Environmental Engineering and Management Journal October 2022, Vol. 21, No. 10, 1721-1731
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu
http://doi.org/10.30638/eemj.2022.153

"Gheorghe Asachi" Technical University of Iasi, Romania

A TOOLKIT TO MONITOR MARINE LITTER AND PLASTIC POLLUTION ON COASTAL TOURISM SITES

Domenico Vito[1]*, Gabriela Fernandez[1], Carol Maione[1,2]

[1]Metabolism of Cities Living Lab, Center for Human Dynamics in the Mobile Age, Department of Geography, San Diego State University, 5500 Campanile Drive, San Diego, 92182 California, USA
[2]Department of Management, Economics, and Industrial Engineering, Politecnico di Milano, Via Lambruschini, 4/B, Milan 20156, Italy

Abstract

Mismanaged waste at sea poses a great challenge to local marine systems. Plastic waste is considered the most abundant litter type in coastal tourism areas; yet, observational data fail to capture the full extent of plastic pollution on tourism beaches and its main drivers. This study aims to advance knowledge of marine litter and plastic pollution (ML&PP) sources, pathways, and drivers on tourism coastal sites. The research involves a 7-step toolkit to comprehensively assess marine pollution, by also engaging citizens in data collection. The toolkit provides a set of guidelines to identify, map, and quantify ML&PP, thereby supplementing to the current paucity of synoptic global analyses on marine pollution.

Key words: citizen science, coastal tourism sites, marine litter, plastic pollution, toolkit

Received: April, 2022; Revised final: October, 2022; Accepted: October, 2022; Published in final edited form: October, 2022

1. Introduction

Marine litter is among the greatest global challenges of the 21st century (Bettencourt et al., 2021). Marine litter is described as "*any persistent, manufactured, or processed solid material discarded, disposed of or abandoned in the marine and coastal environment*" (UNEP, 2009). It is estimated that nearly 80% of all marine litter found from the sea surface to the sea depths is made of plastic (IUCN, 2021), and the volume of ocean plastic is expected to increase further without action (SYSTEMIQ, 2020; WEF et al., 2016), with disastrous consequences for marine ecosystems (Derraik, 2002). Hence, studying the extent and distribution of ocean plastic pollution is of utmost importance to preserve the health and substance of the planet's seas. On the regulatory front, several measures to tackle marine litter and plastic pollution (hereinafter ML&PP) have been implemented. For example, EU member states have adopted the "Marine Strategy Framework Directive" to protect the marine environment across Europe's seas (EC, 2008; Galgani et al., 2013a), and "A European Strategy for Plastics in a Circular Economy", specifically aimed at reducing the plastic footprint (EC, 2018), among others. At the global level, the United Nations promoted measures for the containment of plastic losses and microplastics from land-based sources into the marine environment (UNEP, 2018, 2019a, 2019b), as well as the "Sustainable Ocean Principles" on retention of land-based and sea-based anthropogenic pollution (4.1: End plastic waste entering the ocean) (UNGC, 2020).

At the same time, the industry is increasingly taking action to reduce pressure on the environment by rethinking existing production and consumption models and exploiting innovative technological solutions (UNEP, 2014, 2021). Extant literature shows initial evidence of the industrial transition to a circular economy for plastics (e.g., Dijkstra et al., 2020; Gong

* Author to whom all correspondence should be addressed: domenico.vito@polimi.it

et al., 2020; Maione et al., 2022; Paletta et al., 2019), also thanks to increased consumer awareness and demand for sustainable plastics (Rhein and Schmid, 2020).

Despite initial progress in the fight against plastic pollution, plastic is a persistent pollutant (Geyer et al., 2017) and plastic waste accumulations on coastal tourism sites often result in ingestion from marine organisms (Cózar et al., 2014), degradation of fragile ecosystems (Lamb et al., 2018), and reduction of mariculture (Wang et al., 2019). Marine pollution can also severely affect local economies, causing loss of tourism incomes due to environmental deterioration (Jang et al., 2014; McIlgorm et al., 2011), and a decline of coastal recreational activities (Mohammed, 2002; Staehr et al., 2018), which account for large portions of coastal economies.

A growing body of research indicates the need to further understand the amounts, sources, and contributing factors of ML&PP (Veiga et al., 2016). Monitoring ML&PP presents numerous benefits: first, the identification and quantification of the outflows leaving the system to assess the ecological impacts (UNEP, 2018a, 2019b, 2019c). Second, pollution monitoring can enable detection of loopholes in the plastic's value chain, including material losses during plastic production, handling, sector applications, and waste management of plastic waste (Ryberg et al., 2019). Third, it can supplement the current lack of transparency and traceability of plastic flows across their entire life cycle, including information on plastic production and consumption, data on waste streams and recyclables, and plastic pollution sources and pathways (Geyer et al., 2017), which altogether make the circular economy of plastics a hard-to-reach perspective. Finally, data from ML&PP monitoring can provide industrial stakeholders and policy makers with practical implications and decisional support to strategic interventions on pollution management, as well as to evaluate their effectiveness over time (Barnardo and Ribbink, 2020).

Several protocols for monitoring ML&PP have been developed (e.g., JRC, 2013; Lippiatt et al., 2013; NOWPAP, 2007). These protocols have demonstrated remarkable success employing in situ surveys for the analysis of macro-debris at the sea surface or on beaches, and water or biota sampling for assessing micro-debris in the water column (Salgado-Hernanz et al., 2021). However, observational data still fail to capture the full extent of ML&PP and its pathways from land to sea (Van Sebille et al., 2015).

To this end, this research attempts to provide a comprehensive evaluation of ML&PP, including quantitative assessment of input waste accumulations, sources and pathways of marine pollution, and its rooting causes. The study introduces a 7-step toolkit to monitor ML&PP on coastal tourism sites. Implications from this study can advance knowledge of the hotspot of marine pollution, its main drivers, and the main challenges faced when dealing with plastic waste-free oceans.

2. Materials and methods

Identifying the origin of the different items that make up marine litter is a difficult and uncertain task. To identify the drivers and deficiencies in the production, consumption, and waste management systems that generate marine pollution, it is important to understand where, by whom, and why litter is released from these systems and how it enters the marine environment. This process is necessary to establish appropriate operational targets, as well as to design, implement, and monitor effective pollution management and mitigation measures. Identifying regional and sectoral differences for different plastic sources and emission hotspots is central to shaping actions against ML&PP. The toolkit presented in this paper is composed of seven steps (Fig. 1): (1) community involvement, (2) problem definition (spatial data), (3) SWOT analysis, (4) better monitoring for better management, (5) field data collection (observation, sampling), (6) perceptions of tourism (interviews), and (7) evaluate the outcomes.

2.1. Step 1. Community involvement

It is important at the early phases of the project to create awareness and engagement among communities regarding the problem of marine litter. This phase also helps the researchers to better understand the context together with the community of study. During this phase, preliminary interviews, common public events, exploratory meetings are essential to build the trust bridges, spread awareness about the environmental problem to the community and connect with the context (Tweddle et al., 2012; Senabre et al., 2021).

Furthermore, the proposed strategies are functional to develop and implement a stakeholder analysis in order to define targeted actions and address problems at different levels and scales.

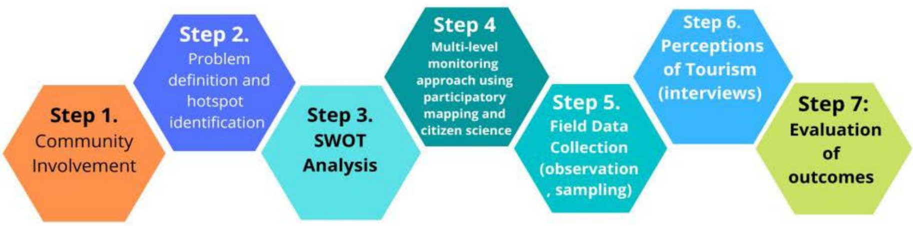

Fig. 1. The toolkit seven steps

2.2. Step 2. Problem definition and hotspot identification

Defining the problem is important to create hotspot and spatial analysis. These spatial analyses are depicted as hotspot points in a map and refer to locations of events or objects. Step 2 focuses on identifying problematic hotspot areas along shores that accumulate the most litter. This action will allow a better understanding of the distribution of plastic pollution in beaches using visualization. This information helps designate plastic beach hotspots in order to better focus on implementing coastal management efforts, in order to understand the sources of plastic pollution, and help others comprehend the vast scale of plastic pollution in the world's oceans. By collecting and visualizing plastic beach hotspots we can compare between beaches and highlight beaches that hold the highest amount of litter based on time and space (most popular tourist destinations). As a preliminary overview of the area, this step gives us a better understanding of the existing conditions of the surrounding environment.

Second, prior to conducting the plastic beach hotspots it is important to gather background information on the beach. For example any storm drains, rivers, stream, wind and wave direction, last high tide, current weather, and beach type should be described and visualized for each plastic beach identified hot spot. Third, other information to be taken into account refers to the presence of significant beach or cliff erosion in the area and the current and general beach use. If statistics on beach use are available through the city, it would be helpful to know about and visualize how many people use the beach annually, monthly, or weekly. Is it a private/public beach? Sandy or rocky beach? Nearest town and location of any outfalls? Furthermore, it is important to understand how often the beach is cleaned as some cities, counties and local environmental groups clean local beaches regularly. As a result, it is important to document as much information on cleanups as possible.

There are several marine litter monitoring programs and methods for identifying hotspots with different spatial and temporal scales, different scales for litter size, and different classification of litter, identify the beaches most likely to be affected. As noted above, in order to identify the hotspots of marine litter pollution, it is first necessary to collect data on the characteristics of the litter, including an analysis of its composition, spatial distribution and, where possible, litter sources, the hydrographic characteristics of the area. According to Guidance on Monitoring of Marine Litter in European Seas (Hanke et. al., 2013) in coastal areas the type of beach survey depends on the objectives of the assessment and the area of coastline pollution. Among the most recent tools, there is the development of numerical models that, based on the circulation of marine currents and the location of marine litter sources, track their movement. It is necessary to monitor pollution accumulations several times, as one-off monitoring is not sufficient to identify hotspots. As a result, at least two surveys per year are recommended during the high- and low-tourism season. However, due to seasonal variations, frequent surveys may be necessary to identify significant seasonal patterns to be considered when treating raw data to identify trends (EC, 2018; Galgani et al., 2013b; Petrov, 2020).

2.3. Step 3. Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis

Performing a SWOT analysis at the city level is useful to maximize the area's strengths, minimize its weaknesses, take advantage of opportunities and limit its threats. The analysis involves specifying the objectives of the entity and identifying the internal and external factors that are favorable and unfavorable to achieve those objectives. Identification of SWOTs can help establish a framework for future planning efforts including policy development and development review. The analysis determines whether these internal and external factors may support or block the objective. The SWOT analysis can lead to a strategy or an action plan for dealing with negative factors while maximizing strengths and opportunities. For example, it is common to represent a SWOT analysis in a 2 by 2 matrix putting the categories side by side, making it easier to see the correlations among them. It is effective for analyzing and creating a simplified picture of a complex situation. To properly conduct the analysis of the efforts on marine litter Table 1 shows an example of a SWOT matrix ML&PP transformation (de Taxis du Poet and Beukering, 2018). The SWOT analysis findings show transformation/recycling can use membrane technology separately as the best technology for filtering microplastics and marine litter.

2.4. Step 4. Multi-level monitoring approach using participatory mapping and citizen science

It is important to assess a multivariate data integration matching different data sources to have an effective monitoring of ML&PP at sea and along the shores to implement circular and redesign value chains toward regenerative models. For this reason, our methodological toolkit combines satellite data with participatory mapping in order to grant comprehensive reliable information.

Tracking pollution is crucial to implement effective marine management strategies, especially along border regions where plastic debris can be transported by wind, currents, and float in transboundary waters. When tracking transboundary pollution, a major challenge pertains to the difficulty of obtaining standardized, homogenous data on pollution cycles cross-borders.

Table 1. SWOT Matrix ML&PP Transformation (Beukering, 2018)

Internal Factors	
Strengths (+) - Thermal treatment (i.e. energy recovery) may be considered a viable option for some plastic waste collected from the sea, in particular for plastic that has been in the sea for long enough to become too degraded or contaminated for material recycling - Recycling plastics cuts back on oil consumption. Helps to extend the lifespan of fossil fuel reserves. - Recycling uses energy but less than making fresh plastic - Plastic recycling is a well-established industry.	*Weaknesses* (-) - Transformation processes currently involve visible plastics, but recycling opportunities have not yet been found for microplastics.
External Factors	
Opportunities (+) -New technologies involving different inputs, outputs, scales and processes are changing the market. -Recycling plastics can be an alternative to landfill potentially causing environmental harm.	*Threats* (-) -Recycling may be seen as a disincentive for avoiding the continuous increase of plastic production. -Recycling plastics delays rather than avoids final disposal.

Issues can include limited traceability associated with different systems for material/pollution monitoring and accounting; different policies and measures to allocate resources, and keep material flows accountable; a lack of information exchange across borders; or uneven use and communication of data analytics. To address this problem, satellite imagery and aerial photos have shown initial progress in pollution monitoring as they allow real-time or nearly real-time data acquisition, wide area coverage, and high spatial resolution (Biermann et al., 2020; Topouzeli et al., 2019). Multi-data and multi-method approaches can be integrated with remote sensing, GIS technologies, satellite data and participatory GIS (Frails, 2021). The proposed toolkit aims to provide a consistent global, harmonized system for assessing particles swirling in coastal tourism sites, including abundance, distribution, and location of the sources and pathways of pollution into the marine environment. Regarding data collection the toolkit is part of a multi-level monitoring approach that combines remote sensing and proximity sensing techniques. In fact the data acquired by citizen science can be combined with open-source space-based earth observation to map pollution accumulations and create a consistent ocean particle tracking model (Figure 2). (Rummel et. al., 2016). Following, satellite imagery can be combined with high resolution spectrometric images to detect the extent of plastic accumulations that are not readily visible through satellite images (e.g., smaller plastic particles, ocean plastic flows at the water surface) (Free et al., 2014)

Second, effective ML&PP measurement should integrate available data on water quality (e.g., national statistics and accounting, environmental reports) with proximity sensing techniques (e.g., detection sensors) and in-situ observations. Furthermore, the use of the “citizen science” paradigm allows citizens to acquire litter data in a participatory way. Traditional data sources can indeed lack accessibility and spatial variations (Fritz et al., 2019).

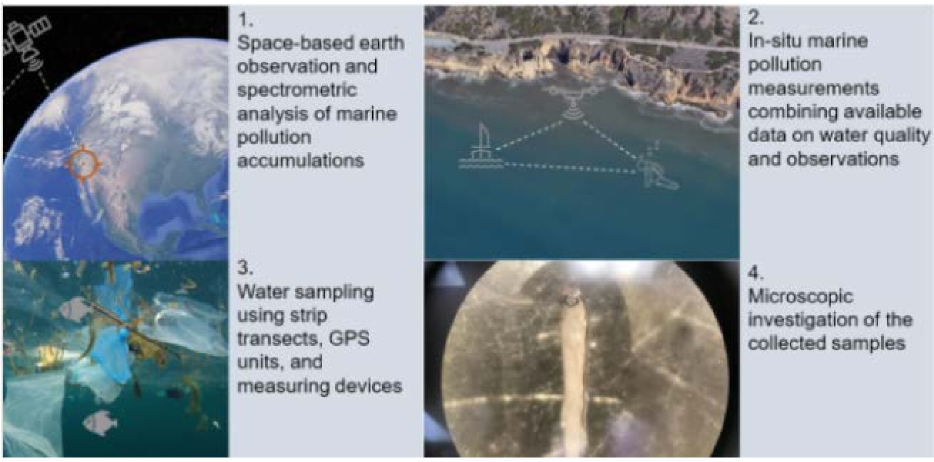

Fig. 2. Example of multi-level monitoring combining remote and proximity sensing techniques with in situ sampling

Participatory science then offers a tool to supplement satellite data to develop multilevel and multi raster maps to create "participatory maps". For this reason, not only could citizen science contribute to data collection, but it can also support monitoring and reporting, thereby enhancing timely decisions (Fraisl et al., 2020). Finally, using participatory approaches can foster community resilience contributing to a better knowledge and framing of the context, allowing to know better the boundary conditions of the environmental problems under investigation (Vito, 2019).

2.5. Step 5. Field data collection (observations and sampling)

This step is used to conduct beach litter surveys. These surveys are generally carried out to answer the following questions: (1) Where are the areas where litter is most prevalent? (2) How much litter occurs in the selected study site? (3) What is the litter composition (wet, recyclable, non-recyclable)? (4) What are the principal types of material (e.g., plastic, paper, metal etc.)? (5) What are the principal litter items? (6) Does the amount of litter vary across different transects? (7) What are possible variables that affect the input of litter at sea? To answer these questions, data should be collected at the sampling locations using the survey methodology for macro- (larger than 2.5 cm) and meso-debris (between 2.5 cm and 0.5 cm) as suggested by Lippiatt et al. (2013) and Barnardo and Ribbink (2020).

Prior to sampling, the site conditions need to be assessed by the survey supervisor(s), including the weather conditions, tide, and accessibility to the site to ensure the safety requirements during data collection. The site boundaries are then marked and the sampling area is divided into transects running perpendicular to the shoreline. The start point should identify with a permanent element, such as the edge of a seawall, sidewalk, parking lot, or a large rock. Latitude and longitude of the transects should be recorded to allow repeated measurements for future comparisons. The number and size of transects should be selected based on the dimensions, accessibility, and conditions of the sampling site. The rule of thumb is to set up an adequate number of transects to capture the diversity of the beach environment under assessment, for example, free beach, dunes, adjacent roads, waterways, polluting coastal activities (e.g., restaurants, hotels, tourism attractions, fisheries), ports, or mangrove forests etc. Table 2 summarizes the main sampling activities and materials. The surveyors collect photographic evidence and georeferenced coordinates of the assigned sampling area. For each transect, each and every piece of litter is recorded as follows: ID, date, transect n., collector, material type. Labeled litter bags can be used to collect and separate litter, for example, based on material type, to avoid material contamination. Table 3 describes the most common beach litter items by material type found in coastal areas.

Following, for each sampled transect, ML&PP is assessed based on litter item count (number), litter weight (kg), litter abundance (kg/surface), and litter coverage (estimated visual coverage, usually indicated according to four intervals: 0-25%, 25-50%, 50-75%, 75-100% of the transect surface). For a synoptic spatial evaluation of the transect, it could be useful to develop a cleanliness index that takes into account different measurements of pollution (an example of cleanliness index is offered by Alkalay et al. (2007)).

2.6. Step 6. Perceptions of tourism (Interviews)

This step investigates tourism-related perceptions via qualitative data collection. Structured interviews are conducted at each site to investigate the state and conditions of production and management of waste during the high tourism season. The interviews are to assess (1) waste facilities on tourism sites, (2) perception of tourism as a sector that generates waste, plastic materials, and (3) tourist littering practices (Table 4). To depict a more comprehensive picture of tourism-related perceptions, interview questions should target a variety of stakeholders, such as workers in the tourism and restoration sector (e.g., hotel staff, human resources coordinators, hotel managers, and restaurant owners), local operators (e.g., tour guides, drivers, and vendors), waste workers (e.g., waste pickers, street sweepers, officers from the municipal waste management services, and project managers from private waste management companies) and tourists.

Table 2. Survey activities and materials (adapted from Maione, 2021)

	Site preparation	***Litter counting***	***Litter composition analysis***
Activities	• Marking site boundaries. • Setting transects.	• Visual inspection of debris. • Litter separation by material type.	• Debris classification by material type. • Weighing of plastic debris.
Materials	• Flag markers. • 20-meter measuring tape. • Strip transect. • Digital camera. • Handheld GPS unit.	• Digital camera. • Datasheets. • Pencils. • Litter bags. • Gloves.	• Scale. • Datasheets. • Pencils.

Table 3. Categorization of common beach litter items (adapted from Fleet et al., 2021)

Category	*Items*
cloth/textile	clothing; carpet & furnishing; hessian sacks/packaging; shoes & sandals; sails & canvas; backpacks & bags; other textile; fishing net
food waste	food waste
wood	wooden corks; wooden crates/boxes; ice-cream sticks, wooden forks, chopsticks, toothpicks; wooden pallets; other wood; greens
glass & ceramics	glass bottles; jars; light bulbs; tableware (plates, cups, glasses); construction materials (bricks, tiles, cement); pieces of glass; other glass items; other ceramic/pottery items
plastics	six-pack rings; plastic shopping bags; drink bottles (< 0.5 liter); drink bottles (> 0.5 liter); cleaning products containers; cosmetics/body care containers; plastic jerry cans; plastic crates, boxes, baskets; vehicle parts; plastics caps/lids; plastic rings from bottle caps; cigarette lighters; pens; combs/hair brushes; sunglasses; chips/sweets wrappers; other wrappers; plastic cutlery (fork, spoon, knife); straws; stirrers; plastic plates, trays; plastic heavy-duty sacks; mesh bags; gloves; plastic tags; plastic sheetings; rope; fishing nets; fish boxes; fishing lines; plastic floats; plastic buoys; buckets; plastic industrial packaging; nurdles; plastic shoes; flip flops; beach toys; polystyrene pieces; styrofoam containers; CDs & DVDs; masks, fins and snorkeling equipment; syringes/needles; sanitary towels, panty liners, diapers, nappies, tampons; other personal care/hygiene products; plastic cotton bud sticks; medical/pharmaceuticals containers, tubes, packaging; plastic pipes; masks; cigarette buts
rubber	balloons; balls; rubber footwear; tires; belts; rubber sheets; tubes; rubber band; condoms
paper & cardboard	paper bags; cardboard boxes; paper packaging; cartons & tetrapack; cigarette packets; cups/drink containers; paper plates & trays; newspapers & magazines; paper fragments; other paper items; tissues
chemicals & hazardous waste	wax/paraffin; candles; medicines; batteries
metal	aerosol/spray cans; beverage cans; food cans; foil wrappers, aluminum foil; bottle caps/lids; disposable BBQs; appliances (refrigerators, washers, etc.); metal tableware & cutlery; fishing weights/sinkers; industrial scrap; barrels; paint tins; wires; vehicle parts; cables; cookware; wheel-related metal pieces; other metal items

Table 4. Examples of interview questions (adapted from Maione, 2019)

Topic	*Question example*
Waste facilities on tourism sites	Do you manage waste at work?
	Do you recycle any materials? Which ones?
	Do you store waste at work? Where?
Perception of tourism as a sector that generates waste	Do you think that tourism activities contribute to generating more waste?
	Has plastic waste increased with tourism?
Tourist littering practices	Are tourists respectful of the local environment?
	Do you think that tourists dispose of their waste into the ocean?
	Have you seen any plastic waste in the ocean?

2.7. Step 7: Evaluation

The evaluation step allows to decide whether the existing plan needs to be revised, or whether a new plan is needed to better address the problem. If you are not pleased with the outcome, return to Step 2 to select a new solution or revise the existing solution, and repeat the remaining steps. In order to integrate the evaluation step, it is important to revisit the array of considerations that need to be considered. Identifying and defining the problem, generating possible solutions, evaluating alternatives, deciding on a solution, implementing the solution and evaluation of the outcome.

3. Results and discussion

In this section we provide a case study implemented by the authors during a beach cleanup in Villapiana Scalo, Cosenza, IT, on August 22th 2022, to demonstrate the applicability of the multi-step toolkit proposed in this research.

3.1. Step 1. Community involvement

Before performing a beach cleanup, training webinars and public events have been performed to educate the volunteers and the local community on the importance of a correct management of waste on the shore and on the impacts of mismanaged waste on coastal ecosystems, as well as to train volunteers on the data collection procedure.

3.2. Step 2. Problem identification

A coastal site of 3 km along the southern end of the city was selected for analysis. This area hosts 3 bathing facilities as well 2 areas of free beaches. In particular, one of these is adjacent to a camping site with direct access to the shore, while another is peripheral and further from the main urban area, to assess how tourism specifically contributed to beach pollution.

3.3. Step 3. Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analysis

Table 5 resumes a SWOT analysis applied on the selected site. The SWOT has been functional also to understand the socio-cultural context of application of the toolkit.

3.4. Step 4. Multi-level monitoring approach using technologies and citizen science

Data collection involved volunteers to record GIS position and quantity of the wastes collected. GIS positions have been taken through smartphones by volunteers thanks to the app Geopaparazzi©. GIS data have been combined also with preliminary satellite backgrounds as in Fig. 3 give an example of the spatialization of data:

The beach strip of analysis has been divided in 4 transects delimited by morphological elements, such as canals, roads, and private/public beach. The GPS coordinates of transect delimitation has been taken and indicated as blue stars in Figure 3. The red points represent the places where litter has been found and for each point a photo and an annotation on the type of litter has been done through the app. A total estimation of the waste collected per transect has been also done at the end of the collection into the transect, recording the number of waste collected and a weight when possible.

3.5. Step 5. Field data collection (observations and sampling)

Beach litter was collected over 4 consecutive transects, as shown in Fig. 3. Plastic was the most abundant type of litter on all transects. The most common plastic litter items were bottles, plastic wrapping, bottle caps, and cigarette buts. A detailed analysis of the beach litter composition is reported in Table 6. Transect C recorded the highest amount of beach litter, and specifically plastic waste. A possible reason is that the transect is adjacent to a camping site. This also explains the higher variety of litter items found. For example, we recorded a higher number of plastic/glass bottles and cans from beach bonfires.

3.6. Step 6. Perceptions of tourism (Interviews)

To assess the increased waste production during the high tourism season (June-September), the authors collected data on the management of plastic waste and marine pollution by interviewing key stakeholders from the tourism sector, waste workers, and tourists.

The majority of the study's participants reported that waste generation was greater during high tourism season, suggesting that tourism is a primary waste-generating sector on the study site. Some waste pickers indicated that, during the high tourism season, the amount of solid waste, and single-use plastics in particular, doubled on beaches.

Table 5. Examples of interview questions (adapted upon Maione, 2019)

Internal Factors	
Strengths (+) The selected site is a tourist site that have still margin of growth and improvement for management Local population perceive a need for change The location is a typical tourist example for south of Italy	*Weaknesses (-)* The site is very active only in summer and activity are very focused on profit on tourism Lack of proper facilities and infrastructure for a proper waste management Very traditional context quite resistant for implementing changes even if problems are perceived

External Factors	
Opportunities (+) If correctly involved citizens are very participative As classical businesses are still not hardly settled, there are margin for proposing sustainable solutions. The case study offer the possibility to scale the experience in different	*Threats (-)* As it is a very traditional context, there could also be resistance ons implementing ecosystem management activities. Skepticisms on the final results of the application of the toolkit Lack of follow up after the activities Technical problem and glitches in data acquisition due to a lack of confidence with the protocol

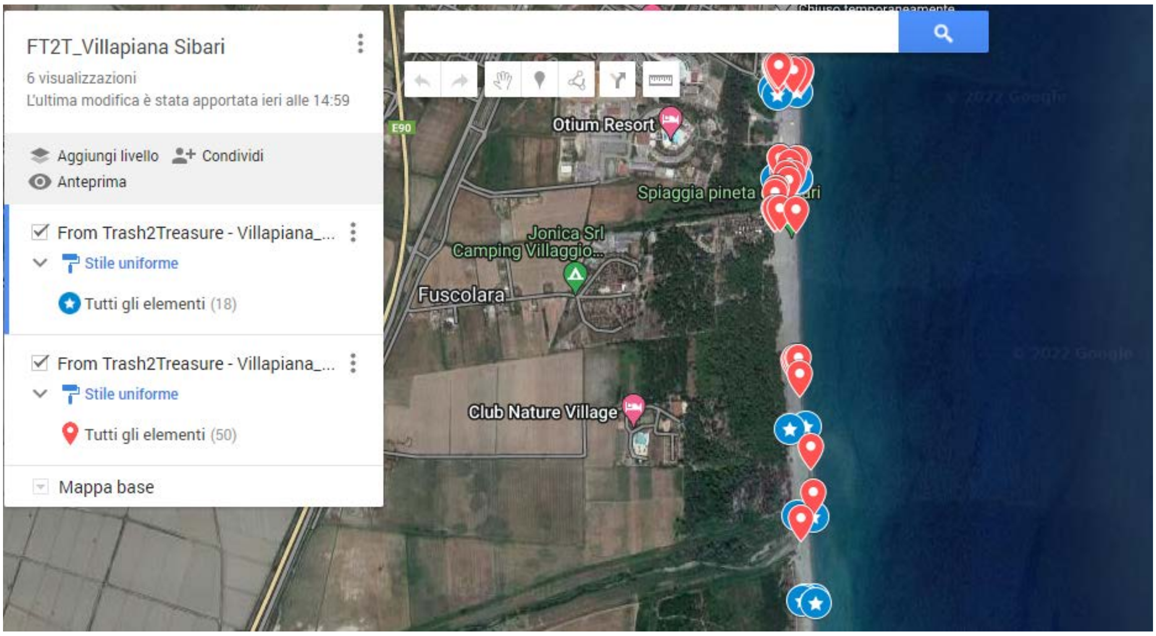

Fig. 3. Spatial representation of GIS data collected with a citizen science approach + Satellite background

Table 6. Beach litter composition analysis by transect.

ID	***Material***	***Items***	***Count (n)***	***Weight (kg)***
		Transect A		
1	Plastics	Cigarette buts	45	0.09
2	Paper & Cardboard	Paper packaging	1	0.05
3	Plastics	Mask	1	0.12
4	Plastics	Miscellaneous	1/2 bag	1.2
5	Metal	Can	1	0.03
		Transect B		
1	Plastics	Cigarette buts	23	0.05
2	Glass & Ceramics	Bottle	3	1.5
3	Plastics	Miscellaneous	1/4 bag	0.3
4	Paper & Cardboard	Paper packaging	2	0.1
5	Cloth/textile	Fishing net	1	6
6	Metal	Metal mesh	1	3
		Transect C		
1	Plastics	Miscellaneous	4 bags	10.8
2	Glass & Ceramics	Miscellaneous	16	8
3	Metal	Cans	10	0.3
4	Rubber	Tyres	4	28
5	Paper & Cardboard	Tissues	2	0.02

6	Plastics	Cigarette buts	27	0.05
7	Cloth/textile	Fishing net	1	5
8	Other	Trash deposit	7	0.5
9	Plastics	Mask	1	0.12
Transect D				
1	Plastics	Bottle	1	0.35
2	Cloth/textile	Slipper	1	0.4

Interview respondents indicated that the persistence of plastic litter was primarily driven by three factors. First, marine littering was mentioned by all respondents as a major driver of beach and coastal pollution, especially among the tourist population. A second driver of beach pollution was insufficient provision of waste management services on the beach. This was due to the inability of the municipal waste sector to provide regulations for all stakeholders (e.g., waste-generating activities such as hotels and food services, private waste management services, recycling associations) on one hand, and the absence of trash cans and official waste collection activities on the other.

Finally, the study participants mentioned that the proximity of camping sites to the beach was another main driver of beach pollution.

4. Conclusions

Social awareness is increasing but so does plastic ending into oceans. There is no one magic bullet to solve it all. What counts most is the coherence between different solutions to form a strong package of measure. This study explored the potential for monitoring ML&PP through a multi-step, multi-method toolkit to overcome some of the existing challenges to detecting sources, pathways, and rooting causes of marine pollution.

The paper presents a 7-step toolkit to assess beach litter, with a particular focus on tourism-related plastic waste. The toolkit describes simple steps which can easily be implemented by non/scientists. Another advantage of the present protocol consists of the use of low-cost tools, hence fostering the participation of citizens in scientific research. However, some limitations of this approach pertain to the integrated use of several methods, which may extend the overall duration of the data acquisition process.

Relevant implications for assessing ML&PP can be drawn from this study. Our approach supports a more detailed understanding of the main elements affecting the extent and distribution of marine pollution. The key message emerging from our research is that only a comprehensive monitoring of ML&PP, aimed at detecting pollution pathways from source to sink, can set the right path towards reducing marine pollution. Furthermore, one size does not fit all. As a result, technologies should be adapted to the social and industrial context of the point of intervention. Thus, there is a need to develop long term and short term approaches, while considering all levels, from local, to national, European, G7, or worldwide.

References

Alkalay R., Pasternak G., Zask A., (2007), Clean-coast index - a new approach for beach cleanliness assessment, *Ocean & Coastal Management*, **50**, 352-362.

Barnardo T., Ribbink A. J., (2020), *African Marine Litter Monitoring Manual. African Marine Waste Network. Sustainable Seas Trust*, Port Elizabeth, South Africa, Online at: https://sst.org.za/wp-content/uploads/2020/07/Barnardo-Ribbink-2020_African Marine-Litter-Monitoring-Manual.pdf

Bettencourt S., Costa S., Caeiro S., (2021), Marine litter: A review of educative interventions, *Marine Pollution Bulletin*, **168**, 112446, https://doi.org/10.1016/j.marpolbul.2021.112446

Cózar A., Echevarría F., González-Gordillo J.I., Irigoien X., Úbeda B., Hernández-León S., Duarte C.M., (2014), Plastic debris in the open ocean, *Proceedings of the National Academy of Sciences*, **111**, 10239-10244.

Derraik J.G., (2002), The pollution of the marine environment by plastic debris: A review, *Marine Pollution Bulletin*, **44**, 842–852.

de Taxis du Poet F., Beukering V. P., (2018), Marine litter: how to monitor, reduce and prevent ocean debris. Focus on plastics and microplastics, Vrije Universiteit Amsterdam, The Netherlands.

Dijkstra H., van Beukering P., Brouwer R., (2020), Business models and sustainable plastic management: A systematic review of the literature, *Journal of Cleaner Production*, **258**, 120967, https://doi.org/10.1016/j.jclepro.2020.120967

EC, (2008), *Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)*, European Commission, On line at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056

EC, (2015), *Closing the loop - An EU action plan for the Circular Economy*, European Commission, On line at: https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF

EC, (2018), *A European Strategy for Plastics in a Circular Economy*, European Commission, On line at: https://ec.europa.eu/environment/strategy/plastics-strategy_en

Fath B.D., Fiscus D.A., Goerner S.J., Berea A., Ulanowicz R.E., (2019), Measuring regenerative economics: 10 principles and measures undergirding systemic economic health, *Global Transitions*, **1**, 15-27.

Fleet D., Vlachogianni T., Hanke G., (2021), *A Joint List of Litter Categories for Marine Macrolitter Monitoring*, EUR 30348 EN, Publications Office of the European Union, Luxembourg, On line at: https://doi.org/10.2760/127473

Fraisl D., Campbell J., See L., Wehn U., Wardlaw J., Gold M., Fritz S., (2020), Mapping citizen science contributions to the UN sustainable development goals, *Sustainability Science*, **15**, 1735-1751.

Free C.M., Jensen O.P., Mason S.A., Eriksen M., Williamson N.J., Boldgiv B., (2014), High-levels of microplastic pollution in a large, remote, mountain lake, *Marine Pollution Bulletin*, **85**, 156-163.

Fritz S., See L., Carlson T., Haklay M.M., Oliver J L., Fraisl D., West S., (2019), Citizen science and the United Nations sustainable development goals, *Nature Sustainability*, **2**, 922-930.

Fullerton J., (2015), *Regenerative Capitalism. How Universal Principles and Patterns Will Shape Our New Economy?*, Capital Institute, The future of Finance, On line at: https://cbey.yale.edu/event/regenerative-capitalism-how-universal-principles-and-patterns-will-shape-our-new-economy

Galgani F., Hanke G., Werner S.D.V.L., De Vrees L., (2013a), Marine litter within the European marine strategy framework directive, *ICES Journal of Marine Science*, **70**, 1055-1064.

Galgani F., Hanke G., Werner S., et al., (2013b), *Monitoring Guidance for Marine Litter in European Seas. A Guidance Document within the Common Implementation Strategy for the Marine Strategy Framework Directive,* European Commission, MSFD Technical Subgroup on Marine Litter, JRC Scientific and Policy Reports, Online at: https://mcc.jrc.ec.europa.eu/documents/201702074014.pdf

Geyer R., Jambeck J.R., Law K.L., (2017), Production, use, and fate of all plastics ever made, *Science Advances*, **3**, e1700782, http://doi.org/10.1126/sciadv.1700782

Gong Y., Putnam E., You W., Zhao C., (2020) Investigation into circular economy of plastics: The case of the UK fast moving consumer goods industry, *Journal of Cleaner Production,* **244**, 118941, https://doi.org/10.1016/j.jclepro.2019.118941

Hanke G., Galgani F., Werner S., Oosterbaan L., Nilsson P., Fleet D., Liebezeit G., (2013), Guidance on Monitoring of Marine Litter in European Seas: a Guidance Document within the Common Implementation Strategy for the Marine Strategy Framework Directive, On line at: https://mcc.jrc.ec.europa.eu/documents/201702074014.pdf

IUCN, (2021), Marine Plastic Pollution, International Union for Conservation of Nature, Online at:https://www.iucn.org/sites/default/files/2022-04/marine_plastic_pollution_issues_brief_nov21.pdf

Jang Y.C., Hong S., Lee J., Lee M.J., Shim W.J., (2014), Estimation of lost tourism revenue in Geoje Island from the 2011 marine debris pollution event in South Korea, *Marine Pollution Bulletin*, **81**, 49-54.

JRC, (2013), *Guidance on Monitoring of Marine Litter in European Seas*, Joint Research Centre of the European Commission, Ispra, EUR 26113 EN. On line at: https://mcc.jrc.ec.europa.eu/documents/201702074014.pdf.

Lamb J.B., Willis B.L., Fiorenza E.A., Couch C.S., Howard R., Rader D.N., Harvell C.D., (2018), Plastic waste associated with disease on coral reefs, *Science*, **359**, 460-462.

Lippiatt S., Opfer S., Arthur C., (2013), Marine debris monitoring and assessment: recommendations for monitoring debris trends in the marine environment, NOAA Technical Memorandum NOS-OR&R-46, Online at: https://pub-data.diver.orr.noaa.gov/marine-debris/pacificislands/Lippiatt%20et%20al.%202013

Maione C., (2019), *Emergence of plastic pollution on tourism beaches in Zanzibar*, MSc Thesis, School for Environment and Sustainability, University of Michigan, USA.

Maione C., (2021), Quantifying plastics waste accumulations on coastal tourism sites in Zanzibar, Tanzania, *Marine Pollution Bulletin*, **168**, 112418, http://doi.org/10.1016/j.marpolbul.2021.112418

Maione C., Lapko Y., Trucco P., (2022), Towards a circular economy for the plastic packaging sector: Insights from the Italian case, *Sustainable Production and Consumption*, **34**, 78-89.

McIlgorm A., Campbell H.F., Rule M.J., (2011), The economic cost and control of marine debris damage in the Asia-Pacific region, *Ocean & Coastal Management,* **54**, 643-651.

Mohammed S.M., (2002), Pollution management in Zanzibar: the need for a new approach, *Ocean & Coastal Management*, **45**, 301-311.

Mohee R., Mauthoor S., Bundhoo Z.M., Somaroo G., Soobhany N., Gunasee S., (2015), Current status of solid waste management in small island developing states: A review, *Waste Management*, **43**, 539-549.

NOWPAP, (2007), *Guidelines for Monitoring Litter on the Beaches and Shorelines of the Northwest Pacific Region*, NOWPAP CEARAC, On line at: http://hdl.handle.net/20.500.11 822/27232.

OECD, (2018), *Improving Markets for Recycled Plastics: Trends, Prospects and Policy*, Organization for Economic Co-operation and Development (OECD) Publishing, Paris, On line at: https://doi.org/10.1787/9789264301016-en.

Paletta A., Leal Filho W., Balogun A.L., Foschi E., Bonoli A., (2019), Barriers and challenges to plastics valorisation in the context of a circular economy: Case studies from Italy, *Journal of Cleaner Production,* **241**, 118149, https://doi.org/10.1016/j.jclepro.2019.118149

Petrov P., (2020), *Methodology for Identification of Hotspots and Litter Reduction Measures*, RedMarLitter, Municipality of Burgas, European Union, Online at: https://redmarlitter.eu/wp-content/uploads/2021/01/OP1_Metodology_Blacksea_Beach-litter_final_EN.pdf

Rhein S., Schmid M., (2020), Consumers' awareness of plastic packaging: More than just environmental concerns, *Resources, Conservation and Recycling*, **162**, 105063.

Ryberg M.W., Hauschild M.Z., Wang F., Averous-Monnery S., Laurent A., (2019), Global environmental losses of plastics across their value chains, *Resources, Conservation and Recycling*, **151**, 104459, https://doi.org/10.1016/j.resconrec.2019.104459

Rummel C.D., Löder M.G., Fricke N.F., Lang T., Griebeler E.M., Janke M., Gerdts G., (2016), Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea, *Marine Pollution Bulletin*, **102**, 134-141.

Salgado-Hernanz, P.M., Bauzà, J., Alomar, C., Compa, M., Romero, L., Deudero, S., (2021), Assessment of marine litter through remote sensing: recent approaches and future goals, *Marine Pollution Bulletin*, **168**, 112347, https://doi.org/10.1016/j.marpolbul.2021.112347

Senabre Hidalgo E., Perelló J., Becker F., Bonhoure I., Legris M., Cigarini A., (2021), *Participation and Co-Creation in Citizen Science*, In: *The Science of Citizen Science*, Vohland K., Land-Zandstra A., Ceccaroni L., Lemmens R., Perelló J., Ponti M., Samson R., Wagenknecht K. (Eds), Springer, Cham, 199-218.

Staehr P.A., Sheikh M., Rashid R., Ussi A., Suleiman M., Kloiber U., Muhando C., (2018), Managing human pressures to restore ecosystem health of Zanzibar coastal waters, *Journal of Aquaculture & Marine Biology*, **7**, 59-70.

SYSTEMIQ, (2020), Breaking the Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution, The Pew Charitable Trusts, SYSTEMIQ, On line at: https://www.pewtrusts.org/-/media/assets/2020/10/breakingtheplasticwave_mainreport.pdf.

Tweddle J.C., Robinson L.D., Pocock M.J.O., Roy H.E., (2012), Guide to citizen science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK, NERC/Centre for Ecology & Hydrology, On line at: https://www.ceh.ac.uk/sites/default/files/citizenscienceguide.pdf

Ulgiati S., Zucaro A., (2019), Challenges in urban metabolism: sustainability and well-being in cities, *Frontiers in Sustainable Cities,* **1**, http://doi.org/10.3389/frsc.2019.00001

UNEP, (2009), *Marine Litter: a Global Challenge,* United Nations Environment Programme, Nairobi, On line at: http://hdl.handle.net/20.500.11822/7787

UNEP, (2014), *Valuing Plastics: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry,* United Nations Environment Programme, Nairobi. On line at: https://wedocs.unep.org/20.500.11822/9238

UNEP, (2018), *Report of the First Meeting of the Ad Hoc Open-Ended Expert Group on Marine Litter and Microplastics,* United Nations Environment Programme, Nairobi, On line at: https://papersmart.unon.org/resolution/uploads/k1801471.pdf

UNEP (United Nations Environment Programme), (2019a), *Report of the Second Meeting of the Ad Hoc Open-Ended Expert Group on Marine Litter and Microplastics,* United Nations Environment Programme, Geneva, Online at: https://papersmart.unon.org/resolution/uploads/k1801471.pdf

UNEP (United Nations Environment Programme), (2019b), *Report of the Third Meeting of the ad hoc Open-Ended Expert Group on Marine Litter and Microplastics,* United Nations Environment Programme, Bangkok, On line at: https://wedocs.unep.org/bitstream/handle/20.500.11822/31115/K1905085%20-%20UNEP-AHEG-2019-3-6%20-%20SECOND%20ADVANCE%20FOR%20CLIENT%20ONLY.pdf?sequence=1&isAllowed=y

UNEP (United Nations Environment Programme), (2019c), *Report of the third meeting of the ad hoc open-ended expert group on marine litter and microplastics,* United Nations Environment Programme, Bangkok, On line at: https://wedocs.unep.org/bitstream/handle/20.500.11822/31115/K1905085%20-%20UNEP-AHEG-2019-3-6%20-%20SECOND%20ADVANCE%20FOR%20CLIENT%20ONLY.pdf?sequence=1&isAllowed=y

UNEP (United Nations Environment Programme), (2021), *From Pollution to Solution. A global assessment of marine litter and plastic pollution,* United Nations Environment Programme, Nairobi. Online at: https://www.unep.org/resources/pollution-solution-global-assessment-marine-litter-and-plastic-pollution

UNGC, (2020), *Ocean Stewardship 2030. Ten Ambitions and Recommendations for Growing Sustainable Ocean Business*, United Nations Global Compact, New York, Online at: https://ungc-communications-assets.s3.amazonaws.com/docs/publications/Ocean-Stewardship-2030-Report.pdf

Veiga J.M., Fleet D., Kinsey S., Nilsson P., Vlachogianni T., Werner S., Galgani F., Thompson R.C., Dagevos J., Gago J., Sobral P., Cronin R., (2016), *Identifying sources of marine litter*, MSFD GES TG Marine Litter Thematic Report, JRC Technical Report, https://doi.org/10.2788/018068.

Van Sebille, E., Wilcox, C., Lebreton, L., Maximenko, N., Hardesty, B.D., Van Franeker, J.A., Eriksen, M., Siegel, D., Galgani, F., Law, K.L., (2015), A global inventory of small floating plastic debris, *Environmental Research Letters*, **10**, 124006, http://doi.org/10.1088/1748-9326/10/12/124006

Vito D., (2018), *Enhancing Participation through ICTs: how Modern Information Technologies Can Improve Participatory Approaches Fostering Sustainable Development,* In: *Sustainable Urban Development and Globalization,* Petrillo A., Bellaviti P. (Eds.), Springer, Cham, 131-145.

Wang, M. H., He, Y., Sen, B., (2019), Research and management of plastic pollution in coastal environments of China, *Environmental Pollution*, **248**, 898-905.

WEF (World Economic Forum), Ellen MacArthur Foundation, McKinsey & Company, (2016), The new plastics economy: rethinking the future of plastics, Geneva, On line at: http://coscienzeinrete.net/wp-content/uploads/2017/02/WEF_The_New_Plastics_Economy.pdf