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A Survey of Marine Coastal Litters around Zhoushan Island, China and Their Impacts

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Abstract: Rapid development of the economy increased marine litter around Zhoushan Island. Social-ecological scenario studies can help to develop strategies to adapt to such change. To investigate the present situation of marine litter pollution, a stratified random sampling (StRS) method was applied to survey the distribution of marine coastal litters around Zhoushan Island. A univariate analysis of variance was conducted to access the amount of litter in different landforms that include mudflats, artificial and rocky beaches. In addition, two questionnaires were designed for local fishermen and tourists to provide social scenarios. The results showed that the distribution of litter in different landforms was significantly different, while the distribution of litter in different sampling points had no significant difference. The StRS survey showed to be a valuable method for giving a relative overview of beach litter around Zhoushan Island with less effort in a future survey. The questionnaire feedbacks helped to understand the source of marine litter and showed the impact on the local environment and economy. Based on the social-ecological scenarios, governance recommendations were provided in this paper.

Keywords: marine coastal litter; distribution; composition analysis; Zhoushan Island

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1. Introduction

Marine litter has become a hot issue in the global marine environment and has been listed by the United Nations Environment Program (UNEP) among the ten most urgent environmental problems in recent years [1,2]. Marine litter refers to the artificial solid waste which was disposed into the ocean, including fishing nets, buoys, plastic bags, plastic bottles (cans), and various production and household litter [2]. More than 90% of marine litter is plastic litter [3]. There are two major sources of marine litter. The first source is land-based, i.e., litter is carried into the ocean through rivers and sewage outlets, or it is generated by coastal human activities. The second major source of marine litter is the litter generated by various marine activities (e.g., mariculture, fishery, marine shipping, and marine tourism) that directly discard the litter into the sea [3–5]. One study showed that 192 coastal countries and regions in the world discharged from 480×10^4 to 1270×10^4 t of plastic waste into the ocean every year [6]. Of that, 64×10^4 t of dilapidated fishing nets and fishing implements were discarded into the ocean.

Marine litter has and will have a profound influence on the marine environment and ecosystem. The accumulation of marine litter will damage the marine landscape and affect the marine tourism economy [7]. At the same time, plastic waste can absorb environmental pollutants and may cause local water pollution and damage to the chemical integrity of the water environment. Among marine litter, discarded fishing nets or plastic ropes are the most harmful. They can wind up marine life and lead to the death of animals, and threaten the integrity of the marine ecosystem [8–11]. In addition, fishing nets and plastic ropes can wind up the ship's power system and cause a great danger to ship safety [12]. Finally, the decomposition of marine plastic litter will create plastic fragments and microplastic particles that may have a toxic effect on the health of marine organisms [13,14].

Zhoushan Island is the main island of the Zhoushan archipelago located in the coastal area of eastern Zhejiang province of China. In recent years, the government acknowledged the importance of the development and utilization of marine resources in this area [15]. Zhoushan is focused on cultivating and developing marine industry as the center of marine economy development with the Zhoushan Archipelago New Area designated as a state-level economic reform pioneer zone in the national strategy [15,16]. The rapid development of the economy caused the increase in household and industrial waste that degrades the environment. Policymakers need to understand how societies can develop strategies to adapt and continue to develop in such change. Social-ecological scenario studies can inspire and facilitate adaptive governance through dialogues with decision-makers and other stakeholders [17]. Where the scenarios should be grounded in data concerning both the natural and the social sciences [17]. As Zhoushan Island is surrounded by sea at the southern flank of the Yangtze River estuary, the beaches consist of different landforms with complex litter pollution. Accordingly, to implement waste management more effectively, it is imperative to understand the distribution and source of beach litter.

Therefore, the main purpose of this study is to reveal the distribution of beach litter in different landforms such as mudflats, rocky beaches, and artificial beaches around Zhoushan Island, as well as the source and type of litter. Additionally, this study wants to understand the impact of marine litter on local people's life and the public's awareness of marine environmental protection to provide the obtained knowledge and results for the local policymakers and public.

2. Materials and Methods

2.1. Study Sites

A survey on marine litter was conducted in Zhoushan Island in July 2019. The research mainly focused on the Putuo District. According to the beach types of Zhoushan Island, the study sites were divided into three types: mudflats, rocky and artificial beaches. For each type, two representative areas were randomly selected before the survey was conducted: mudflat(a) at Shenjiamen wharf and mudflat(b) at Haibin park; Rocky beach(a) in the lotus sculpture park and rocky beach(b) in Haibin park; and Artificial beach(a) in lotus ocean sculpture park and artificial beach(b) at Dongsha beach (Figure 1). Where the artificial beaches are regularly supervised and cleaned by local managers.

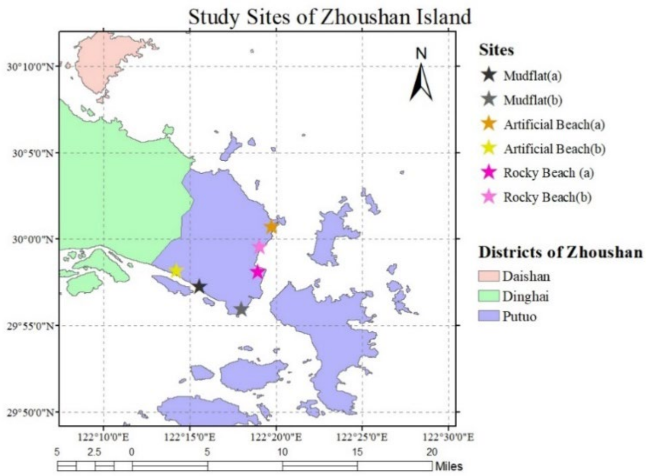

Figure 1. Study sites of Zhoushan Island.

2.2. Survey Design

The method of stratified random sampling (StRS) was carried out in the field survey on Zhoushan Island. StRS is widely used in marine litter surveys [18–21]. UNEP also recommended that the location of sampling sites for beach litter assessment should be stratified [22]. A well-designed StRS scheme can achieve relatively precise and accurate estimates with reduced sample size compared to other sampling methods [23]. Considering that different landforms may have different litter, and for long-term monitoring survey purposes, we divided the landforms into mudflats, artificial beaches, and rocky beaches. Two areas (a and b) were randomly selected and inspected on each of the three landforms. Furthermore, according to the survey site conditions, five quadrats (5 m × 4 m) were also randomly selected from each area to investigate the distribution of beach litter in each landform. All litter was collected and counted in each quadrat.

The structure of the sampling strategy is shown in Figure 2. As described above, for long-term monitoring survey purpose, sampling efforts should be rationally allocated among strata to get representative and accurate survey data. However, since this is the first time of the surveys, we equally allocated the sampling efforts among different landforms. Results from this survey are used as basic data for future survey design.

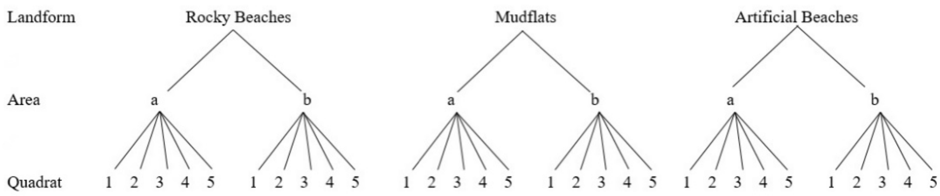

Figure 2. Structure of the sampling strategy.

Furthermore, a questionnaire survey was conducted for local residents and tourists to understand their awareness of marine litter and the difficulty of cleaning it up, as well as to access the impact of litter on the local environment and economy. A questionnaire survey for tourists was conducted in tourist spots, while a questionnaire survey for residents was conducted in fishing ports targeting local fishermen. The questionnaires were supplied in the Supplementary Materials (Questionnaire S1, Questionnaire S2).

2.3. Data Analysis

After litter collection, the classification statistics and density analysis were performed. Also, the univariate analysis of variance was applied to study whether there were significant differences in the amount of litter in different landforms.

The statistical method of the Northwest Pacific Action Plan (NOWPAP) was used to classify the litter and analyze the litter types in different landforms and regions [24]. Litter sources were classified into five categories: human coastal activities, shipping/fishing activities, smoking supplies, medical/hygiene supplies, and other waste. Furthermore, to explore the material types of litter from human activities, they were further divided into nine categories: plastic, glass, rubber, paper, fabric, metal, polystyrene foam, wood, and others. Where, plastic litter includes all kinds of plastic bags, plastic bottles, bottle caps, lunch boxes, etc. Fabric litter includes old clothes, towels, fishing nets, etc. Metal litter includes electrical wiring, cans, paint buckets, etc. More example items of different materials are given in Table 1.

Table 1. Example items of different materials.

Materials	Items
plastic	plastic bags, plastic bottles, bottle caps, lunch boxes, etc.
glass	glass fragments, glass bottles, etc.

rubber	tires, rubber gloves, rubber shoes, etc.
paper	newspaper, book, disposable paper cup, carton, etc.
fabric	old clothes, towels, fishing nets, etc.
metal	electrical wiring, cans, paint buckets, etc.
polystyrene foam	plastic foam board, etc.
wood	desks, chairs, wood waste, etc.
others	cigarette ends, sponge, ceramic bowl, etc.

By counting the types, quantities, or weight of marine litter, quantity density (pieces/m^2) or mass density (kg/m^2) of marine litter in the sea area can be obtained. In this study, only quantity density was analyzed. For this purpose, Equation (1) for marine debris monitoring and evaluation (trial implementation) can be implemented:

$$\widehat{D} = \frac{\mathrm{n}}{\mathrm{L} \times \mathrm{W}} \quad (1)$$

where $\widehat{D}$ represents the density of marine litter in pieces/m^2; n is the sum of the mass or quantity of litter fragments; W is the effective width (m) of the surveyed section and L is the length (m) of surveyed section.

The advantage of using StRS was to ensure that estimates can be made with equal accuracy in different parts of the region and that comparisons of sub-regions can be made with equal statistical power. However, it was difficult to understand whether litter distribution was related to the landform. Accordingly, the univariate variance analysis method was used to analyze whether there was a significant difference in the litter distribution in each landform type.

Questionnaire feedbacks were analyzed to understand the impact of beach litter on local people's life and the public's awareness of marine environmental protection. Two versions of questionnaires were designed for local fishermen and tourists. An on-site paper anonymous questionnaire survey was conducted with those who met the initial requirements, and then the collected information was counted and classified.

3. Results and Discussion

3.1. Sample Statistics

The number of collected samples in each quadrat from each landform is presented in Table 2.

Table 2. Number of samples collected in each quadrat from each landform.

	Mudflat(a) /Pieces	Mudflat(b) /Pieces	Rocky Beach(a) /Pieces	Rocky Beach(b) /Pieces	Artificial Beach(a) /Pieces	Artificial Beach(b) /Pieces
Quadrat1	25	19	6	9	1	4
Quadrat2	14	22	3	17	2	0
Quadrat3	10	6	7	30	5	0
Quadrat4	13	11	15	11	0	2
Quadrat5	13	9	10	23	1	0
Sum	75	67	41	90	9	6

As litter was not weighed in this survey. Formula (1) was used to calculate the quantity density of litter in each district. The litter density of each sampled quadrat from the three types of landforms and the average density with sample standard deviation are presented in Table 3. Based on the total amount and quantity density of litter in each district, the double-coordinate Figure 3 was created. The red line represents the maximum density of debris in each landform, while the pink line represents the minimum density of debris. It can be noticed that mudflats had the largest amount of litter, yet rocky beaches had the largest density. Artificial beaches had both the least amount of debris and the least density.

Table 3. Quantity density of litter in each district.

	Mudflats Pieces/m²	Rocky Beaches Pieces/m²	Artificial Beaches Pieces/m²
Quadrat 1	2.2	2.75	0.25
Quadrat 2	1.8	1	0.1
Quadrat 3	0.8	1.85	0.25
Quadrat 4	1.2	1.3	0.1
Quadrat 5	1.1	1.65	0.05
Mean ± SD	1.42 ± 0.57	1.71 ± 0.67	0.15 ± 0.09

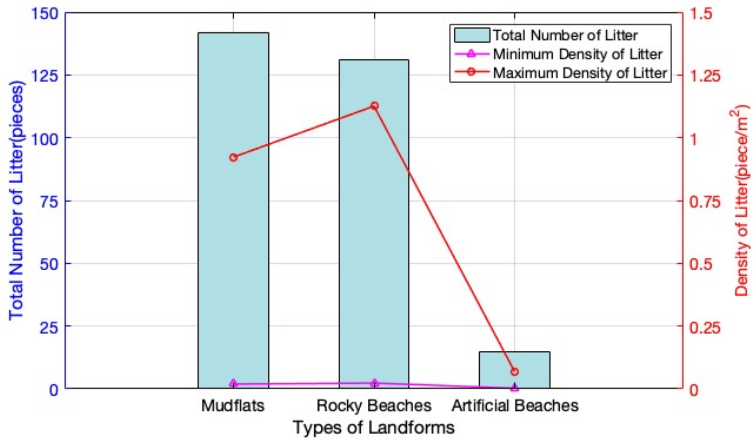

Figure 3. Total number and density of litter in different landforms.

3.2. Classification of Sampled Litters

Table 4 shows the source classification statistics of marine litter from the survey samples following NOWPAP Guidelines [24].

Table 4. Sources classification of marine litter from the survey samples.

	Mud-flat(a) /Pieces	Mud-flat(b) /Pieces	Rocky Beach(a) /Pieces	Rocky Beach (b) /Pieces	Artificial Beach(a) /Pieces	Artificial Beach(b) /Pieces
Human Coastal Activities	33	28	14	45	1	3
Shipping/ Fishing Activities	25	30	6	15	2	0
Smoking Supplies	2	0	0	0	2	2
Medical/ Hygiene Products	1	0	0	1	0	0
Other Wastes	14	9	21	29	4	1
Sum	75	67	41	90	9	6

The composition of litter categories in each area (Figure 4) indicated that human coastal activities and fishing activities were the main sources of marine litter. The distribution histogram of litter material types is shown in Figure 5 for each landform type. From the figure, it can be noticed that the plastics are dominant on mudflats, yet plastic and metal litter are the majority on the rocky beach (a), while on the rocky beach (b) plastics and fabric have similar significance. Finally, artificial beaches dominate other types of garbage.

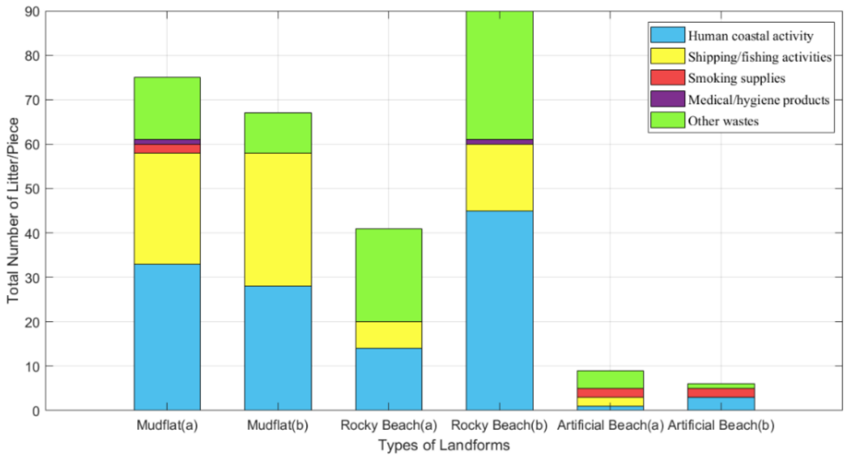

Figure 4. Proportion chart of marine litter sources from the survey samples.

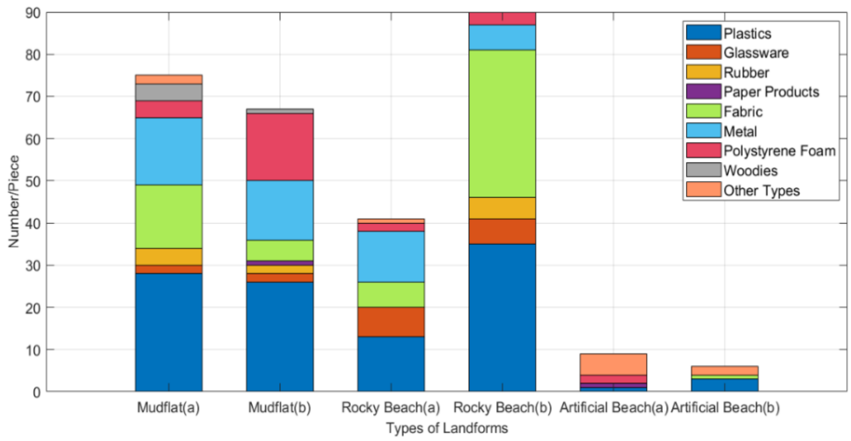

Figure 5. Classification results by types of litter from the survey samples.

3.3. Relationship Between Litter and Landform

Figures 6 and 7 show the comparison intervals for the mean litter density for different landforms and different sampling points. In the figures, the red bars represent the median value, the black bars represent the maximum and minimum value of the sample, the blue bars represent the upper and lower quartile of the sample, while the range between upper and lower conner points represents a 95% confidence interval of the litter density distribution. Figure 6 shows significant differences in the distribution of litter in different landforms (p = 0.0006), while Figure 7 shows no significant differences in the distribution of litter in different sampling points (p = 0.9854).

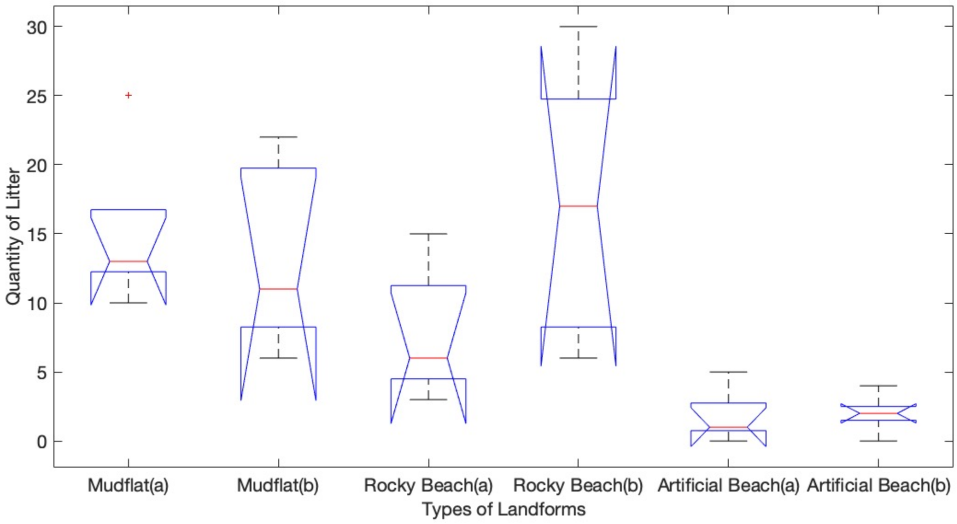

Figure 6. Result of Univariate Analysis of Variance in different landforms from the survey.

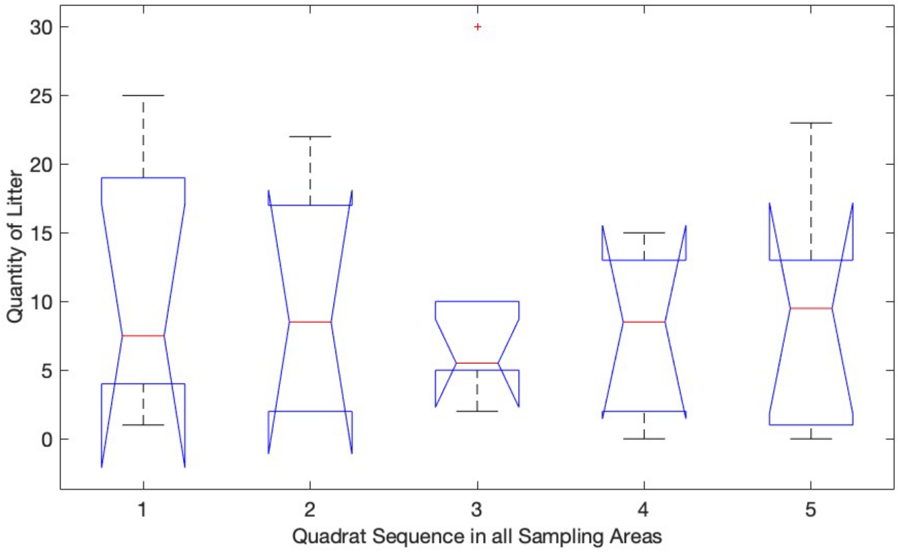

Figure 7. Result of Univariate Analysis of Variance in different sampling points from the survey.

3.4. Questionnaire Feedbacks

The questionnaire survey was conducted on 91 tourists aged 18 to 50. The statics of the survey feedbacks can be found in the Supplementary Materials (Feedbacks S1). The majority of tourists had a basic understanding of litter classification and handling and agreed that it is necessary to perform the beach litter classification. Furthermore, half of the visitors were not familiar with the present situation of the marine environment. Finally, more than 70% of visitors obtained information about the present situation of the marine environment through the news. Age and education level are two important factors that affect people's level of knowledge on environmental issues. Older tourists are generally less aware of marine litter than younger tourists. While higher education level people have more awareness on these issues. Older people tend to access their knowledge on marine litter from newspapers and TV, while younger people pay more attention to social media platforms such as Weibo.

The questionnaire survey was also conducted on 30 fishermen. The statics of the survey feedbacks can be found in the Supplementary Materials (Feedbacks S2). The majority of the participants (90%) understood the harmful consequences of marine litter and showed a strong will to decrease the behavior that leads to the pollution of the marine environment. Unfortunately, there are many sources of marine litter, while the number of disposal sites is limited, and several fishermen throw their litter directly into the sea. According to the fishermen, volunteers were asked by the government to clean up the litter, but there are only a few litter salvage vessels that can regularly deal with the litter. The local fishermen believe that marine litter has a great impact on the fishing output.

Zhoushan Island has undergone visible changes due to litter pollution. Most of the survey participants think that the litter created by residents is the main source of marine litter. Furthermore, the marine litter is also created by tourists, fishing activities, aquaculture, industry, and sea freight (Figure 8).

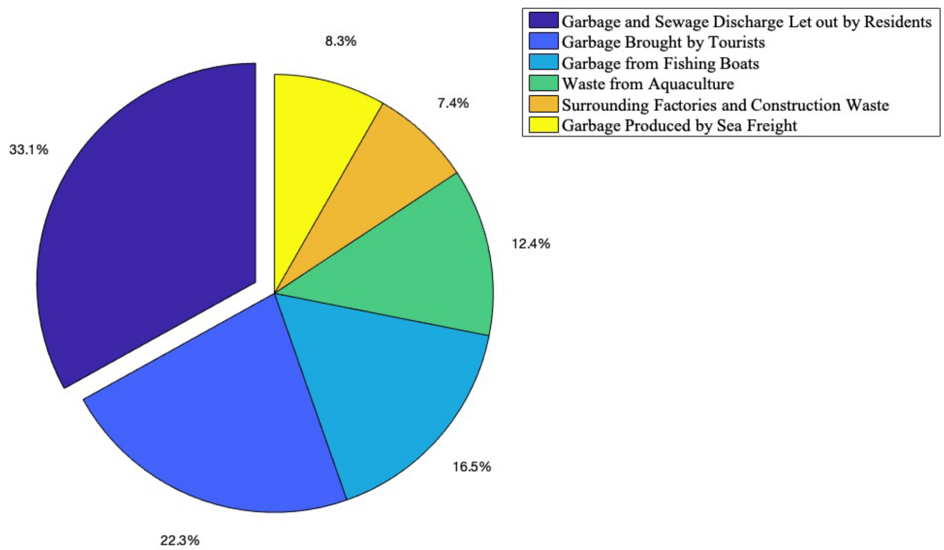

Figure 8. Feedback from tourists and fishermen on the source of litter.

3.5. Discussion

This study found that plastics, fabric, and metal are the most common types of litter in mudflats and rocks (Figure 5). These kinds of litter are most likely to be found in fishing boats and construction sites. Typhoons, storms, and other inclement weather can wash up the plastic buried inland or unburied litter into the sea [25]. Furthermore, there is a lack of awareness about marine environmental protection and people in the shipping industry dump their litter into the sea. There are other examples of how the litter ends up on beaches and in the sea: the cargo ship was caught in a storm and containers fell into the sea; lighter materials, such as plastic and foam, were carried away by the ocean currents; people traveling on holidays and living by the sea throw rubbish away; the trash is carried into the ocean by currents, monsoons, and tides and pushed back onto beaches and rocks. Figure 5 shows that the amount of rubbish on the artificial beach was significantly less than that of the other two types of landforms, which is speculated to be because the artificial beaches were regularly supervised and cleaned.

In this study, a significant difference in the distribution of litter in different landforms was noticed. It can be discussed that the landform can cause that the quantity of litter is not evenly distributed. For example, as the tide rose and fell, one part of the litter stayed on the shore, while the other part drifted with the tide into the sea. As both mudflats were located in harbors and were heavily influenced by human activities, the total amount of litter was the largest among the three types of landform. The sea litter carried by the high tide fell down after the low tide, and it was difficult to flow back to the sea at the next high tide because of the blocking and obstruction of the rocks. Accordingly, this kind of landform was also the hardest to clean up. Although both of the two artificial beaches were open to the public, they had the lowest amount of litter because they were probably supervised and maintained.

Variations in the accumulation of beach litter may also be related to the time of year. Some factors may be weather and ocean conditions like winds and surface currents [26]. Some factors of seasonal human activities, such as recreational boating in the summer season, which may be considered as an important marine-based littering source [27]. As this study was conducted in a short period, we cannot present these variations related to the time of year, but they should be listed in future surveys.

From the perspective of litter sources, this paper adopted the NOWPAP method and divided litter sources into human coastal activities, shipping/fishing activities, smoking supplies, medical products, and other wastes. The results showed that human coastal activities produce the vast majority of litter, which means that land-based litter is dominant. Similarly, Gabrielides et al. [28] recognized that litter quantity has a direct relationship with the number of people visiting the beach. It is also similar to the result that litter quantity is closely linked with people's activity, concentration, and crowding [29]. Alshawafi et al. [30] recognized that tourism is a significant litter source in many parts of the world. The abundance of different types of litter, especially the high quantity of plastic litter, suggested that recreational activities or a land-based origin were the main source [31].

According to the classification of litter types in this study, plastic litter accounts for the largest proportion (46.18%), followed by fabric litter (21.53%). The quantity of plastic litter is similar to the quantity of plastic litter found on beaches of Qingdao in China [32] and Korean beaches [33]. The proportion of plastic litter varied from 60% to 80% of various Mediterranean and South African beach litter [34] and exceeded 80% on remote islands [35]. The quantity of fabric litter is equivalent to that counted on the beaches of Liaodong Bay in China [1]. Synthetic fishing gears, ropes, and nets have been observed for several years on the beach [36]. On the contrary, the beach of Shandong Province in China accounted for only 1.77% of the fabric litter [37]. Wood is also one of the most abundant litter types and is prevalent in different coastal regions of the world [33,38]. However, in this study, the proportion of wood litter is only 0.02%.

From the results of the questionnaire survey, we noticed that the current situation of the Zhoushan area is not optimistic. Accordingly, the government and relevant departments should strengthen management, enact relevant laws and regulations, add ocean disposal delivery and processing site, as well as to increase the number of litter salvage ships to retrieve the litter promptly.

4. Conclusions and Recommendation

In the field survey of the main island of Zhoushan island, we investigated the distribution and density composition of beach litter on two mudflats, two artificial beaches, and two rocky beaches. An StRS method was used to analyze the amount of marine litter in different landforms and samples.

The results showed that the distribution of litter in different landforms was significantly different, while the distribution of litter in different sampling points was not significantly different. A classification method of NOWPAP was used to classify the sources of litter, and the results showed that most of the litter was generated by human coastal and fishing activities. Three litter types with the largest proportion were plastic, fabric, and metal litter. Since this survey mainly focuses on the coastal litter, it is speculated that the litter may be generated by coastal activities and then drifted to the shore, or it can be caused by human activities on the shore. Taking into consideration the results of the present study, different clean strategies can be applied to different landforms. Furthermore, a strategy should emphasize a systems approach addressing not only cleaning up litter but addressing the source of litter and making progress against the root causes of the problem [39].

The questionnaire results showed that the marine environment in Zhoushan has undergone significant changes in recent years. Additionally, most of the fishermen believed that the reasons behind that could be attributed to the impact of marine litter. In addition, the questionnaire for tourists showed that most tourists have a certain understanding of the marine environment and litter, yet few tourists are not familiar with the current situation of the marine environment. This is a drawback since marine environmental protection needs the participation of all people. To this end, corresponding measures must be taken to effectively prevent and reduce the production of marine litter. Based on the social-ecological scenarios provided in this study, the recommendations are:

(1) The awareness of the public and policymakers related to marine litter governance should be improved. At present, most people have a weak awareness of participating in beach litter governance, and the actual institutions for beach litter governance are relatively limited. Therefore, the number of social organizations concerned with marine environmental protection should be increased. Furthermore, the publicity and education activities on the marine environment should be carried out to enhance public awareness of marine environmental protection, which could reduce the pollution caused by marine litter. A good example is a nationwide campaign of voluntary beach clean-ups in Greece: "Clean up the Med", which can raise public awareness on marine environmental issues and promote a sense of responsibility in protecting marine resources [27].

(2) Relevant laws and regulations should clarify the public's right to participate in marine environmental protection, empower them with the information and knowledge about the marine environment, enabling them to participate in the decision-making process, and clearly stipulating that the public can get rewards in the process of marine litter management to improve the public's enthusiasm. It is also important to ensure that the public has timely access to adequate information about the sea and pollution to collect their opinions and feedback on time.

(3) A simple and scientific-based method to survey marine litter like our study conducted could provide to the public, especially to volunteer organizations, that provided opportunities for public involvement in in coastal management and scientific data gathering.

Supplementary Materials: The following are available online at www.mdpi.com/2077-1312/9/2/183/s1, Questionnaire S1: Questionnaire for Local People, Questionnaire S2: Questionnaire for Tourists, Feedbacks S1: Feedbacks of Questionnaire for Tourists, Feedbacks S2: Feedbacks of Questionnaire for Local People.

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