largest Italian river, by Munari et al., (2021) confirmed the results of the review of Schmid et al., (2021b): PE, PP and PS were the most abundant polymers, respectively 40.5%, 25.7% and 14.9% of total plastics. However, in the Po case study and in all studies investigated in the review, polymer identification was performed by means of Fourier-transform infrared spectroscopy (FT-IR) analysis on a sub-fraction of the collected particles. Conversely, in this study, identification was performed on the totality of collected waste by means of visual identification, according to the indication found on the product or the label, with a probable reduction in the accuracy of results.

No significant differences were detected – either in terms of waste size or composition – between the three different waste collection campaigns, performed respectively in the early summer, late summer and in late autumn, meaning that that our extrapolations (made below) to yearly scales are relatively robust with regard to this source of variation in the collected data. Nevertheless, our study lacks winter data, and some variability may still be assessed across the investigated seasons, likely due to unavoidable natural stochasticity, manual collection system and moreover to the lifting of COVID-19 restrictions following the first litter collection campaign. The latter issue implies that the waste collection campaign was not representative of a routine situation devoid of restrictions. Future studies based on a larger amount of data should relate the collected wastes to weather conditions (such as rain or extreme events), to detect the relationship between the waste load obtained from the canal network and meteorological events, thereby improving the potential for generalization and future extrapolability of results. The inclusion of meteorological information would aid the understanding of whether and how the waste litter load changes across dry and wet periods and how it depends on extreme weather events which could move litter from the city into the water or mobilize litter found in riparian vegetation.

Bearing these uncertainties and limitations in mind, the waste accumulation rates per day and per year were calculated (as detailed below and reported in Table 2) for the Tronco Maestro canal stretch (A) and for the Scaricatore canal stretch (B), as representative of the waste accumulation in water and on the canal banks. The waste accumulation rate was not calculated for the Roncajette canal stretch because of the unknown period of time during which the accumulation had occurred prior to cleaning operations.

Combining this information with both the length of the canal network and length of the banking system of the city of Padova (calculated using the QGIS software), the total amount of litter found in one year in the waterways

TABLE 2: Waste accumulation rates per day and per year for the Tronco Maestro (A) and Scaricatore canal stretches (B).

Canal stretch	Tronco Maestro canal (A)	Scaricatore canal (B)
[%] of wastes collected during the campaigns (and place of collection)	100% (in water)	100% (on the right canal bank)
Last waste collection campaign date before this study	20/12/2020	20/12/2020
Last waste collection campaign date within this study	23/11/2021	30/11/2021
Days between the date of the last collection campaign within this study and the date of the last collection campaign before this study	338	345
Waste collected during the three collection campaigns [kg]	83.61	220.72
Waste accumulation per day [kg/d]	0.25	0.64
Waste accumulation per year [kg/y]	90.29	233.52

and along the banks was estimated (Table 3). Indeed, this estimation was made not only for litter retrieved from the water system (thus extrapolating the results of the investigated Tronco Maestro canal stretch), but also for litter found on the canal banks (extrapolating the results from the investigated Scaricatore canal stretch), based on the acknowledged fact that litter from banks enters the waterways transported by wind and atmospheric events. The overall urban canal network considered for this estimation is limited south-westwards by the point at which the Bacchiglione river splits into the Tronco Maestro canal and Scaricatore canal, south-eastwards by the point at which the Scaricatore Canal encounters the Sabbionari bridge, north-eastwards by the point at which the San Gregorio canal meets the Piovego Canal (Figure 8), and north-eastwards by the path of the Piovego canal. The length of the bank system was calculated taking into account solely banks accessible to the population or reachable by litter thrown from adjacent streets.

It was assumed that the quantity of litter found in the waters of the Padova canals corresponded to that retrieved from the initial stretch of the Tronco Maestro. On the one hand, this assumption seems plausible since the stretch in question is situated upstream of the city and its canals, whilst on the other hand, the presence of litter in water however is likely affected by the crossing of a series of different neighbourhoods by the canals and diverse use of the banks, thus complicating evaluations. Similar considerations were applied to estimation of the amount of litter produced yearly by the canal bank system, which might prove to be an overestimate: indeed, the Scaricatore canal stretch chosen as a collection point in this study is close to an ag-

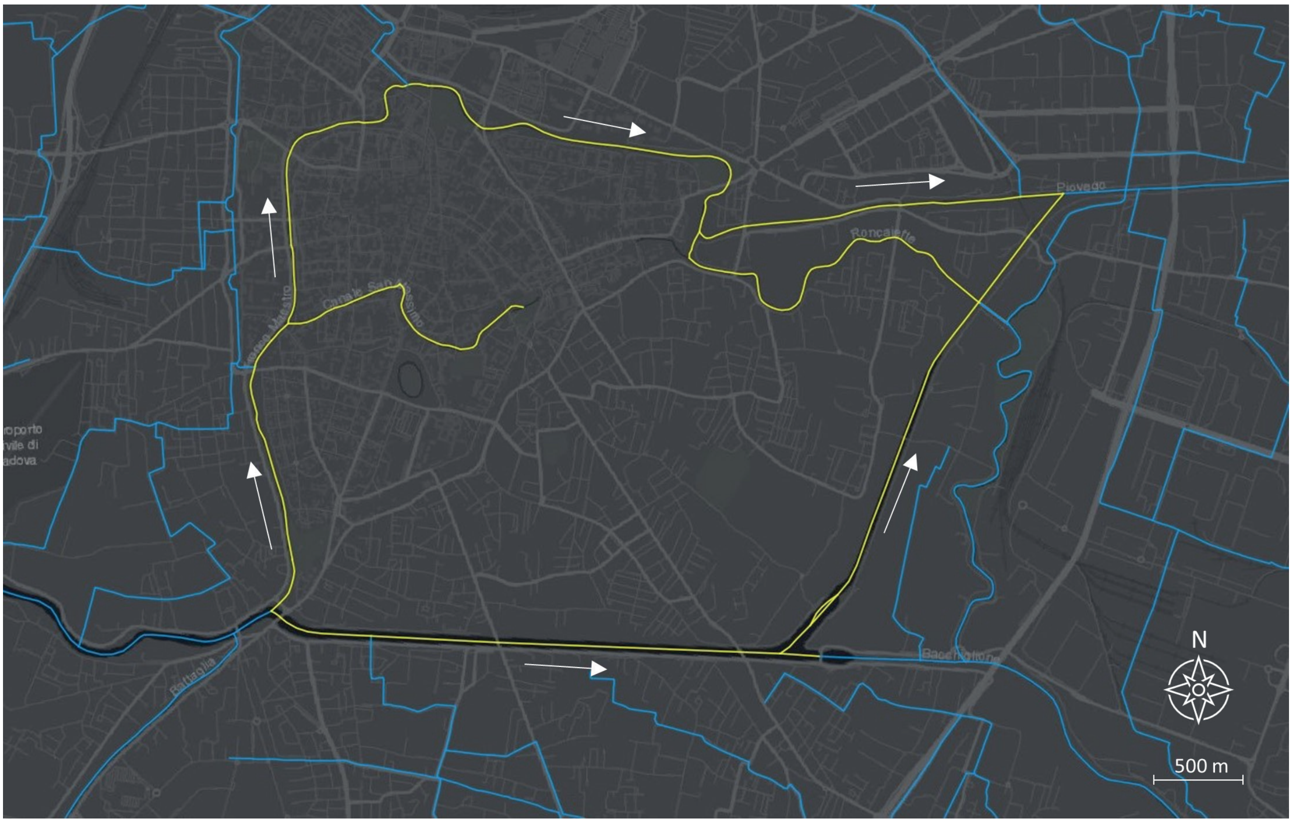

FIGURE 8: Representation of the canal network taken into consideration (yellow lines) for the calculation of the annual litter production by the watercourses of the city of Padova. White arrows represent the flow direction.

gregation point for the population and this may result in a higher waste accumulation rate compared to other points along the bank system of the city. Finally, the litter present at the Roncajette accumulation point has not been taken into account, due to the impossibility of calculating waste accumulation rates, meaning that the results of the litter in water could be an underestimate of the true scale of the litter problem, particularly when considering that the canal network under investigation in this study contains multiple hydraulic works and bridges (Valdemarca et al., 2016) that presumably act as accumulation points. Additional uncertainties in litter accumulation rates both in water and on the canal banks are also given by the fact that the first collection campaign was undertaken immediately after the lifting of COVID-19 restrictions, thus implying that the amount of waste obtained in the first collection was almost certainly lower compared to a routine situation devoid of any restrictions, thereby leading to an underestimation of the problem of waste litter in the canal network of the city of Padova.

The annual litter production for the watercourse of the channel network of the city of Padova (water and banks) is estimated to correspond to almost 17,000 kg. The estimate for waste litter production in water (650.65 kg/y) is fairly accurate, although it does not take into account accumulation points along the canal network and the likely lower quantities obtained during the first collection due to COVID restriction measures. Conversely, the figures obtained for waste litter production on the canal bank system (16,190.76 kg/y) is a rough overestimate, considering that the canal stretch investigated is a place where the population congregates for recreative purposes. To compute a more precise estimation, representative of the whole bank system of the city, other collection campaigns should be conducted at different points of the city banks, to allow the assessment of different litter accumulation rates relating to different points of the network.

Annual litter production for the watercourses was finally normalized to the population of the city of Padova, resulting in the production of 80.26 g/inhabitant/y of waste litter, corresponding to the 0.02% of the total annual waste generation per person in 2021, in turn equal to 464 kg/inhabitant/y (Arpav, 2022). The same consideration made for the reliability of annual litter production estimates are applicable here. In fact, the per capita annual litter production in water (equal to 3.10 g/inhabitant/y) is a fairly trustworthy estimate, while the per capita annual litter production from the banks (equal to 77.16 g/inhabitant/y) needs more data in different points to be considered reliable. Tramoy et al., (2022) reported a production of approx. 10 g/inhabitant/y in the rivers Huveaune and Seine, considering solely plastic present in the water, whilst on a European level this production has been estimated by González-Fernández et al., (2021) to be in the range of 1-10 g/inhabitant/y. These results are in line with those obtained for the Padova canal network when considering solely the production of litter in water, corresponding to 1.46 g/inhabitant/y of plastic litter.

Despite the uncertainty in estimates discussed above, however, the waste retrieved from the banks of the canal network should probably be higher or at least comparable to that found in water: the finding that watercourse banks act as a repository for litter and plastics has important management implications, highlighting that by removing litter from river banks, i.e. on land, before it enters the water (for example windborne), the final amount of plastics found in the water can be significantly minimised. Cesarini and Scalici, (2022) studied the role of riparian vegetation in trapping plastic litter in 8 central Italian rivers, demonstrating that these zones may provide a further ecosystem service as mechanical filter against litter dispersion, particularly in urban contexts. Based on the experience gained in Padova, the management of riparian vegetation along the banks of watercourses represents a double-edged sword: on the one hand, if performed perfunctorily using mechanized tools, grass mowing and shrub cutting can shred plastics into tiny fragments, making removal impossible and promoting dispersion into the environment, including water, and the formation of microplastics. On the other hand, if litter removal is planned together with riparian vegetation management and implemented shortly before using manual tools and, where possibly, the same operators, this would allow plastic loads entering watercourses to be significantly reduced, whilst at the same time economising through the joint implementation of two activities (vegetation management, which is already routinely carried out along urban watercourses, and litter removal). Therefore, our recommendation is that litter removal and riparian vegetation management should be planned and implemented concomitantly in urban areas to minimize the impact of plastics on watercourse ecosystems. More empirical observation are needed in order to confirm the role of riparian vegetation as a mechanical filter against plastic dispersion in the water environment.

This study tends to highlight the finding of a significant amount of waste litter in the canal network of the city of Padova – waste which would ultimately reach the Adriatic Sea ecosystem without any proper collection action. This waste flux is mainly composed of plastics, which fragment through the action of mechanical forces (such as currents, waves or wind) into microplastics, demonstrated to be harmful for the marine fauna (Arcangeli et

TABLE 3: Annual litter production from the canal network of the city of Padova (in water and on the banks).

Canal stretch	Tronco Maestro canal (A)	Scaricatore canal (B)
Length of the canal/bank involved in the collection campaign [m]	2,545.00	430.00
Waste per year per meter [kg/y/m]	0.04	0.54
Total length of the canal network [m] (A) and banking system [m] (B) of the city of Padova	18,340.00	29,814.00
Waste per year entering the canal network of the city of Padova [kg/y]	650.65	16,190.76

al., 2018; Cincinelli et al., 2019; GESAMP, 2019; Schmid et al., 2021a, 2021b; Zeri et al., 2018). Further sampling activities should be carried out to obtain a more precise estimate of yearly litter fluxes generated by the canal network of the city of Padova. This information will be crucial to allow decision-makers to evaluate the magnitude of the littering issue and to investigate whether it is possible (and economically feasible) to implement waste management strategies other than landfilling and waste-to-energy, for example urban mining. This latter, in fact, is an essential step for putting into effect reuse and recycling policies. One option, for example, could be the implementation of a deposit system for the collection of PET beverage bottle, considering their large presence among the collected waste.

4. CONCLUSIONS

Land-based sources are predominantly responsible for the presence of plastic materials in the environment, which is subsequently transported towards the sea by watercourses. The implementation of waste collection strategies at a local level before they reach the seas and oceans would contribute towards reducing waterway-originated pollution and improve the health of oceans worldwide. This study focused on waste litter present in the watercourses of the city of Padova in the year 2021. No noticeable seasonal variations were observed, either in terms of waste size or composition. The litter retrieved was mainly composed of coarse material, with plastics being the most widely represented category (47% by weight of the total collected waste). Other recyclable fractions (glass/inerts and metals) accounted for 26% and 7% by weight, respectively: the recyclable part of the waste litter corresponded to 80%, amounting to more than 13,000 kg per year considering the whole canal network of the city of Padova. This fraction could be diverted from the waste management options typical used for unsorted waste (landfilling and incineration). However, our estimates are limited by a series of uncertainties and more reliable estimates should be yielded to inform decision making. Similar considerations apply to the finding that litter amounts along canal banks seem to be much higher than rates retrieved from the water: this observation, if corroborated by additional sampling activities, would indicate that the integrated planning of riparian vegetation management, already commonly carried out along urban water courses, with litter removal has the potential to strongly reduce the loads of waste, such as plastics, transported by watercourses into the marine ecosystems. In addition to improving and reinforcing efforts to minimize mismanaged waste inland, actions aimed at raising awareness of the harmful effects of waste abandonment and littering on biodiversity, the ecosystem services it provides, and human health should also be prioritized.

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