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Marine Litter in Transitional Water Ecosystems: State of The Art Review Based on a Bibliometric Analysis

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Received: 30 December 2019; Accepted: 17 February 2020; Published: 24 February 2020

Abstract: Transitional water ecosystems (TWEs), despite their ecological and economic importance, are largely affected by human pressures that could be responsible for significant inputs of litter in the marine environment. Plastic input in coastal ponds, lagoons, river deltas and estuaries, could be driven by a wide range of human activities such as agriculture, waste disposal, municipal and industrial wastewater effluents, aquaculture, fishing and touristic activities and urban impacts. However, it remains unknown what the impact of plastic input in these TWEs could have on natural capital and, therefore, the ability for an ecosystem to provide goods and services to human beings. Given the large interest with regards to the conservation of transitional water ecosystems and the clear exposure risk to plastic and microplastic pollution, this study aims to perform: (i) a bibliometric analyses on existing literature regarding the levels of marine litter in such environments; (ii) a selection among the available literature of homogeneous data; and (iii) statistical analyses to explore data variability. Results suggest that: (i) research on microplastics in these ecosystems did not begin to be published until 2013 for lagoons, 2014 for river mouths and 2019 for coastal ponds. The majority of articles published on studies of microplastics in lagoons did not occur until 2019; (ii) sediments represent the matrix on which sampling and extraction variability allow the statistical analyses on data reported by the literature; (iii) the Analysis of Similarities (ANOSIM) test two-way evidenced that the level of protection of marine and terrestrial areas produced similar values while the habitat type showed low significance in terms of its effect on microplastic levels, shape and size in sediments.

Keywords: microplastics; VOSviewer; marine microplastics; marine litter; metadata analysis; natural capital; transitional water ecosystems

1. Introduction

Although the topic of microplastics was first presented in 1972 by Carpenter and Smith, the scientific research on the issue did not show significant growth until 2013 [1]. Furthermore, despite authors including Rayan, Galloway, and Kedzierski [2–4] continually expressing the need for integrated approaches in microplastic research, a recent study indicated that current studies remain largely focused on ecotoxicology or environmental chemistry [1]. This observation suggests that the impact of microplastics on ecological quality remains underweighted, making it difficult for stakeholders to adequately address the problem of microplastics through the ecosystem lens. Reaching an exhaustive knowledge on the dynamics affecting plastic transfer towards aquatic trophic webs represents a task that is yet to be completely achieved even if, according to the Marine Strategy Framework Directive (MSFD), it should be targeted by 2020.

Recent literature shows different levels of microplastic particles in sediments according to habitat type [5,6] suggesting the need for improved exploration of factors affecting distribution, levels and chemical composition of microplastics in sediments of different transitional water ecosystems (TWEs) as these habitat types were clearly understudied with respect to other marine habitats [7]. Transitional water experiences particularly high human and natural stress [8] leading to high levels of microplastics in the sediments of these aquatic ecosystems [9]. In addition, studies show that the production of marine table salt is affected by microplastic pollution in salt marshes, an example of TWEs [10–15]. Estuaries have also been shown to accumulate plastics [16] and experts expect to soon see a dramatic increase of microplastic pollution in estuaries [17].

Sediments represent the principal sink for marine litter and plastic particles [18] in which levels of plastic and microplastics ranged within 1.45-1.037 items/kg d.w. as widely reported by scientific literature [19,20]. However, particles are also abundant in the water column at varying depths due to their diverse densities [21]. Furthermore, microplastics have been shown to impact microalgae [22] and benthic biodiversity [23] of species that occupy a key role in helping decision makers determine the health of marine ecosystems and the status of their natural capital assets [24–26]). Some recent studies have indicated that plastic could have the ability to penetrate the trophic food web [27,28]. For example, microplastics could be ingested by cetaceans both directly via filter feeding [29], and indirectly via the consumption of species of lower trophic levels which had previously ingested MP particles [19]. Studies also show the presence of microplastics in different fish species of human interest such as large predators [30], small pelagic and planktivorous fish [5,31–33]. Almost all benthic species analysed to date have been shown to ingest microplastics [6,7,34], with a clear difference concerning ingested shapes according to the trophic level [35].

Due to the significant spatial and temporal variability of ecosystems, ecological status can be difficult to determine. For this reason, transitional and coastal ecosystems can be useful in identifying the key signals that are indicative of the impacts anthropogenic pressures might have on ecological status [26]. Given that the value of an ecosystem tends to be determined by considering the services it provides [36], decision makers could benefit from increased knowledge of microplastic impact on TWEs to more effectively develop, improve or change mitigation strategies regarding plastic production and pollution.

To address knowledge gaps that might add to the complexity of decision-making in terms of microplastic pollution, this study involves a metadata analysis on the existing literature regarding microplastics in transitional water ecosystems. The data were analysed using VOSviewer (version 1.6.13) bibliometric analysis software. VOSviewer allows the user to create maps based on bibliographic network data, which displays relationships among keywords, authors, countries and journals. The maps provide a "big picture" view of existing literature focused on the habitats and matrices of interest making the software useful for identifying which research areas currently characterize the scientific literature on microplastics. This type of network analysis can be helpful in determining research needs, which could be causing knowledge gaps in the area of study being investigated. In addition to the bibliometric analysis, a homogeneous selection of data from available literature was statistically analysed to evaluate significant aspects of microplastic pollution responsible for linking transitional water ecosystems. This analysis concerns the sizes and shapes of recorded microplastics in sediments due to the current knowledge that sediments are a principal sink for these particles.

2. Review Methodology

2.1. Bibliographic Data Acquisition and Bibliometric Analysis

About VOSviewer: VOSviewer software is an effective tool for performing a bibliometric analysis, which can allow for a thorough investigation, on a solid statistical basis, of relationships between countries, journals, organizations, authors and keywords involved in the investigated topic

[37]. The software is also effective in demonstrating the development of research fields [38,39]. VOSviewer allows for the creation, visualization and exploration of maps based on bibliometric network data by basing the analysis on social networks as reported and applied by Pauna [1]. The methodological approach performed in this study is widely described by previous literature, which was used as a technical reference [1,40,41]. In this study, the approach described below was developed in such a way as to demonstrate the current status of the scientific research on microplastics in TWEs.

Document search and VOSviewer analysis: Three Web of Science Core Collection searches were conducted on September 25th, 2019 to obtain the data inputs for VOSviewer. The first search was for "microplastic* AND lagoon*", followed by "microplastic* AND river mouth*", and finally "microplastic* AND coastal pond*". These keywords were chosen because an initial search using "microplastic* AND transitional water ecosystem*" resulted in literature not directly related to TWEs. The time frame for each search was set to include all available publication years in the Web of Science Core Collection database which is automatically set from 1990 to 2019. All data was saved as "Tab-delimited (Mac)" files, which contained "Full Record" content. The "Full Record" content for each search was then respectively used for co-authorship and co-occurrence analyses (e.g., network map of authors and keywords) by inputting all datasets simultaneously into VOSviewer.

Co-occurrence keyword: The keyword occurrence restriction recommendation by VOSviewer was not altered, therefore, only the keywords, which occurred at least 5 times in the inputted bibliometric data were included in the analysis. Given that there are sometimes diverse spelling or modes of writing terms in scientific articles, a thesaurus was created to aggregate like-terms. The thesaurus terms are shown in Table 1.

Co-authorship author: Based on the VOSViewer recommendations, documents with more than 25 authors were excluded from the analysis. The minimum number of documents per author was changed from the recommended restriction of 2 to 1. Finally, only authors which were connected with links were displayed in the network map.

Table 1. Thesaurus for term aggregation in the co-occurrence authors bibliometric analysis.

Label	Replace By
Microplastic	Microplastics
Mytilus-edulis	Mytilus-edulis l.
Polychlorinated biphenyls PCBF	Polychlorinated-biphenyls
Lagoons	Lagoon
Lagos lagoon	Lagoon
Lagoon Mar Menor	Lagoon
Indian river lagoon	Lagoon
Mosquito lagoon	Lagoon
Lagoon of Venice	Lagoon
La-Plata estuary	Estuary
Beach sediments	Beach sediment
FT-IR	FT-IR
Patos lagoon estuary	Estuary
Gulf of Lion	Gulf
Gulf-of-Mexico	Gulf
ATR-FT-IR	FT-IR-ATR

2.2. Data Collections and Statistical Analyses

Data collection was performed on online data sources (Web of Knowledge, Scopus) using the following key word: "microplastic* AND transition*ecosystem AND lagoon". Reported data by the literature were checked concerning sampling strategy, analysed matrix, measurement units and methods of extraction from the matrix and of analyses. Known grey literature were also used if they were shown to be available and suitable for this study. Data on plastic litter were grouped by size (i.e., macroplastics > 5.0 mm, mesoplastics 2.5-5.0 mm and microplastics < 2.5 mm) and shapes (i.e., fibres, fragments, film, other), according to recommendations provided by literature [18,20,42,43]. Colour and chemical types were not considered in this study because these details were not available in all of the scientific articles considered. The number of items/kg recorded for the size and shape categories were converted to a percentage to reduce comparative mistakes. Geographical locations (i.e., Country, Province) of the sampling site and habitat type (TWE, Beach, Sea) were provided with respect to the data collected from the literature.

Given that a correlation between microplastics and grain-size of sediments did not result in previous research [20,43–45], the factor of variability "grain-size of sediment" was not considered in this study. Statistics were performed to evaluate multivariate relationships recorded in tested samples and environmental factors of specific interest (i.e., geographical locations and habitat types). Univariate statistics (mean, 95% interval of confidence of mean, standard deviation, maximum and minimum) of collected data were performed by GraphPad Prism v. 5.0 (GraphPad Software, San Diego, CA, www.graphpad.com). Multivariate statistics were performed using Primer-E package v6.0 (Plymouth Marine Laboratory, UK). The Euclidean matrix of distance was calculated on normalized data of recorded levels in sediments (items/kg) expressed as percentages compared to total amounts [46]. The ANOSIM test two-way was run to explore the significance of the observed segregation and their interference according to factors *a priori* selected [46,47]. Principal Component Analyses (PCA) was performed on loadings values to evaluate similarities according to the chemical composition of microparticles, also, eigenvectors associated to PCA were reported.

3. Results and Discussion

3.1. Bibliometric Analysis

The three Web of Science Core Collection searches for "microplastic* AND lagoon*", "microplastic* AND river mouth*" and "microplastic* AND coastal pond*" resulted in 27 articles, 13 articles and 1 article, respectively. The search also indicated that research on microplastics in these particular transitional ecosystems did not begin to be published until 2013 for lagoons, 2014 for river mouths, and 2019 for coastal ponds. The majority of articles published on studies of microplastics in lagoons did not occur until 2019, with already 13 articles published at the time of the search on September 25th, 2019.

Co-occurrence keywords. The VOSviewer recommended restrictions (i.e., only include keywords with an occurrence of at least 5) were selected to generate the co-occurrence keywords network map which resulted in a total of 18 displayed items and 3 clusters (Figure 1). The size variation among the different keywords indicates their relative Total Link Strength values (Table 2). It is worth noting that "Sediments" had a Total Link Strength of 31 with 16 links, while "Lagoon" had a Total Link Strength of 18 with 12 links. Both "Sediments" and "Lagoon" had direct links to each other which is more clearly shown in Figure 2a,b, respectively. This direct connectivity indicates that microplastic studies from sediment samples are related to the study of microplastic presence in lagoons.

Table 2. Top 5 keywords, microplastics omitted, with respect to Total Link Strength.

Keyword	Total Link Strength	Links	Occurrences
Plastic Debris	71	16	20
Accumulation	60	17	13
Ingestion	46	14	10
Marine Environment	42	15	10
Pollution	41	14	11

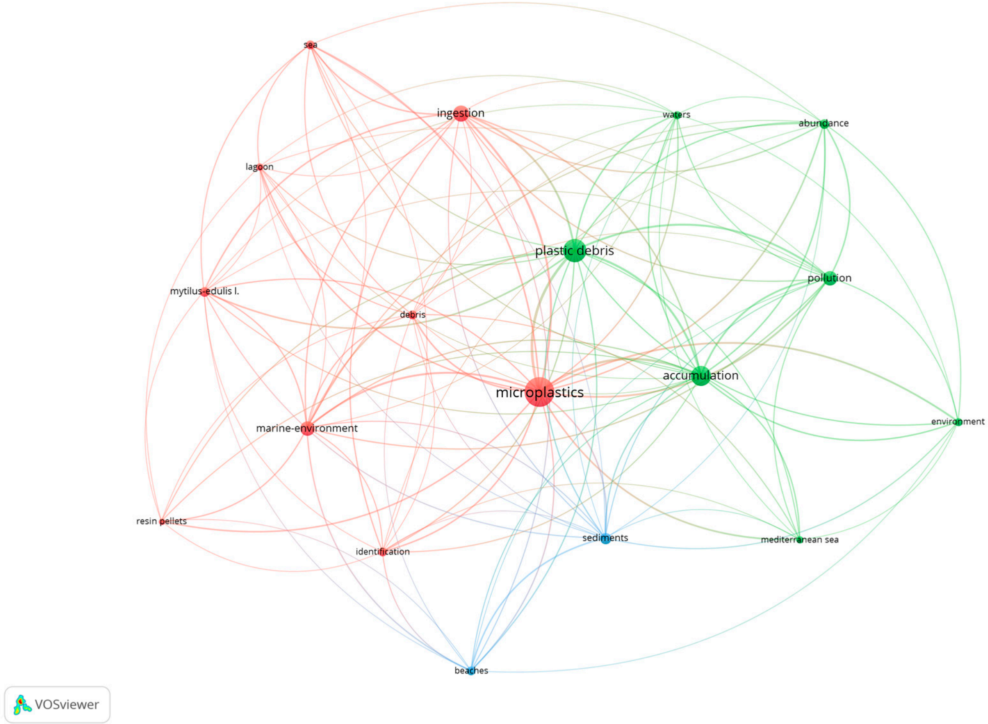
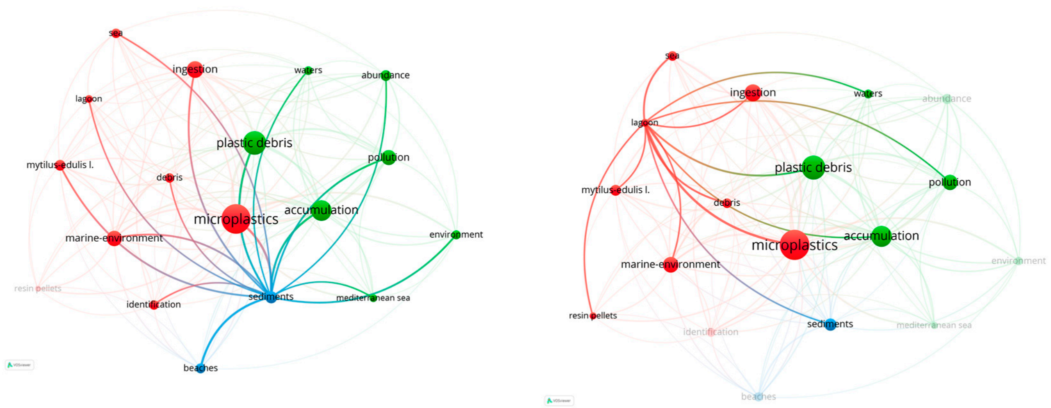


Figure 1. VOSviewer network map of keywords from Web of Science Search. Sizes of nodes are based off of Total Link Strength.



(**a**) (**b**)

Figure 2. Highlighted sections of the co-occurrence keyword network map: (**a**) the blue curved line which starts at "Sediments" and gradually turns to red when it meets "Lagoon" shows the direct connection between the terms, the exact opposite for "Lagoon" and "Sediments" is shown in (**b**).

Given the results of the co-occurrence keywords analysis it appears that sediment samples are often utilized in the investigation of microplastic presence in lagoons. Furthermore, there is a domination of research on lagoons when compared to river mouths and, especially, coastal ponds. Therefore, it could be beneficial to also focus some microplastic research efforts on river mouths and coastal ponds to more comprehensively understand the impacts of microplastics on the sediments found in transitional ecosystems. It should be of particular interest for decision makers to understand the presence and impacts of microplastics in sediments found in TWEs because they are an important soil resource (i.e., natural capital asset) [36].

Co-authorship authors. The co-authorship authors bibliometric analysis resulted in 201 authors, 22 of which were connected to each other with links. The Total Link Strength among authors did not show much variability among individuals, indicating that these authors in the same clusters tend to collaborate (Figure 3). The author Vianello, Alvise had, by far, the greatest Total Link Strength with a value of 23, followed by Palazzo, Luca and de Lucia, Giuseppe Andrea who both had a Total Link Strength value of 18. Each author in the red cluster had a Total Link Strength value of 13. The three authors with the highest Total Link Strength values also had direct links to each other despite their clusters being separated by the central red cluster. In addition to the collaboration shown among the top three authors and within clusters, the network map also indicates that there is strong author collaboration between clusters. This is particularly clear with Vianello, Alvise, Palazzo, Luca, and de Lucia, Giuseppe Andrea. These three authors act as connecting nodes between two clusters (i.e., Vianello, Alvise connects the green cluster of authors with the red cluster). The high level of collaboration among microplastic researchers is indicative of the natural interdisciplinarity of this area of study. According to the results of the co-authorship authors analysis, researchers with diverse specializations tend to work together, especially when investigating the impact of microplastics on transitional ecosystems.

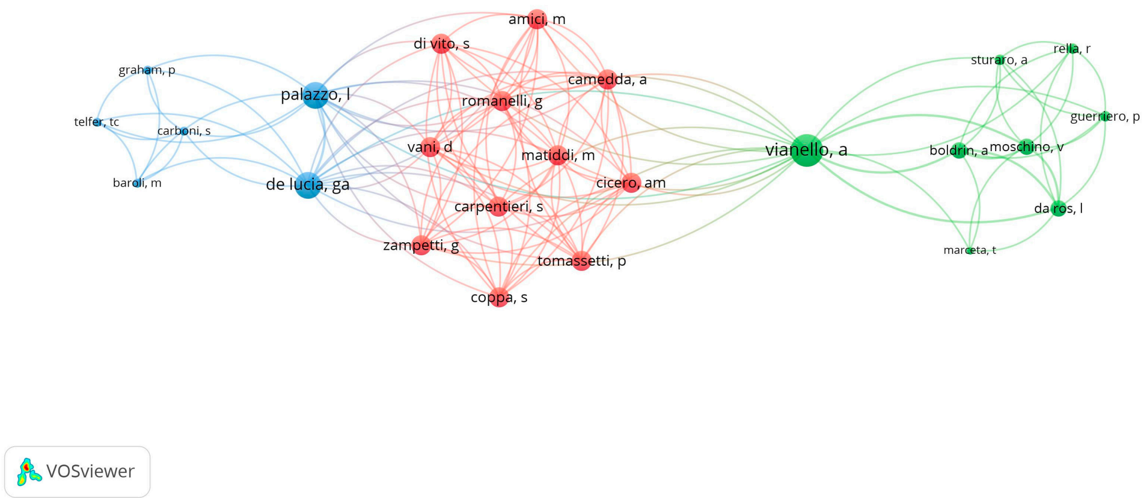


Figure 3. VOSviewer network map of authors based on Total Link Strength.

3.2. Statistical Analyses on Marine Litter In Sediment

After 2004, microplastics were recorded in sediments from harbours [45,48–50], and marine protected areas [5,7,43]. Microplastics levels recorded in sediments ranged widely as reported by the literature. Mean values recorded in sediment from sea and beaches ranged between 1.5–671.0 items/kg [51,52]. Harbours showed mean values ranging between 4.4 and 166.7 items/kg [45,50]. Thompson et al. recorded mean values of 31.0 items/kg in estuarine sediments [48], while, Vianello et al. recorded mean values of microplastic in sediments of 1445.2 items/kg in the Venice lagoon [9]. The literature highlights that rivers could be an important source of microplastics in marine coastal sediments [50,53]) and in transitional water ecosystems [53]. Vianello et al. reported high pollution levels for the Venice lagoon, recording microplastics from all tested sampling sites and demonstrating a wide distribution of this type of pollution in lagoon ecosystems [9]. Sources of plastic litter in transition water ecosystem (TWE) are wide as these ecosystems are largely impacted by agricultural, industrial and municipal effluents [18,54–57]. Such levels in TWE could highlight possible risks concerning pollutant absorption; in fact, microplastics have the potential to sorb substantially more contaminants in estuaries due to higher reported concentrations of contaminants than those found in riverine and marine waters [58].

The Principal Component Analyses (PCA) performed on the whole dataset collected from available literature is reported in Figure 4. The first three axes account for 96.6% (respectively 58.2%, 33.4% and 5.0%) of the total variance. Eigenvectors (i.e., coefficients in the linear combinations of variables making up PCs) showed that the larger part of the variability related to the first axis is explained by a direct relationship to % microplastic (0.524) and by indirect relationship to % mesoplastic (−0.519), % macroplastic (−0.433) and others (−0.479). On the contrary, concerning the second axis, the majority of the recorded variability is directly related to % fragments (0.698) and indirectly related to % fibres (−0.657). Concerning macroplastics, distribution is affected by plastic density and it is related to its chemical composition. According to Andrady et al. [59], polyethylene (PE) and polypropylene (PP) demonstrate a specific gravity lower than 1.025 g/cm^3 of seawater (i.e., 0.91−0.97 g/cm^3 PE and 0.83-0.91 g/cm^3 PP) causing particles of this type to float on the water surface; meanwhile nylon (polyamide PA, 1.02-1.15 g/cm^3), polyethylene terephthalate (PET, 1.37−1.45 g/cm^3), and polyvinyl chloride (PVC, 1.16−1.58 g/cm^3) tend to sink within close proximity of their sources into the environment. Microplastics are dominant in the sediments considered in this study. A recent study reported that TWE could be more affected by fibre pollution than marine ecosystems [60]; nevertheless, tested data in this study do not always support this hypothesis as the Venice lagoon was shown to be more affected by fragments on average than by fibers [9]. Anoxic conditions limit plastic fragmentation and degradation processes [59], and could result in a significant difference in measured levels, shapes and sizes of particles found in reduced sediments. Such a kind of variability should be considered and weighted in TWE due to the large occurrence of reduced sediments in these environments [8]. Microplastics trends are not yet well known given that floating or sinking tendency could be affected by a large number of factors such as currents, fouling and biofilm formation [61], sedimentation processes and so on. In particular, in TWE, where the salinity of the water is continuously fluctuating on both a daily and yearly basis [8]. Furthermore, other confounding factors such as industrial polymeric mixtures and the introduction of small air pockets during plastic moulding processes can increase buoyancy [62]. Concerning the differences among geographical locations, results obtained by the ANOSIM test two-way indicate that there is a significant level of sample statistics of 0.01% (Global R of sample statistics = 0.631). The pairwise tests that were performed showed that the Telaščica (Marine Protected Area; Croatia)-Cecina (Natural Park; Italy) couple is not significantly different (Global R = 0.084; p = 20.7%) suggesting that the level of protection of marine and terrestrial areas produced similar values in these tested TWEs. Differences related to habitat type resulted in a low significance (Global R = 0.094; p = 15.1%). The pairwise tests performed demonstrated no significant differences between tested couples supporting as previously recorded by literature on levels, size and shape features of microplastics [63]. In fact, in this recent study performed on sediments from the Adriatic Sea, any statistical correlations were recorded between plastic litter levels measured in sediments and species abundance (*B. lanceolatum*) or Mäerl bed habitats presence/absence. Recent studies indicate that habitat type is more able to affect the chemical composition of recorded marine litter when comparing lagoons to open sea, rather than levels, size and shape features (Renzi et al., 2018b [6]; Renzi et al., 2018c [63]). Furthermore, sediments reported low significance in differences concerning the factor habitat types rather than benthic species [7,43] reported that some local geographical features (i.e., wind/current ratio and wide/length ratio) could affect microplastic distribution in sediments. Vianello et al. [9] demonstrated that microplastic distribution in lagoon sediments could be affected significantly by local hydrodynamics showing that microplastics tend to accumulate in low-dynamic areas, commonly sandbars and the inner part of the lagoon; while low microplastic levels are recorded in sediments from zones characterized by a water current > 1 m/s. Even if some general trends are recorded, exceptions were recorded by analysed data.

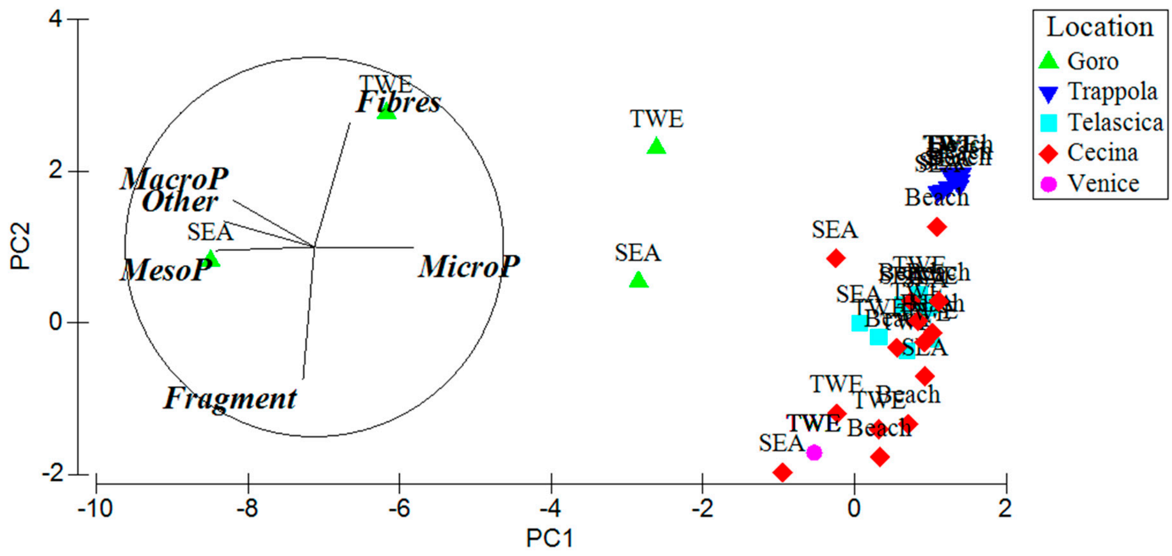


Figure 4. Principal Component Analysis performed to evaluate similarities according to literature data. Data used to plot PCA are related to loadings (percentages) of data reported by the literature. Sampling stations are labelled according three different habitat types (HT): Sea (sampling station highly influenced by sea dynamics); TWE (sampling station properly affected by transitional water dynamics); Beach (sampling station closed or on sandbars). Geographical locations are, also, highlighted (Location).

The difficulty in generalizing common trends in TWE was also reported by Vermeiren et al. [64], which developed a large estuary-wide scale model of the distribution patterns of micro- and macroplastics within estuaries, also accounting for their salinity. Authors showed that increased baseline data is needed to validate interactions occurring between physical, chemical and biological domains in such dynamic ecosystems. Furthermore, Bessa et al. [65] recorded higher microplastic ingestion by fishes in freshwater/estuaries systems compared to marine environments. This suggests a clear difference in interaction among biota and microplastics occurring in TWE and highlights a need for future research to better explain these types of observed behaviours.

4. Conclusions

The results obtained in this study showed the need to better explore marine litter levels and chemical composition particularly in transitional ecosystems. In particular, the bibliometric analysis indicated that the scientific research of microplastics in lagoons, river mouths, and coastal ponds is relatively new with respect to the field of study. Specific knowledge on marine litter in transitional water ecosystems are lacking and are often of scarce consistence. Given the youth of the study of marine litter in TWEs, it appears that specific papers are few, consequently the methodological differences among studies appears to be large and the findings do seem to allow for a solid statistical analysis to be performed. Transitional water ecosystems represent an important ecological link between land and sea as well as human beings and nature. Decision makers are interested in the health of ecological links (such as TWEs) in order to better understand which ecosystem services are negatively impacted by human behaviour. Unhealthy ecosystems display a depletion of natural capital, which results in a reduction or lack of ecosystem services that can be provided to benefit humans.

While all transitional water ecosystems were of interest in this study, the results of the bibliometric analysis indicate that lagoons have been the most abundantly studied. Furthermore, within the study of microplastic presence in lagoons, sediments have been the matrix of choice in terms of determining their presence. Due to the overall scarcity of research on marine litter in TWEs and specifically with respect to river mouths and coastal ponds, it seems clear that there should be more research effort aimed towards these study areas.

The complexity of ecosystems and their relationship to the social system can make decision making difficult. As plastic production continues to grow, plastic pollution remains inevitable. Therefore, an exhaustive knowledge of the dynamics that affect marine litter is prescriptive in allowing management strategies that can ensure both ecosystem conservation and human health preservation for the future decades. Perhaps the knowledge of these dynamics can be more efficiently obtained by focusing more research effort on TWEs as they have been shown to provide valuable information regarding the status of an ecosystem of interest.

Author Contributions: Conceptualization and methodology, analysis, and discussion of results, V.H.P., M.R.; investigation, formal analysis, data curation, C.M., F.P.; Writing—original draft preparation, F.P., V.H.P., M.R.; Writing—review and editing, V.H.P., M.R.; Supervision, M.M.; project administration, M.M., M.R.; internal founding acquisition, M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: Authors are grateful to BsRC research and technical team to administrative and technical support received during the development of internal-funded studies and to perform donations in kind (e.g., materials used for the research project).

Conflicts of Interest: The authors declare no conflict of interest.

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