CLEAN – Soil, Air, Water

WILEY-VCH

CLEAN Soil Air Water

RESEARCH ARTICLE OPEN ACCESS

Developing a Citizen Science Approach to Monitor Stranded Marine Plastics on a Remote Small Island in Indonesia

Radisti A. Praptiwi[1,2] | Carya Maharja[3,4] | Fauzan Cholifatullah[5] | Dwi C. J. Subroto[5] | Sainal Sainal[5] | Peter I. Miller[6] | Victoria V. Cheung[7] | Tatang Mitra Setia[8] | Nasruddin[9] | Datu[10] | Jito Sugardjito[5] | Melanie C. Austen[7]

[1]Research Center for Ecology and Ethnobiology, National Research and Innovation Agency (BRIN), Cibinong, Bogor, Indonesia | [2]Sustainability Research Cluster and Department of Biotechnology, Universitas Esa Unggul, Jakarta, Indonesia | [3]Yayasan Puspa Hanuman Indonesia, Bogor, Indonesia | [4]School of Psychology, University of Plymouth, Plymouth, UK | [5]Centre for Sustainable Energy and Resources Management, Universitas Nasional, Jakarta, Indonesia | [6]Remote Sensing Group, Plymouth Marine Laboratory, Plymouth, UK | [7]School of Biological and Marine Sciences, University of Plymouth, Plymouth, UK | [8]Department of Biology, Universitas Nasional, Jakarta, Indonesia | [9]Bappelitbangda Kabupaten Kepulauan Selayar, Benteng, Indonesia | [10]Lembaga Kampung Penyu, Kabupaten Kepulauan Selayar, Indonesia

Correspondence: Carya Maharja (carya.maharja@plymouth.ac.uk)

Received: 24 November 2023 | **Revised:** 26 July 2024 | **Accepted:** 10 January 2025

Funding: This work has received funding in part from the Global Challenges Research Fund (GCRF) United Kingdom Research and Innovation (UKRI) (Grant NE/P021107/1 and NE/P021107/2) to the Blue Communities Project. This work was also supported by the Natural Environment Research Council (NERC) (Grant NE/V006428/1).

Keywords: Global South | marine debris | marine litter | marine pollution | transdisciplinary

ABSTRACT

Marine plastics stranded on the coastlines of remote small islands threaten both the ecological integrity of local ecosystems and communities' well-being. However, despite the growing quantities of stranded plastics in these locations, the remote nature of these sites renders monitoring and intervention efforts difficult to undertake. Within this context, we developed a citizen science approach to monitor stranded marine plastics in collaboration with villagers living on a remote small island in Indonesia. This study reports the co-development and application of an approach that can be used and maintained independently by remote coastal communities. In the monitoring stage, the participants quantified both the weight and composition of stranded marine debris on a beach located in their village for a 4-week period from late May to mid-June 2021. The results revealed that the weekly accumulation of stranded marine debris on the beach was 3.97 kg/m^2, with 58% categorized as plastics. The stranded plastics sampled in this study were sorted and collected for recycling, estimated to provide a total economic value of 91,700 Indonesian Rupiahs (USD 5.84), or equivalent to 12.77% of the average monthly household income in the area. The citizen science activities indicated that the local villagers were capable of operating the designed monitoring system effectively, with the added benefits of supplementary earnings from recycling. An independently operated monitoring approach combined with collection efforts for recyclable items is important as remote islands have to manage increasing quantities of stranded marine debris despite the lack of an adequate local waste management system.

1 | Introduction

Plastic production has seen exponential growth globally [1], accompanied by the increasing leakage of plastic waste items from consumer markets into the oceans [2, 3]. One of the main drivers of plastic leakage into the oceans is inadequate waste management in mainland areas [4]. The most recent estimates revealed that this leakage could range from 4.8 to 12.7 million metric tons of plastic annually [5], resulting in the accumulation of 5 trillion plastic pieces with a weight of over 250, 000 tons in the Earth's oceans [6]. A substantial quantity of these plastic waste materials is dispersed over large distances, due to their buoyancy in seawater, which enables them to be transported around oceans through surface circulation [7]. Ever since the turn of the 21st century, there has been a growing recognition that an increasing quantity of these marine plastics would be washed ashore in coastal areas around the globe creating localized environmental and waste management burdens [8, 9].

Marine plastics stranded on coastlines pose significant threats to the integrity of coastal ecosystems and the biota living in them, particularly due to the threat of ingestion, entanglement, smothering, and spreading of invasive species [10, 11]. Stranded marine plastics have been estimated to create economic loss exceeding 13 billion USD annually due to damages caused to coastal ecosystems [12] and their supply of ecosystem services [13]. Moreover, in the region of Asia Pacific, stranded marine plastics generate losses of up to 1.26 billion USD per year due to disruptions in economic activities performed in coastal areas [14].

Remote islands are particularly vulnerable to stranded marine plastics as they have been shown to act as sinks for plastic debris coming from mainland areas [15, 16]. The vulnerability extends beyond the natural ecosystems and includes the livelihood and well-being dimensions of the people living on these islands, who are directly dependent on the impacted coastal ecosystems [13, 17]. However, difficulties in accessing remote islands to conduct monitoring studies have rendered such areas as the blind spot of marine plastic pollution research, and there are gaps in data from these locations [18]. This condition is reflected in Indonesia, the largest archipelagic country in the world with thousands of remote small islands [19] and the second biggest emitter of marine plastics after China [5]. Despite these characteristics, there have only been limited numbers of studies measuring stranded marine plastics in Indonesia, with existing research mainly focusing on its most densely populated island, Java [19].

Nonetheless, the Indonesian government has made the issue of stranded marine plastics a central point in its national development plan, with the combined targets of reducing 70% of plastic leakage to the ocean by 2025 and accelerating research looking at local characterization of stranded marine debris [20]. One approach to the management of stranded marine plastics is to mobilize local residents through citizen science projects aimed at both monitoring and managing marine plastics. Such projects have been shown to result in the collection of stranded marine plastics for recycling purposes and monetary gain, which act as incentives for local people to get involved in the monitoring and management scheme [21]. However, to date, this approach has not been developed and adopted in remote islands in the Indonesian context. In this regard, combining beach clean-up activities with citizen science efforts with the aim to characterize stranded marine debris can act as a more time- and cost-efficient means of managing marine plastic pollution than existing clean-up technologies [22]. The information gathered from these combined citizen science activities is also important for providing information to develop and implement solutions at both local and regional levels [7].

Citizen science involves members of the general public who conduct research in a non-professional capacity [23]. Citizen science is not only an important means of gathering data but also a platform for awareness raising and increasing engagement with scientific issues [24]. Furthermore, engaging volunteers in citizen science efforts may induce behavior change conducive to environmental protection and sustainability [25]. However, a recent systematic review revealed that citizen science research has been mainly focused on biodiversity research, with fewer applications in pollution issues [26]. Furthermore, most citizen science monitoring efforts have been typically performed in terrestrial settings, with limited relevance for the purpose of coastal and marine management efforts [27].

Within this context, this study aims to develop and apply a standardized protocol for citizen science monitoring efforts of stranded marine plastics to be implemented in remote islands in Indonesia. A standardized procedure for citizen science is important to ensure the reliability of the data produced and the scalability of the citizen science activity [28]. The citizen science approach in this study applied monitoring methods that did not require sophisticated analytical skills, with simplicity as the main feature, to enable the engagement of as-wide-as-possible volunteers in local areas, so that the activities may be sustained over a longer term [29]. This study was thus designed to be a case study seeking to test a co-developed approach to citizen science, devised and implemented with local island communities to support mitigation efforts and inform decision-making at the community level.

2 | Materials and Methods

2.1 | Study Area

The study was performed as a part of the Blue Communities research program (https://www.plymouth.ac.uk/research/institutes/marine-institute/our-research/blue-communities), which aimed to support sustainable marine spatial planning in Southeast Asia. Data collection was conducted on the coastline of Barugaiya village on Selayar Island, the main island of an archipelago of small islands situated in the transition zone of UNESCO's Taka Bonerate Biosphere Reserve, Indonesia (Figure 1). The land area of Selayar Island measures 798 km^2, comprising 33,713 households spread over 88 villages [30]. Selayar Island is remotely located and can only be reached by using slow boats and infrequent flights [31]. The key livelihoods of the island population are as artisanal fishers, directly dependent on near-shore fisheries located on its surrounding coastal ecosystems [32], especially as other economic sectors in the island, such as tourism, are underdeveloped [31]. In regard to waste management, the island is served by limited infrastructure, with very infrequent clean-up efforts in its coastal areas, which

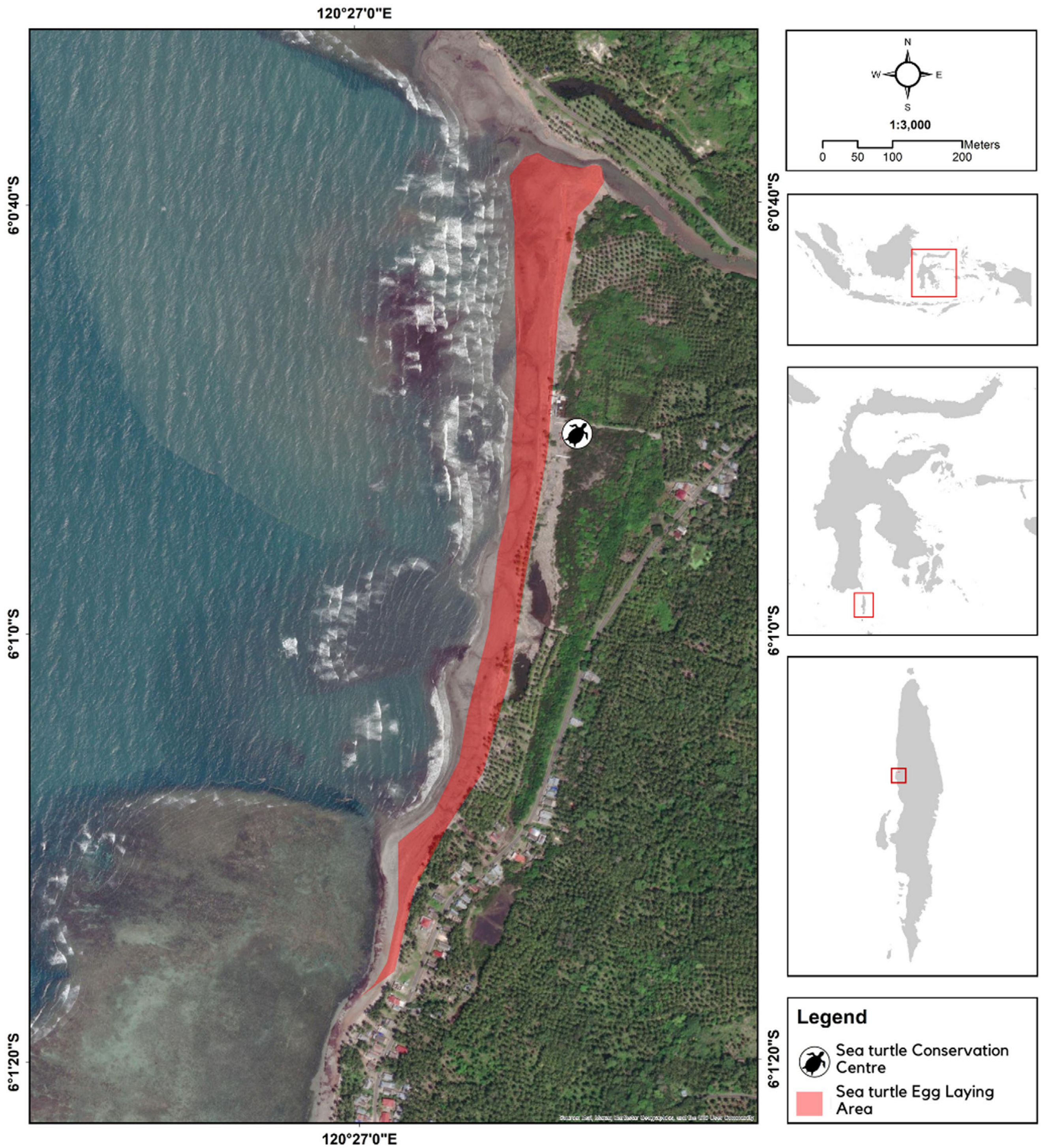

FIGURE 1 | Map of the study area.

regularly receive debris from the sea rather than from local inland sources [33].

The coastal and marine area of Selayar Island is known to have a high level of marine biodiversity, particularly in relation to its coral reefs, seagrass, and mangrove ecosystems [34, 35]. More specifically for the coastline of Barugaiya village, where this study was conducted, recent data indicated that there were 88 individuals of 4 sea turtle species laying over 8370 eggs on its sandy beach in 2019 [36]. These sea turtle species consisted of *Lepidochelys olivacea*, *Chelonia mydas*, *Caretta caretta*, and *Eretmochelys imbricata* [37], categorized as vulnerable, endangered, vulnerable, and critically endangered species, respectively [38]. As well as being important for biodiversity, the coastal environment of the area is also used by local communities for recreational activities and is important for their health and well-being [39]. Nonetheless, despite the importance of its coastal area, studies measuring stranded marine plastics in the island's coastlines have yet to be performed, creating a substantial knowledge gap regarding the risk that marine plastics pose to the

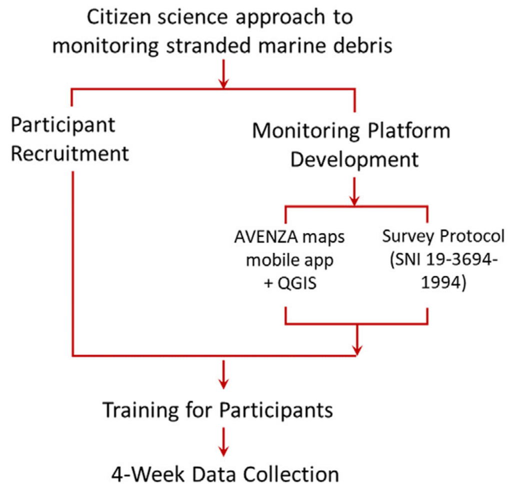

FIGURE 2 | Schematic diagram of the development of citizen science approach to monitor stranded marine plastics on a remote island in Indonesia.

local environment and its ecosystem services, hence to coastal communities relying on them.

2.2 | Development of Citizen Science Approach

The citizen science approach adopted in this study was prepared following the guidelines developed by Ottinger [40], in which the problem to be addressed was jointly identified with local community members with the aim of providing evidence to support local campaigns and efforts to address the problem of stranded marine plastics. The complete sequence of the development of the citizen science approach and its application took place over a period of 9 weeks, involving the development of a monitoring platform, participant recruitment and training, and 4 weeks of data collection (Figure 2). The development of the monitoring platform was performed concurrently with participant recruitment, in consultation with local stakeholders, comprising local civil society organizations and individual community members. Of particular considerations, the stakeholders highlighted the need to develop an approach that could be applied despite technological, skill, and time limitations existing within the local communities. As such, following Bergmann et al. [41], we decided to forego both sorting the stranded marine plastics into separate categories of litter items and counting them individually. Furthermore, on the basis of the consultations with the local stakeholders, the following research questions (RQs) were set out:

1. RQ1: What are the average accumulation rates of stranded marine debris and plastics, Over the monitoring period, in the study area?
2. RQ2: What is the proportion of marine plastics in the stranded marine debris, sampled in the study area?
3. RQ3: Are there any spatio-temporal variations of the stranded marine plastics, sampled in the study area?

Specifically for RQ3, the following null hypotheses (H_0) were set out to be tested through quantitative statistical approaches:

- $H_0$1: The stranded marine plastics would be accumulated in similar quantities across the time period in the study area (i.e., no temporal variations).
- $H_0$2: The stranded marine plastic would be uniformly distributed across the study area (i.e., no spatial patterns).

On the basis of stakeholder consultation, it was decided to combine smartphone GPS data with open-source geographic information system (GIS) software as the main monitoring platform for stranded marine plastics. For this purpose, Avenza software was installed on smartphones commonly owned by local villagers to capture the coordinates of stranded marine debris on the shorelines of the local village. It has been demonstrated that the use of this software in smartphones produced acceptable accuracy levels in comparison with recreation-grade GPS receivers in various environments [42]. The coordinates collected using Avenza would then be exported as a GIS format for mapping using QGIS, an open-access GIS software, which has been shown to outperform other open-access software in limited computing conditions [43].

Following the recruitment of volunteer participants from the local village, a training workshop was held to provide technical knowledge on how to perform beach surveys and use Avenza for field data collection and QGIS for data visualization using a communal laptop. The recruitment of participants resulted only in five adults willing to dedicate their time and efforts voluntarily for the citizen science project, possibly as a result of the low awareness of the island's residents regarding the issue of marine plastic pollution [33]. These volunteer citizen scientists went on to undertake a 3-day training workshop that equipped them with the skills to operate the tools and equipment independently and enabled them to monitor stranded marine plastics on the shoreline of their village. The training was provided by the scientific researchers involved in this study.

2.3 | Data Collection and Statistical Analysis

Field data collection took place after the training workshop was completed. The sampling transects were determined according to inputs from a local turtle conservation organization, which identified crucial areas for the nesting of sea turtle eggs along the village shoreline, consisting of five locations. The participants monitored the stranded marine plastics in the identified areas and inputted the geographic coordinates into the Avenza software on their smartphones (which can be downloaded for free from https://store.avenza.com/), with a frequency of once per week for the period of 4 weeks from late May to mid-June 2021. The decision to undertake a once-a-week monitoring frequency was mainly driven by the necessity to accommodate the time availability of the participating citizen scientists. The beach surveys were conducted on each occasion at low tide conditions, at the same time period during the day, with tide levels (obtained from local tide charts at https://www.tideschart.com/Indonesia/South-Sulawesi/Benteng/) and observations of weather conditions recorded by the participating citizen scientists. The survey measurements were based on transect sampling for each location, using five 1 m^2 quadrat plots, over a transect of 160 m, parallel to the shoreline. The stranded marine debris in each quadrat

TABLE 1 | Date, time, tide conditions, and observed weather patterns during the monitoring period.

Sampling week	Date (day/month/year)	Time	Tide level (m)	Weather conditions during sampling	Weather conditions on the night before sampling
1	25/5/2021	2.00–5.00 p.m.	Low tide (0.35)	Sunny, clear, light breeze	Clear, no rain
2	4/6/2021	2.00–5.00 p.m.	Low tide (0.3)	Sunny in the beginning and rainy at the end, light breeze	Clear, no rain
3	10/6/2021	2.00–5.00 p.m.	Low tide (0.2)	Sunny, clear, light breeze	Clear, no rain
4	17/6/2021	2.00–5.00 p.m.	Low tide (0.2)	Sunny, clear, light breeze	Clear, no rain

was weighed and sorted for plastic items, which were then quantified by weight separately. The separated marine plastics were also collected to be recycled by the citizen scientists, who also recorded their economic values based on the price given by a local recycling entrepreneur. Each transect survey consumed about 1–2 h depending on the quantity of stranded marine debris collected on each occasion. The survey measured the weight of stranded marine debris and its plastic composition based on best practice guidelines from Badan Standar Nasional Indonesia [44] and Kosmala et al. [45]. After each survey day was completed, the participants returned to the village meeting hall to store their data in spreadsheets, export the coordinates from the Avenza software into the QGIS platform, and map the hotspots of stranded marine plastic accumulation on the village shoreline. We provided each citizen scientist with a step-by-step protocol (Supporting Information 1) detailing the above methodological activities prior to the training workshop, which they could refer to throughout the monitoring period.

The gathered data were also subjected to statistical analysis to test the significant difference between each survey period and location, specifically to address RQ3 and the null hypotheses related to it. The types of statistical tests were chosen according to similar studies performing beach monitoring of stranded marine debris [46–48]. Both stranded marine debris and marine plastic accumulation data were tested for normal distribution using the Shapiro–Wilks test. As the data were not normally distributed, non-parametric tests were then applied using the Kruskal–Wallis *H*-test and Mann–Whitney U test for pairwise comparisons, with applied post hoc analysis using Bonferroni correction. The statistical analysis was performed using PSPP, a free and open-source statistical software.

3 | Results and Discussion

This study is one of the first efforts to quantify and characterize stranded marine debris in a remote location in Indonesia, which has been very rarely performed [19]. Over a period of 4 weeks, despite the relatively stable weather and low tide conditions during the survey periods and on the preceding days (Table 1), the amount of stranded marine debris was found to fluctuate, with statistically significant differences (RQ3) in the surveyed locations for both total marine debris (Kruskal–Wallis *H*-test, $H = 43.71$, $df = 4$, $p < 0.05$) and stranded marine plastics (Kruskal–Wallis *H*-test, $H = 46.89$, $df = 4$, $p < 0.05$) (Table 2). Over a period of 4 weeks, the weekly accumulation of stranded marine debris across the surveyed locations was 3.97 kg/m^2 (RQ1), with stranded marine plastics accumulating at a weekly rate of 2.29 kg/m^2 (RQ1), or approximately 58% of the stranded debris (RQ2). The weekly average for stranded marine debris accumulation for each of the survey locations ranged from 2.93 to 5.46 kg/m^2 (RQ1), with plastics forming approximately 35%–72% of the quantified debris (RQ2). From the results of pairwise comparison using the Mann–Whitney U test (RQ3), the differences amongst the surveyed locations ($p < 0.008$ after Bonferroni correction) were observed mainly for location P2 (Table S1), where the highest amount of stranded marine plastics was found in the first and last week of the survey period (Figure 3). These statistical tests indicated statistically significant differences in the quantities of stranded marine plastics between the survey periods and locations that the null hypotheses ($H_0$1 and $H_0$2) of RQ3 were rejected. In addition, the final week of the survey also saw the highest amount of stranded marine debris and plastics covering the area (Figure 4).

The photos of the sampled marine plastics stranded on each of the survey spots across the monitoring periods (Figure 5) indicated that most of the accumulating plastics could be categorized as packaging for food and beverage products, mainly bottled water. These types of plastics are typically composed of polyethylene (PE) and polypropylene (PP), which have positive buoyancy in seawater [49] and have formed the majority of plastic strandings on Indonesian beaches [50]. According to existing studies [51, 52], these types of plastics are mainly released to Indonesian seas from riverine sources from Indonesian Islands located in the western and central part of the country, with the rivers from the island of Sulawesi, the most adjacent large island to our remote study site, likely contributing substantially to the observed marine plastic strandings in our study. However, as discussed further below, the recycling revenue obtained from the collected marine plastics in our study was lower than what can be obtained from urban areas, due to the degradation and contamination of the stranded plastics, indicating that the beached plastics had spent considerable time floating on the sea or accumulating on the beach.

TABLE 2 | Quantity of stranded marine debris and marine plastics in the surveyed areas over a period of 4 weeks.

Surveyed area	Stranded marine debris (kg/m²)				Stranded marine plastics (kg/m²)			
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 1**	**Week 2**	**Week 3**	**Week 4**
P1	5.12	11.10	1.90	4.64	1.50	5.21	1.90	2.75
P2	3.11	3.39	3.42	6.10	2.00	2.90	1.30	5.50
P3	3.56	3.24	3.42	5.54	1.40	1.90	3.42	4.43
P4	1.93	1.62	1.24	3.69	0.25	0.60	1.24	3.69
P5	2.44	1.90	4.66	7.34	0.45	1.70	0.50	3.21
Average accumulation (kg/m²)	**3.23**	**4.25**	**2.93**	**5.46**	**1.12**	**2.46**	**1.67**	**3.92**
Weekly accumulation (kg/m²)	**3.97**				**2.29**			

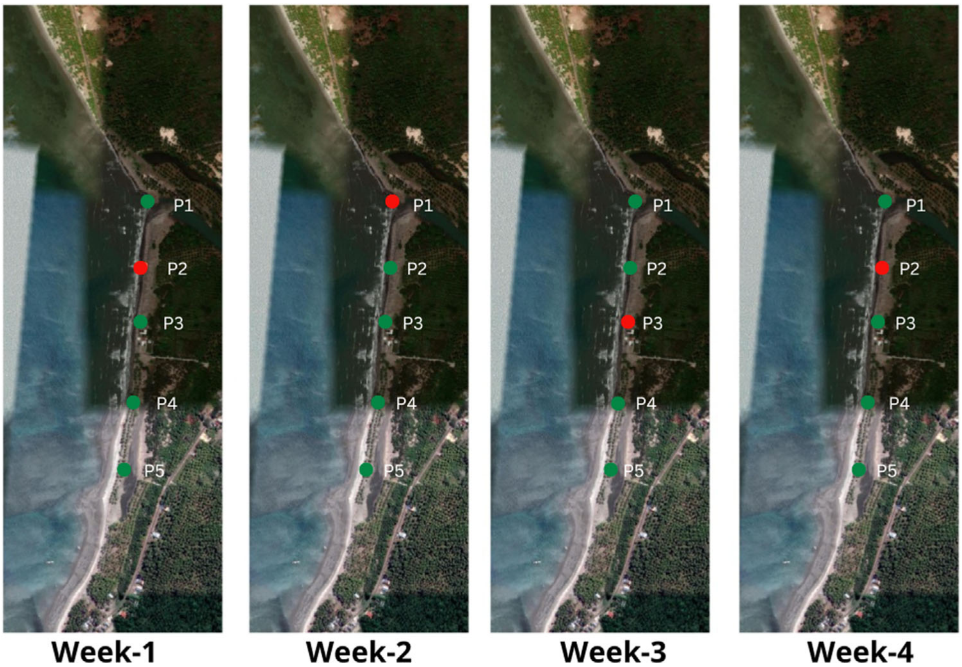

FIGURE 3 | The five beach survey locations. Red dots indicate locations with the highest amount of stranded marine plastics for each survey period.

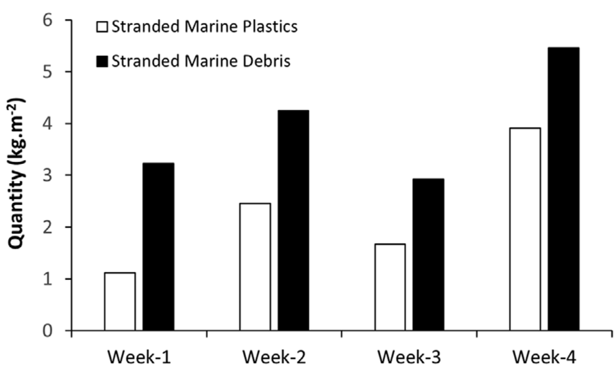

FIGURE 4 | The average accumulation, across the five survey locations, of stranded marine debris and plastics covering the area quantified over a period of 4 weeks.

The dominance of plastics in the marine debris characterized in this citizen science study was similar to the conditions found in other remote islands located around the world, as indicated in recent emerging evidences, which have reported weekly accumulation of stranded plastics between 0.4 and 3.1 kg/m² (e.g., as stated in these studies [41, 53, 54]). This finding suggests that similar to other remote islands, Selayar Island may also act as a potential sink for marine plastics. Our results also support the findings of a recent systematic review which found that plastic items dominate the composition of marine debris found on Indonesian coastlines [19]. As discussed in the previous paragraph, the majority of these stranded plastic items were released by rivers from Indonesian Islands and transported by sea currents, with the area where Selayar Island is located receiving marine plastics originating from the western and central parts of the country [52].

FIGURE 5 | Photos of the stranded marine plastics sampled by the participating citizen scientists taken at: (a) location P1, week 2; (b) location P2, week 3; (c) location P3, week 4; (d) location P4, week 1; (e) location P5, week 4.

Both the statistical tests and the mapping of the accumulation hotspots of stranded marine plastics for the duration of our survey in the study site (Figure 3) revealed that these hotspots were concentrated in the northern part of the surveyed beach. Our citizen science monitoring was performed in the sea turtle nesting parts of the beach, which can be classified as the backshore zone, above the wrack zone and most of the tidal actions [55]. According to the existing literature on marine debris monitoring focusing on the backshore part of beaches, variations in the accumulation of debris in this zone were mostly determined by wind movements [56] and beach geomorphological characteristics, such as topography [57] and substrate [3], that may lead to high localized accumulation rates despite the lack of strong wind-wave regimes [58], as also indicated in the observed tide and weather conditions in our study site (Table 1). The lack of tidal actions in the backshore zone of beaches has been observed to enable the deposition of debris and marine plastics underneath sand particles, causing the backshore area to become a long-term sink for marine plastics [59]. All of these indicate that the northern part of the beach surveyed in our citizen science study may possess specific geomorphological characteristics rendering them more vulnerable to the accumulation of stranded marine plastics during our monitoring period and beyond.

Nonetheless, the accumulation of marine debris in coastal areas is highly unpredictable as it is influenced by a range of interacting hydrometeorological and geomorphological factors, including local currents, coastal topography, and weather patterns [60]. Besides these aspects, the distance to locations with high population density and the existence and intensity of shipping activities also likely influence the amount and distribution of stranded debris [61]. Nonetheless, despite the many factors influencing their stranding, the characteristics of marine debris in coastal areas still act as good proxy indicators for marine debris composition in the adjacent oceanic system [62]. As such, our results indicate that plastics are also likely to be prevalent in the sea surrounding the island.

In regard to the survey locations, which are used by sea turtles as nesting places, the accumulation of stranded marine plastics represents an ecological risk. Plastic materials on sandy beaches can change the heat transfer and permeability characteristics of the sand grains, affecting the physical and chemical characteristics of beach ecosystems [63]. Furthermore, as observed by Mortimer et al. [64], turtle nesting habitats are particularly vulnerable to stranded marine plastics as they often overlap with accumulation hotspots. Various case studies around the world link stranded

TABLE 3 | Economic value of recyclable stranded marine plastics collected in this study.

Surveyed area	Economic value of the collected stranded marine plastics (IDR)			
	Week 1	Week 2	Week 3	Week 4
P1	3000	10 420	3800	5500
P2	4000	5800	2600	11 000
P3	2800	3800	6840	8860
P4	500	1200	2480	7380
P5	900	3400	1000	6420
Total	**11 200**	**24 620**	**16 720**	**39 160**

marine plastics with sea turtle mortality and injuries, reduction in the number of sea turtle eggs and nesting, and increases in hatchling failures [65–67]. Considering these ecological risks, further research is needed to monitor the impacts of marine plastics on sea turtles in the area, especially considering that such knowledge on marine species endemic in Indonesia is still very limited [68].

The case study in this article therefore demonstrates that a simple citizen science approach can be an efficient and effective method to monitor and report waste pollution problems in remote islands, especially as the approach can be performed by local community members, who have low resources to use more sophisticated methods. The participants of this study also obtained an economic benefit in the form of additional income revenue as a result of the resale of the recyclable stranded marine plastics, with a total value of IDR 91,700 (USD 5.84) (Table 3). As the average monthly household income in the area is IDR 718, 000 [39], this recycling revenue was equivalent to about 12.77% of the monthly earning of the average household in Selayar. However, this economic value was approximately 65% lower than what can be obtained from recyclable plastics of similar quantity traded in urban residential areas in Indonesia [69]. The reduction in value is due to the quality of the collected marine plastics, which are typically degraded and contaminated, and in need of additional cleaning before being processed for recycling [70]. Yet, the collection of recyclable plastics in this project provides some degree of economic incentives for the management of stranded marine plastics by local communities.

3.1 | Limitations and Future Studies

Beach surveys in Indonesia and in other parts of the world typically target macroplastics, resulting in substantial knowledge gaps regarding microplastics [71, 72]. Surveying beach ecosystems for these smaller fragments of plastics is important as beach sediments have been shown to act as a sink for microplastics [15]. However, incorporating an assessment of microplastics and polymer characteristics in a citizen science project would increase the workload requirements and require sophisticated equipment and monitoring methods that are not widely available in Indonesia [50, 68]. Considering the low resource context of the location of this study, the citizen science approach used here was developed to ensure that local residents can independently employ and scale up its use, hence its focus on simplicity and ease of application.

Nonetheless, our study only managed to recruit five volunteering citizen scientists from the local village, despite the low resource requirement of our citizen science approach. Besides the relatively low awareness of local communities on the pressing issue of marine plastic pollution [33], other factors might have contributed to the low recruitment rate, including local work commitments, involving lengthy stays on the sea and intensive workload requirements, of the predominantly small-scale fishers living in the village [17], and the perceived urgency of other environmental issues, especially climate change, that competed for the prioritization of resources and efforts of local stakeholders, including community members [73]. However, as shown in other studies [74, 75], marine plastic pollution and changing coastal regimes due to climate change, such as sea level rise and ocean acidification, act as combined stressors that imperil ecosystem and human health. This situation highlights the urgent need for awareness-raising campaigns, which can be combined with environmental education programs, on the issue of marine plastic pollution in the area. It is also worth noting that local initiatives in our case study area have emerged, innovatively combining recycling enterprises with community monitoring activities, via the establishment of waste bank cooperatives [76]. Such emergence of locally-led mitigation efforts indicates the potential for further replications and scale-up of citizen science monitoring of marine plastic pollution in the area.

Besides the aforementioned considerations, the citizen science effort in this study still needs to be subjected to further replication and scale-up of data collection to ascertain the spatiotemporal variability of aggregated accumulation of stranded marine debris and plastics in the area. The monitoring of stranded marine plastics in this study was only undertaken once per week, limiting our ability to capture detailed variations in the stranding patterns across space and time. To address such limitations, continuous monitoring of stranded marine debris and plastics in coastal areas is needed to understand plastic pollution dynamics, including the transport and movement of debris existing in the area, degradation and burial processes, and removal by waves and tides [4, 11, 16, 21]. Such intensive and extensive monitoring efforts can be augmented with the utilization of remote sensing, which enables cost-effective measurement and characterization of stranded marine debris [77]. This remote sensing approach can be combined with citizen science activities, with the participants geotagging and photographing the quantified stranded marine debris and plastics, which will provide data that can be used for further processing, for instance as training samples for object identifications using machine learning algorithms [78]. These further monitoring studies can be combined with detailed measurements of local wind-wave regimes and beach geomorphological characteristics to ascertain the factors driving the strandings and accumulations of marine plastics. Such knowledge is important to inform targeted mitigation and beach management efforts at a local scale [54] and also to evaluate the effectiveness of any local, national, or global interventions to reduce plastic waste.

4 | Concluding Remarks

Stranded marine plastics are a major challenge faced by many coastal communities worldwide today, particularly in regions that do not have adequate infrastructure or resources to manage the stranded plastics. Remote islands, especially those located in the Global South, often suffer from a lack of adequate waste management infrastructure, rendering them vulnerable to marine plastic pollution stranded along their coastlines. Engaging residents in citizen science projects aimed at monitoring and then managing marine plastics through recycling with monetary gain can act as an incentive for local people to get involved in addressing the global and locally experienced challenge.

This study developed and demonstrated the application of a citizen science methodology to monitor and map the accumulation of stranded marine plastics along a shoreline situated on a remote island in Indonesia. The citizen science approach was designed with the specific focus of local replication in subsequent monitoring efforts to be performed by citizen scientists comprising the island's residents. Our results indicated that the participants of the citizen science study had the capability to gather and analyze stranded marine plastics data by following the co-developed protocol. The data gathered by the citizen scientists showed that the marine debris stranded on the coastline of their village was mainly composed of plastics, providing more evidence of the potential role of remote islands as sinks for marine plastics. Our findings especially contribute toward developing an under-researched area regarding marine plastic pollution in remote locations in Indonesia, with the potential to inform management and the implementation of mitigation strategies and interventions. Future studies are also identified, especially related to the need to investigate both the impacts of marine plastic pollution on the endemic species of sea turtles and the spatiotemporal variations in marine debris and plastics accumulated in the coastlines of the island where the study was performed.

Author Contributions

Radisti A. Praptiwi: project administration, conceptualization, methodology, investigation, data curation, writing–original draft, writing–review editing. **Carya Maharja**: conceptualization, methodology, investigation, formal analysis, data curation, writing–original draft, writing–review editing. **Fauzan Cholifatullah**, **Dwi C. J. Subroto**, and **Sainal Sainal**: investigation, visualization, writing–review editing. **Peter I. Miller**: methodology, writing–review editing. **Datu**, **Nasruddin, Tatang Mitra Setia**: resources, writing–review editing. **Victoria V. Cheung**: project administration, writing–review editing. **Jito Sugardjito** and **Melanie C. Austen**: funding acquisition, writing–review editing.

Acknowledgments

This work has received funding in part from the Global Challenges Research Fund (GCRF) United Kingdom Research and Innovation (UKRI) under grant agreement reference NE/P021107/1 and NE/P021107/2 to the Blue Communities Project. This work was also supported by the Natural Environment Research Council (NERC) grant number NE/V006428/1: "A Systems Analysis Approach to Reduce Plastic Waste in Indonesian Societies: PISCES". The authors would also like to thank the Government of Kabupaten Kepulauan Selayar, the Head of Barugaiya village, and all study participants for their support in this study. Finally, we would like to thank the editor and anonymous reviewers for constructive comments that improved the manuscript.

Ethics Statement

The research was approved by the Research Ethics Committee of Universitas Nasional, Indonesia (04/DKEP/UNAS/V/2021). We comprehensively explained the objectives and methods of the study to the participants and obtained written informed consent from each of them.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. Plastics Europe. *Plastics—the Facts 2020* (Brussels: Plastics Europe, 2020), accessed July 19, 2023, https://plasticseurope.org/knowledge-hub/plastics-the-facts-2020/.

2. R. Geyer, J. R. Jambeck, and K. L. Law, "Production, Use, and Fate of All Plastics Ever Made," *Science Advances* 3 (2017): e1700782, https://doi.org/10.1126/sciadv.1700782.

3. B. D. Hardesty, T. J. Lawson, T. van der Velde, M. Lansdell, and C. Wilcox, "Estimating Quantities and Sources of Marine Debris at a Continental Scale," *Frontiers in Ecology and the Environment* 15 (2017): 18–25, https://doi.org/10.1002/fee.1447.

4. A. V. Duhec, R. F. Jeanne, N. Maximenko, and J. Hafner, "Composition and Potential Origin of Marine Debris Stranded in the Western Indian Ocean on Remote Alphonse Island, Seychelles," *Marine Pollution Bulletin* 96 (2015): 76–86, https://doi.org/10.1016/j.marpolbul.2015.05.042.

5. J. R. Jambeck, R. Geyer, C. Wilcox, et al., "Plastic Waste Inputs From Land Into the Ocean," *Science* 347 (2015): 768–771, https://doi.org/10.1126/science.1260352.

6. M. Eriksen, L. C. M. Lebreton, H. S. Carson, et al., "Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250, 000 Tons Afloat at Sea," *PLoS ONE* 9 (2014): e111913, https://doi.org/10.1371/journal.pone.0111913.

7. S. Nelms, C. Coombes, L. Foster, et al., "Marine Anthropogenic Litter on British Beaches: A 10-Year Nationwide Assessment Using Citizen Science Data," *Science of The Total Environment* 579 (2017): 1399–1409, https://doi.org/10.1016/j.scitotenv.2016.11.137.

8. J. G. B. Derraik, "The Pollution of the Marine Environment by Plastic Debris: A Review," *Marine Pollution Bulletin* 44 (2002): 842–852, https://doi.org/10.1016/S0025-326X(02)00220-5.

9. A. C. Vegter, M. Barletta, C. Beck, et al., "Global Research Priorities to Mitigate Plastic Pollution Impacts on Marine Wildlife," *Endangered Species Research* 25 (2014): 225–247, https://doi.org/10.3354/esr00623.

10. M. R. Gregory, "Environmental Implications of Plastic Debris in Marine Settings—Entanglement, Ingestion, Smothering, Hangers-On, Hitch-Hiking and Alien Invasions," *Philosophical Transactions of the*

Royal Society B: Biological Sciences 364 (2009): 2013–2025, https://doi.org/10.1098/rstb.2008.0265.

11. S. D. A. Smith and R. J. Edgar, "Documenting the Density of Subtidal Marine Debris across Multiple Marine and Coastal Habitats," *PLoS ONE* 9 (2014): e94593, https://doi.org/10.1371/journal.pone.0094593.

12. United Nations Environment Programme. *Valuing Plastic: The Business Case for Measuring, Managing and Disclosing Plastic Use in the Consumer Goods Industry—Executive Summary* (Geneva: UNEP, 2014), accessed July 13, 2024, https://wedocs.unep.org/xmlui/handle/20.500.11822/25302.

13. N. J. Beaumont, M. Aanesen, M. C. Austen, et al., "Global Ecological, Social and Economic Impacts of Marine Plastic," *Marine Pollution Bulletin* 142 (2019): 189–195, https://wedocs.unep.org/bitstream/handle/20.500.11822/9238/-Valuing%20plastic:%20the%20business%20case%20for%20measuring,%20managing%20and%20disclosing%20plastic%20use%20in%20the%20consumer%20goods%20industry-2014Valuing%20plasticsF.pdf?sequence=8&%3BisAllowed=y%2C%20Chinese%7C%7Chttps%3A//wedocs.

14. A. McIlgorm, H. F. Campbell, and M. J. Rule, "The Economic Cost and Control of Marine Debris Damage in the Asia-Pacific Region," *Ocean & Coastal Management* 54 (2011): 643–651, https://doi.org/10.1016/j.ocecoaman.2011.05.007.

15. V. Hidalgo-Ruz and M. Thiel, "Distribution and Abundance of Small Plastic Debris on Beaches in the SE Pacific (Chile): A Study Supported by a Citizen Science Project," *Marine Environmental Research* 87–88 (2013): 12–18, https://doi.org/10.1016/j.marenvres.2013.02.015.

16. D. Perez-Venegas, H. Pavés, J. Pulgar, C. Ahrendt, M. Seguel, and C. J. Galbán-Malagón, "Coastal Debris Survey in a Remote Island of the Chilean Northern Patagonia," *Marine Pollution Bulletin* 125 (2017): 530–534, https://doi.org/10.1016/j.marpolbul.2017.09.026.

17. C. Maharja, R. A. Praptiwi, I. Richter, et al., "The People of the Seas and the Seas of the People," in *Oceans and Human Health*, eds. L. E. Fleming, L. B. Alcantara Creencia, W. H. Gerwick, et al. (San Diego, CA: Academic Press, 2023), 499–530, https://doi.org/10.1016/B978-0-323-95227-9.00007-5.

18. M. Bergmann, M. B. Tekman, and L. Gutow, "Sea Change for Plastic Pollution," *Nature* 544 (2017): 297–297, https://doi.org/10.1038/544297a.

19. N. P. Purba, D. I. W. Handyman, T. D. Pribadi, et al., "Marine Debris in Indonesia: A Review of Research and Status," *Marine Pollution Bulletin* 146 (2019): 134–144, https://doi.org/10.1016/j.marpolbul.2019.05.057.

20. Coordinating Ministry for Maritime and Investment Affairs (CMMIA) of the Republic of Indonesia, *National Plan of Action: Marine Plastic Debris Management* (Jakarta: CMMIA, 2017).

21. P. Bennett-Martin, C. C. Visaggi, and T. L. Hawthorne, "Mapping Marine Debris Across Coastal Communities in Belize: Developing a Baseline for Understanding the Distribution of Litter on Beaches Using Geographic Information Systems," *Environmental Monitoring and Assessment* 188 (2016): 557, https://doi.org/10.1007/s10661-016-5544-4.

22. M. Cordier and T. Uehara, "How Much Innovation Is Needed to Protect the Ocean From Plastic Contamination?," *Science of The Total Environment* 670 (2019): 789–799, https://doi.org/10.1016/j.scitotenv.2019.03.258.

23. M. J. O. Pocock, H. E. Roy, C. D. Preston, and D. B. Roy, "The Biological Records Centre: A Pioneer of Citizen Science," *Biological Journal of the Linnean Society* 115 (2015): 475–493, https://doi.org/10.1111/bij.12548.

24. R. Bonney, T. B. Phillips, H. L. Ballard, and J. W. Enck, "Can Citizen Science Enhance Public Understanding of Science," *Public Understanding of Science* 25 (2016): 2–16, https://doi.org/10.1177/0963662515607406.

25. M. I. Severin, L. K. Akpetou, P. Annasawmy, et al., "Impact of the Citizen Science Project COLLECT on Ocean Literacy and Well-Being Within a North/West African and South–East Asian Context," *Frontiers in Psychology* 14 (2023): 1130596, https://doi.org/10.3389/fpsyg.2023.1130596.

26. M. J. O. Pocock, J. C. Tweddle, J. Savage, L. D. Robinson, and H. E. Roy, "The Diversity and Evolution of Ecological and Environmental Citizen Science," *PLoS ONE* 12 (2017): e0172579, https://doi.org/10.1371/journal.pone.0172579.

27. R. M. Jarvis, B. B. Breen, C. U. Krägeloh, and D. R. Billington, "Citizen Science and the Power of Public Participation in Marine Spatial Planning," *Marine Policy* 57 (2015): 21–26, https://doi.org/10.1016/j.marpol.2015.03.011.

28. D. C. McKinley, A. J. Miller-Rushing, H. L. Ballard, et al., "Citizen Science Can Improve Conservation Science, Natural Resource Management, and Environmental Protection," *Biological Conservation* 208 (2017): 15–28, https://doi.org/10.1016/j.biocon.2016.05.015.

29. J. Parsons, R. Lukyanenko, and Y. Wiersma, "Easier Citizen Science Is Better," *Nature* 471 (2011): 37–37, https://doi.org/10.1038/471037a.

30. *Badan Pusat Statistik Kabupaten Kepulauan Selayar and Kabupaten Kepulauan Selayar Dalam Angka 2018* (Benteng, 2018), accessed July 13, 2024, https://selayarkab.bps.go.id/publication/2018/08/16/073e1ff17d7be50dcb123675/kabupaten-kepulauan-selayar-dalam-angka-2018.html.

31. R. A. Praptiwi, C. Maharja, M. Fortnam, et al., "Tourism-Based Alternative Livelihoods for Small Island Communities Transitioning Towards a Blue Economy," *Sustainability* 13 (2021): 6655, https://doi.org/10.3390/su13126655.

32. I. Richter, A. Avillanosa, V. Cheung, et al., "Looking Through the COVID-19 Window of Opportunity: Future Scenarios Arising From the COVID-19 Pandemic Across Five Case Study Sites," *Frontiers in Psychology* 12 (2021): 635686, https://doi.org/10.3389/fpsyg.2021.635686.

33. A. Phelan, H. Ross, N. A. Setianto, K. Fielding, and L. Pradipta, "Ocean Plastic Crisis—Mental Models of Plastic Pollution From Remote Indonesian Coastal Communities," *PLoS ONE* 15 (2020): e0236149, https://doi.org/10.1371/journal.pone.0236149.

34. J. E. N. Veron, L. M. Devantier, E. Turak, et al., "Delineating the Coral Triangle," *Galaxea Journal of Coral Reef Studies* 11 (2009): 91–100, https://doi.org/10.3755/galaxea.11.91.

35. P. Wulandari, S. Sainal, F. Cholifatullah, et al., "The Health Status of Coral Reef Ecosystem in Taka Bonerate, Kepulauan Selayar Biosphere Reserve, Indonesia," *Biodiversitas Journal of Biological Diversity* 23 (2022): 721–732, https://doi.org/10.13057/biodiv/d230217.

36. Lembaga Kampung Penyu. Data for Year 2019 (in Bahasa Indonesia), Lembaga Kampung Penyu (Selayar, 2023), accessed July 18, 2023, https://www.kampungpenyu.org/p/tahun-2019.html.

37. Lembaga Kampung Penyu. Regulation for the Conservation of Sea Turtle and Commonly Found Species of Sea Turtle in Kampung Penyu (In Bahasa Indonesia). Lembaga Kampung Penyu (Selayar, 2023), accessed July 18, 2023, https://www.kampungpenyu.org/2023/05/regulasi-perlindungan-penyu-dan-jenis.html.

38. IUCN. *The IUCN Red List of Threatened Species, IUCN Red List of Threatened Species* (IUCN: Cambridge, 2023), accessed July 18, 2023, https://www.iucnredlist.org/en.

39. C. Maharja, R. A. Praptiwi, B. R. Roberts, et al., "Sea Swimming and Snorkeling in Tropical Coastal Blue Spaces and Mental Well-Being: Findings From Indonesian Island Communities During the COVID-19 Pandemic," *Journal of Outdoor Recreation and Tourism* 41 (2023): 100584, https://doi.org/10.1016/j.jort.2022.100584.

40. G. Ottinger, "Buckets of Resistance: Standards and the Effectiveness of Citizen Science," *Science, Technology, & Human Values* 35 (2010): 244–270, https://doi.org/10.1177/0162243909337121.

41. M. Bergmann, B. Lutz, M. B. Tekman, and L. Gutow, "Citizen Scientists Reveal: Marine Litter Pollutes Arctic Beaches and Affects Wild Life," *Marine Pollution Bulletin* 125 (2017): 535–540, https://doi.org/10.1016/j.marpolbul.2017.09.055.

42. K. Merry and P. Bettinger, "Smartphone GPS Accuracy Study in an Urban Environment," *PLoS ONE* 14 (2019): e0219890, https://doi.org/10.1371/journal.pone.0219890.

43. D. Chen, S. Shams, C. Carmona-Moreno, and A. Leone, "Assessment of Open Source GIS Software for Water Resources Management in Developing Countries," *Journal of Hydro-Environment Research* 4 (2010): 253–264, https://doi.org/10.1016/j.jher.2010.04.017.

44. Badan Standar Nasional Indonesia. SNI 19-3694-1994: Metode Pengambilan *Dan Pengukuran Contoh Timbulan Dan Komposisi Sampah* Perkotaan (Jakarta: BSN Indonesia, 2001), accessed March 25, 2021, https://lmsspada.kemdikbud.go.id/pluginfile.php/90050/mod_resource/content/6/6%20-%20SNI-19-3694-1994-Metode-Pengambilan-Dan-Pengukuran-Contoh-Timbulan-Dan-Kompos.pdf.

45. M. Kosmala, A. Wiggins, A. Swanson, and B. Simmons, "Assessing Data Quality in Citizen Science," *Frontiers in Ecology and the Environment* 14 (2016): 551–560, https://doi.org/10.1002/fee.1436.

46. S. Gündoğdu and C. Çevik, "Mediterranean Dirty Edge: High Level of Meso and Macroplastics Pollution on the Turkish Coast," *Environmental Pollution* 255 (2019): 113351, https://doi.org/10.1016/j.envpol.2019.113351.

47. Y. Suteja, A. S. Atmadipoera, E. Riani, I. W. Nurjaya, D. Nugroho, and A. I. S. Purwiyanto, "Stranded Marine Debris on the Touristic Beaches in the South of Bali Island, Indonesia: The Spatiotemporal Abundance and Characteristic," *Marine Pollution Bulletin* 173 (2021): 113026, https://doi.org/10.1016/j.marpolbul.2021.113026.

48. N.-E. Taïbi, M. E. A. Bentaallah, C. Alomar, M. Compa, and S. Deudero, "Micro- and Macro-Plastics in Beach Sediment of the Algerian Western Coast: First Data on Distribution, Characterization, and Source," *Marine Pollution Bulletin* 165 (2021): 112168, https://doi.org/10.1016/j.marpolbul.2021.112168.

49. L. Lebreton, M. Egger, and B. Slat, "A Global Mass Budget for Positively Buoyant Macroplastic Debris in the Ocean," *Scientific Reports* 9 (2019): 12922, https://doi.org/10.1038/s41598-019-49413-5.

50. P. Vriend, H. Hidayat, J. van Leeuwen, et al., "Plastic Pollution Research in Indonesia: State of Science and Future Research Directions to Reduce Impacts," *Frontiers in Environmental Science* 9 (2021): 692907, https://doi.org/10.3389/fenvs.2021.692907.

51. L. C. M. Lebreton, J. van der Zwet, J.-W. Damsteeg, B. Slat, A. Andrady, and J. Reisser, "River Plastic Emissions to the World's Oceans," *Nature Communications* 8 (2017): 15611, https://doi.org/10.1038/ncomms15611.

52. D. Dobler, C. Maes, E. Martinez, et al., "On the Fate of Floating Marine Debris Carried to the Sea Through the Main Rivers of Indonesia," *Journal of Marine Science and Engineering* 10 (2022): 1009, https://doi.org/10.3390/jmse10081009.

53. S. Krishnakumar, S. Anbalagan, K. Kasilingam, P. Smrithi, S. Anbazhagi, and S. Srinivasalu, "Assessment of Plastic Debris in Remote Islands of the Andaman and Nicobar Archipelago, India," *Marine Pollution Bulletin* 151 (2020): 110841, https://doi.org/10.1016/j.marpolbul.2019.110841.

54. V. Hoare, N. Atchison Balmond, G. C. Hays, et al., "Spatial Variation of Plastic Debris on Important Turtle Nesting Beaches of the Remote Chagos Archipelago, Indian Ocean," *Marine Pollution Bulletin* 181 (2022): 113868, https://doi.org/10.1016/j.marpolbul.2022.113868.

55. B. Witherington, S. Hirama, and A. Mosier, "Sea Turtle Responses to Barriers on Their Nesting Beach," *Journal of Experimental Marine Biology and Ecology* 401 (2011): 1–6, https://doi.org/10.1016/j.jembe.2011.03.012.

56. A. Olivelli, B. D. Hardesty, and C. Wilcox, "Coastal Margins and Backshores Represent a Major Sink for Marine Debris: Insights From a Continental-Scale Analysis," *Environmental Research Letters* 15 (2020): 074037, https://doi.org/10.1088/1748-9326/ab7836.

57. M. L. Haarr, L. Westerveld, J. Fabres, K. R. Iversen, and K. E. T. Busch, "A Novel GIS-Based Tool for Predicting Coastal Litter Accumulation and Optimising Coastal Cleanup Actions," *Marine Pollution Bulletin* 139 (2019): 117–126, https://doi.org/10.1016/j.marpolbul.2018.12.025.

58. M. F. Costa, J. S. Silva-Cavalcanti, C. C. Barbosa, J. L. Portugal, and M. Barletta, "Plastics Buried in the Inter-Tidal Plain of a Tropical Estuarine Ecosystem," *Journal of Coastal Research* 64 (2011): 339–343, accessed July 13, 2024, https://www.jstor.org/stable/26482189.

59. K. A. Willis, T. Jones, R. Cohen, H. Burgess, J. Lindsey, and J. Parrish, "Using Long-Term Citizen Science Data to Distinguish Zones of Debris Accumulation," *Marine Pollution Bulletin* 182 (2022): 114028, https://doi.org/10.1016/j.marpolbul.2022.114028.

60. P. G. Ryan, C. J. Moore, J. A. van Franeker, and C. L. Moloney, "Monitoring the Abundance of Plastic Debris in the Marine Environment," *Philosophical Transactions of the Royal Society B: Biological Sciences* 364 (2009): 1999–2012, https://doi.org/10.1098/rstb.2008.0207.

61. C. A. Ribic, S. B. Sheavly, D. J. Rugg, and E. S. Erdmann, "Trends in Marine Debris along the U.S. Pacific Coast and Hawai'i 1998–2007," *Marine Pollution Bulletin* 64 (2012): 994–1004, https://doi.org/10.1016/j.marpolbul.2012.02.008.

62. P. G. Ryan and A. Schofield, "Low Densities of Macroplastic Debris in the Pitcairn Islands Marine Reserve," *Marine Pollution Bulletin* 157 (2020): 111373, https://doi.org/10.1016/j.marpolbul.2020.111373.

63. H. S. Carson, S. L. Colbert, M. J. Kaylor, and K. J. McDermid, "Small Plastic Debris Changes Water Movement and Heat Transfer Through Beach Sediments," *Marine Pollution Bulletin* 62 (2011): 1708–1713, https://doi.org/10.1016/j.marpolbul.2011.05.032.

64. J. A. Mortimer, N. Esteban, A. N. Guzman, and G. C. Hays, "Estimates of Marine Turtle Nesting Populations in the South–West Indian Ocean Indicate the Importance of the Chagos Archipelago," *Oryx* 54 (2020): 332–343, https://doi.org/10.1017/S0030605319001108.

65. I. Fujisaki and M. M. Lamont, "The Effects of Large Beach Debris on Nesting Sea Turtles," *Journal of Experimental Marine Biology and Ecology* 482 (2016): 33–37, https://doi.org/10.1016/j.jembe.2016.04.005.

66. K. E. Clukey, C. A. Lepczyk, G. H. Balazs, T. M. Work, and J. M. Lynch, "Investigation of Plastic Debris Ingestion by Four Species of Sea Turtles Collected as Bycatch in Pelagic Pacific Longline Fisheries," *Marine Pollution Bulletin* 120 (2017): 117–125, https://doi.org/10.1016/j.marpolbul.2017.04.064.

67. J. Orós, M. Camacho, P. Calabuig, et al., "Postmortem Investigations on Leatherback Sea Turtles (*Dermochelys coriacea*) Stranded in the Canary Islands (Spain) (1998–2017): Evidence of Anthropogenic Impacts," *Marine Pollution Bulletin* 167 (2021): 112340, https://doi.org/10.1016/j.marpolbul.2021.112340.

68. L. C. M. Omeyer, E. M. Duncan, K. Aiemsomboon, et al., "Priorities to Inform Research On Marine Plastic Pollution in Southeast Asia," *Science of The Total Environment* 841 (2022): 156704, https://doi.org/10.1016/j.scitotenv.2022.156704.

69. T. Sekito, T. B. Prayogo, C. Meidiana, H. Shimamoto, and Y. Dote, "Estimating the Flow of Recyclable Items and Potential Revenue at a Waste Bank: The Case in Malang City, Indonesia," *Environment Development and Sustainability* 21 (2019): 2979–2995, https://doi.org/10.1007/s10668-018-0175-2.

70. M. E. Iñiguez, J. A. Conesa, and A. Fullana, "Marine Debris Occurrence and Treatment: A Review," *Renewable and Sustainable Energy Reviews* 64 (2016): 394–402, https://doi.org/10.1016/j.rser.2016.06.031.

71. P. Lestari and Y. Trihadiningrum, "The Impact of Improper Solid Waste Management to Plastic Pollution in Indonesian Coast and Marine Environment," *Marine Pollution Bulletin* 149 (2019): 110505, https://doi.org/10.1016/j.marpolbul.2019.110505.

72. C. Rosevelt, M. L. Huertos, C. Garza, and H. M. Nevins, "Marine Debris in Central California: Quantifying Type and Abundance of Beach Litter," *Marine Pollution Bulletin* 71 (2013): 299–306, https://doi.org/10.1016/j.marpolbul.2013.01.015.

73. C. Maharja, R. A. Praptiwi, and Y. Purwanto, "Understanding the Cultural Impacts of Climate Change Harms on Small-Scale Fisher Communities Through the Lens of Cultural Ecosystem Services," *Maritime Studies* 22 (2023): 41, https://doi.org/10.1007/s40152-023-00332-2.

74. H. V. Ford, N. H. Jones, A. J. Davies, et al., "The Fundamental Links between Climate Change and Marine Plastic Pollution," *Science of The Total Environment* 806 (2022): 150392, https://doi.org/10.1016/j.scitotenv.2021.150392.

75. S. Sharma, V. Sharma, and S. Chatterjee, "Contribution of Plastic and Microplastic to Global Climate Change and Their Conjoining Impacts on the Environment—A Review," *Science of The Total Environment* 875 (2023): 162627, https://doi.org/10.1016/j.scitotenv.2023.162627.

76. T. L. Aspirani, F. Fatmawati, and S. R. Arfah, "Peran Pemerintah Dalam Penanggulangan Sampah Domestik Di Kabupaten Kepulauan Selayar," *Kajian Ilmiah Mahasiswa Administrasi Publik (KIMAP)* 5 (2024): 529–542, https://journal.unismuh.ac.id/index.php/kimap/article/view/14140.

77. B. K. Veettil, N. Hong Quan, L. T. Hauser, D. D. Van, and N. X. Quang, "Coastal and Marine Plastic Litter Monitoring Using Remote Sensing: A Review," *Estuarine, Coastal and Shelf Science* 279 (2022): 108160, https://doi.org/10.1016/j.ecss.2022.108160.

78. W. R. Winans, Q. Chen, Y. Qiang, and E. C. Franklin, "Large-Area Automatic Detection of Shoreline Stranded Marine Debris Using Deep Learning," *International Journal of Applied Earth Observation and Geoinformation* 124 (2023): 103515, https://doi.org/10.1016/j.jag.2023.103515.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.