Marine litter on the beaches of Lesvos Island (Greece) after the refugee crisis: sources, density and composition

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ABSTRACT

The war in Syria led to a massive flow of refugees from the Turkish coast to Lesvos Island (Greece). The irregular immigration to Lesvos on inflatable boats and other vessels that were subsequently abandoned along the coast has led to a devastating marine litter problem, with serious ecological and economic implications. Vessels, life-jackets, inflatable tubes, outboard engines, clothing and other items constitute the composition of the marine litter. After extensive beach clean-ups conducted in 2015 and 2016, this study aimed to investigate the remaining quantities of litter and specifically the overall contribution of immigration. Twenty-four sites along the entire coastline of the island were surveyed, both in beaches affected and unaffected by the influx of refugees. Substantially higher litter densities (both in terms of numbers and mass) were estimated for the migrant disembarkation sites than for those where migrants did not land. Furthermore, the composition of litter differed between affected and unaffected sites. The average density of litter in affected sites averaged 6.03 kg per m length of beach and reached 86.02 kg per m in one site, while in non-affected sites the average density was one order of magnitude lower.

Keywords: coastal litter, refugees, Lesvos Island, immigration crisis, waste management, environmental impact.

1. Introduction

Marine litter is defined as any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment (Galgani *et al*., 2010; UNEP, 2015). Marine litter has deleterious, persistent and wide-reaching effects on the marine environment (Thompson *et al*., 2004; Rochman, 2016). It has been described as a serious mortality factor of marine species due to entanglement (Laist, 1997; Katsanevakis, 2008). Many marine species have been reported to ingest marine litter (mostly plastics), mistaking them for prey, seriously harming their physical condition and survival (Derraik, 2002; Choy and Drazen, 2013). Toxic contaminants eventually enter the food chain through ingested plastics with potentially negative impacts on marine life and human health (Lang *et al*., 2008; Talsness *et al*., 2009; Rochman *et al*., 2015). High marine litter densities may change the structure of benthic communities by assisting the invasion of hard-bottom species in areas otherwise dominated by soft substrates (Katsanevakis *et al*., 2007). The large availability of floating litter provides rafting opportunities and assists the transport of species beyond their natural boundaries, acting as a pathway of biological invasions with serious implications for native biodiversity (Barnes, 2002; Katsanevakis and Crocetta, 2014). Marine litter, especially derelict fishing gear, causes substantial damage to many vulnerable habitats, such as coral reefs and coral facies (Donohue *et al*., 2001; Chiappone *et al*., 2005).

Besides ecological impacts, marine litter has serious social and economic implications such as lost tourism due to the downgrading of beach quality, reduction of fish and crustacean stocks due to ghost fishing, rescue operations for entangled or damaged vessels, costs of clean ups of beaches and reefs, and increased conservation costs (Katsanevakis, 2008; Mouat *et al*., 2010; Irwin, 2012).

The Syrian war was the cause of the biggest migration in the world after the Second World War. More than 6.1 million people have been displaced from Syria to neighbouring countries of the Middle East and North Africa and a percentage of them from there to Europe (UNHCR, 2017). Because of its close proximity to the Turkish coast, the Aegean island of Lesvos became a major destination of refugees from Syria and other Asian countries. Lesvos, an island of about 80,000 inhabitants, has experienced the brunt of the refugee crisis, as more than 500,000 immigrants (mostly refugees) arrived from 2008 until the end of 2015 (>90% of arrivals occurred in 2015) (Mytilene Police office, 2016). Such a massive and sudden influx of people had both direct and indirect negative impacts on the local environment due to the rapid and unplanned production of solid and liquid wastes. On top of the already problematic solid waste collection and treatment in Lesvos due to poor waste management and low economic resources (Harnnarong, 2009), the massive human inflow presented a strain on the island’s waste collection network and limited resources.

Immigrants mainly used inflatable boats and dinghies, wearing life jackets and carrying only necessities like food and clothing as they crossed approximately 9 to 16 miles of sea between the coast of Turkey and the island of Lesvos. Most of these items were disposed of on arrival and during 2015 accumulated in enormous quantities along the island’s coastline (Fig. S1, S2, S3). Marine and coastal pollution became a threat to the local economy as it negatively affected the quality of beaches and tourist operations, which depend heavily upon the high environmental status of the coasts and the sea.

This study aimed to (1) assess the level of coastal pollution by litter along the coastline of Lesvos Island after the refugee crisis in 2015, i.e. after major efforts for cleaning up the beaches; (2) to estimate the composition, abundance and weight of litter in the beaches of Lesvos; (3) to identify the sources of marine litter on beaches and separate immigration-related pollution from other sources; and (4) to compare litter density and mass among regions of the island with different levels of impact by immigration. A sudden unexpected massive arrival of immigrants as a source of marine litter has not been studied before, except for a preliminary study conducted during the main period of immigration flow in two beaches of Lesvos, affected by the massive arrival of immigrants (Katsanevakis, 2015).

2. Materials and Methods

The coastline of Lesvos was divided into three zones, depending on the anticipated environmental impact of the immigration flow. This was empirically done during the design phase of the survey, before any measurements, based on the proximity of the coastline to Turkey and the degree of accessibility for clean-ups.

The first zone was characterized as ‘affected’ (Fig. 1). It included the northern and north-eastern part of Lesvos, which is very close to Turkey (9 to 20 km) and not easily accessed by the municipal garbage trucks. The seven beaches surveyed in this zone were assumed to be highly impacted by the immigration flow.

The second zone was characterized as ‘semi-affected’ and included areas less close to Turkey (20 to 25 km) or close to Turkey (13-18 km) but near the capital of the island with easy access for garbage trucks. The latter sites were regularly cleaned up, and thus less litter remains were expected after the end of the main immigration wave. The nine beaches included in this zone were assumed to also be impacted by the immigration flow but to a lesser degree than the affected sites.

The third zone was assumed to be largely unaffected (‘non-affected’ sites) as it was far from the Turkish marine borders and was principally inaccessible by vessels transferring immigrants. Within this zone, eight beaches were surveyed, considered as reference sites.

In total, 24 beaches were surveyed, classified as affected, semi-affected, and non-affected, including both tourist and non-tourist beaches (Table S1). The survey was conducted between May and August 2016. At each beach, four 25-m transects were defined parallel to the coastline (except in four beaches, which were shorter than 100m and thus only three 25-m transects were surveyed). At each transect, all litter items detected from the tide line to the back border of the beach were counted. The very large and heavy items were weighed *in situ* using a hanging scale (range 0 – 150 kg; accuracy of 1kg), while small items were collected and weighed in the lab by a digital scale (range 0 - 5kg; accuracy of 0.1g).

To test differences in litter density among the three zones, a Kruskal-Wallis test was conducted on the original data instead of an ANOVA, as the design was unbalanced and there were deviations from normality and homoscedasticity. In addition, ANOVA was applied to properly transformed data (in order to achieve normality and homoscedasticity). Tukey’s test on transformed data was applied to identify homogenous groups among the three zones.

To compare the surveyed sites in terms of the composition of marine litter, cluster analysis and multidimensional scaling were conducted, based on a similarity matrix that was created from the original matrix, using Bray-Curtis coefficients and standardized log (1+x)-transformed data. The standardization removes any effect of differing total abundance and only differences due to debris composition are reflected (Clarke and Warwick, 1994).

3. Results

In total, 8950 items of marine litter, with an overall weight of 7.5 tonnes, were counted in the 24 beaches surveyed. The most polluted site surveyed was site 1e (Korakas) with an extreme value for mass per meter of beach (86.02 kg/m), which is due to the great number of inflatable boats (intact and in pieces) and remains of polyester boats with an estimated total mass of 6 tones. Another extreme value (15.16 items per meter) was found in the semi-affected site 2d (St. Ermogenis). This result was due to a nearby illegal dump site that affected the specific beach.

Most of the items found in all the three zones (affected, semi-affected and non-affected) were probably not related to the migrant influx (Fig. 2). The items directly related (inflatable boats, life jackets, swimming rings, remains of polyester vessels, and engines of vessels) or most probably (backpacks, clothes and shoes) together accounted for the 23%, 4% and 5% of the total number of litter items found in the three zones respectively. In terms of weight, the overall outcome differed: the items directly and most probably related to the immigration flow dominated at affected (93%) and semi-affected sites (62%), whereas they were minimal (6%) in non-affected sites (Fig. 2). This was due to the increased weight of many of the immigration-related items (e.g. remains of boats) in contrast to the other items.

Plastic was the most abundant material found on beaches of all three zones (75%), followed by clothing (14%) and wood (4%). Related to mass, plastic (46%) and rubber (28%) ranked top, followed by wood (23%). Small pieces of plastic were the most abundant items in most sites, while in terms of mass, inflatable boats and remains of polyester boats were the heaviest items.

The marine litter abundance (number of items per m of beach length) was the highest in the affected sites with an average of 6.41 items/m, and the lowest in the non-affected sites with an average of 0.5 items/m. In affected and semi-affected beaches, the litter abundance ranged from 1.11 to 15.16 items/m, while in non-affected beaches it ranged from 0.04 to 1.38 items/m. The average mass of litter per m of beach length was 13.24 kg/m in affected sites and 0.05 kg/m in the non-affected sites. The litter mass per beach length ranged between 0.01 and 86.02 kg/meter in affected and semi-affected sites, and between 0.003 and 0.16 kg/meter in non-affected sites (Fig.3; Table S2).

Significant differences were evident among the three zones both in terms of the number of litter items per beach length (Kruskal-Wallis test on original data, $p<0.001$; ANOVA on log-transformed data, $p<0.0001$) and mass per beach length (Kruskal-Wallis test on original data, $p=0.008$; ANOVA on Box-Cox-transformed data, $p=0.005$). In both cases, affected and semi-affected sites were grouped as one homogenous group with litter density substantial higher than in the non-affected sites both in terms of number of items and mass (Tukey's test, at 99% confidence level).

Cluster analysis and MDS (Figs 4, 5) indicated that the composition of litter in non-affected sites differed from that in the affected and semi-affected sites. With only a few exceptions, affected and semi-affected sites were grouped together and were spatially separated from the non-affected sites in the MDS plot. The average dissimilarity between the affected and non-affected sites was 71.3%, between semi-affected and non-affected 67.0%, and between affected and semi-affected 48.8%.

4. Discussion

After the 2015 refugee crisis in Lesvos, extensive clean-up campaigns were organized by NGOs and the municipality. As herein revealed, despite these efforts, elimination of the environmental impact of the huge immigration flow on the coasts of the island was not fully achieved. Huge quantities of litter were collected and disposed of in landfills but the environmental footprint of immigration remained: affected and semi-affected sites had increased quantities of litter, and their composition differed in relation to control (non-affected) sites due to immigration-related items. It should be noted though that the litter densities estimated in this study, after the extensive clean-up campaigns, were substantially lower than the litter densities in 2015, during the outbreak of the problem. The two beaches surveyed during the pilot survey by Katsanevakis (2015) were also surveyed during this study (sites 1b and 2g), and the amount of litter (in terms of mass) had reduced by 96.6% and 82.2% respectively.

This study demonstrated that a large scale human influx can cause littering in a substantially larger scale than usual. The unprecedented influx of refugees to Lesvos challenged its infrastructure, and the local authorities were unable to deal effectively and timely with this new source of marine litter. The uniqueness of this source of litter is not related to a lack of awareness or lack of will to be environmentally responsive but it is the result of switching priorities from environmental health and ecological consciousness to bare survival. In other words, the migrants could not be expected to be environmentally conscious and be concerned about the environmental impact of disposing of inflatable boats, outboard engines, life jackets and swimming rings, while fighting for their lives and the lives of their families.

The items directly and most probably related to the refugee crisis were not the most abundant items on all affected beaches. It is quite possible that the present estimates are biased low, as many items classified as not related to immigration, such as plastic bottles, in fact could have been left by the migrants. On the other hand, some items classified as “most probably related to the refugee crisis”, such as some clothing items, could actually originate from other sources. Despite the uncertainty in these categories, the differences in the amount and composition of litter among the affected, semi-affected and non-affected sites are a strong indication of the significance of immigration as a source of marine litter.

Plastics dominated the composition of litter on the beaches of Lesvos. They dominated in both the immigration-related category (due to the plastic inflatable boats, life jackets, plastic tubes etc.) and the immigration-unrelated category (plastic bottles, plastic bags, fishing lines, synthetic ropes etc.). The literature on marine debris leaves no doubt that plastics make up most of the marine litter worldwide (Derraik, 2002; Katsanevakis, 2008), although they have only existed for just over a century. Plastics may persist in the marine environment for years or centuries, and thus their amount in the oceans is expected to keep increasing.

If plastic items remain for long on beaches, they may progressively fragment into smaller pieces (Thompson et al., 2004), and thus their removal at a later stage will be much more difficult. In fact, numerous small fragments of inflatable boats and life jackets have been recorded in this study. Many of these items end up on the seabed (Katsanevakis, 2015) or floating on the sea surface, with important consequences for marine life (Katsanevakis, 2008; Deudero & Alomar, 2015). The amounts of litter on the seabed or on the sea surface were not investigated in this survey. Such an investigation along with the study of the potential impacts on marine life should be targets of future research.

When it comes to the devastating effect on the environment and the local economy, the origin of marine litter does not matter. Nevertheless, monitoring marine litter is necessary for increasing the effectiveness and efficiency of waste management. From this research, it was possible to realize that after a few months of massive migrant influx, and despite huge efforts to clean the beaches, the problem remains. This first large-scale survey of marine litter on the beaches of Lesvos Island can provide a baseline for further monitoring, and a first assessment of a new and difficult to manage source of litter.

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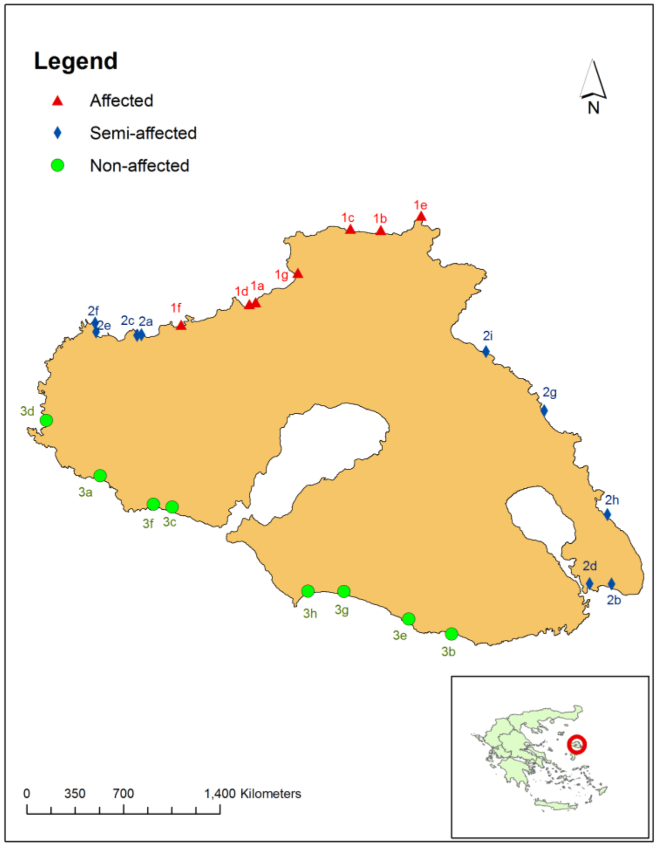

Figure1.Surveyed sites on Lesvos Island. Red symbols: affected beaches; Blue symbols: Semi-affected beaches; Green symbols: Non-affected beaches.

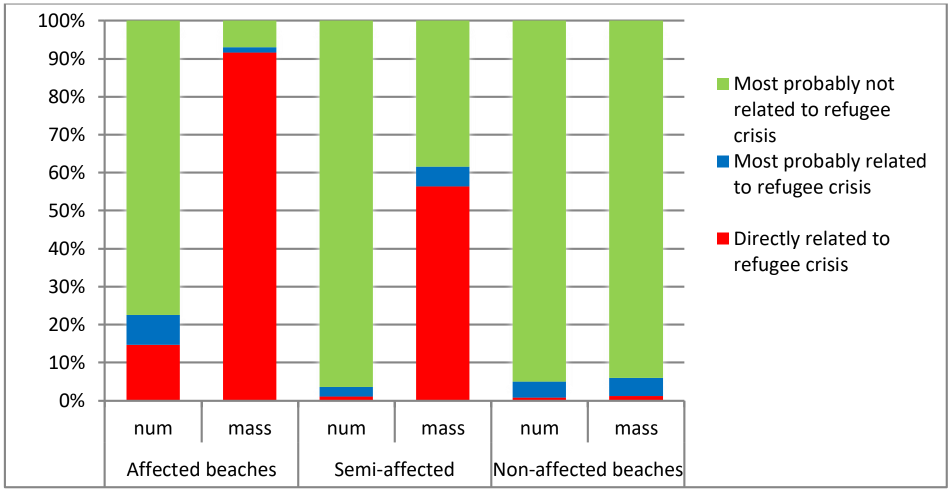

Figure2. Proportion of litter items (#) and mass directly related, most probably related and most probably not related to the migrant influx in all three zones–‘affected’, ‘semi-affected’ and ‘non-affected’ beaches

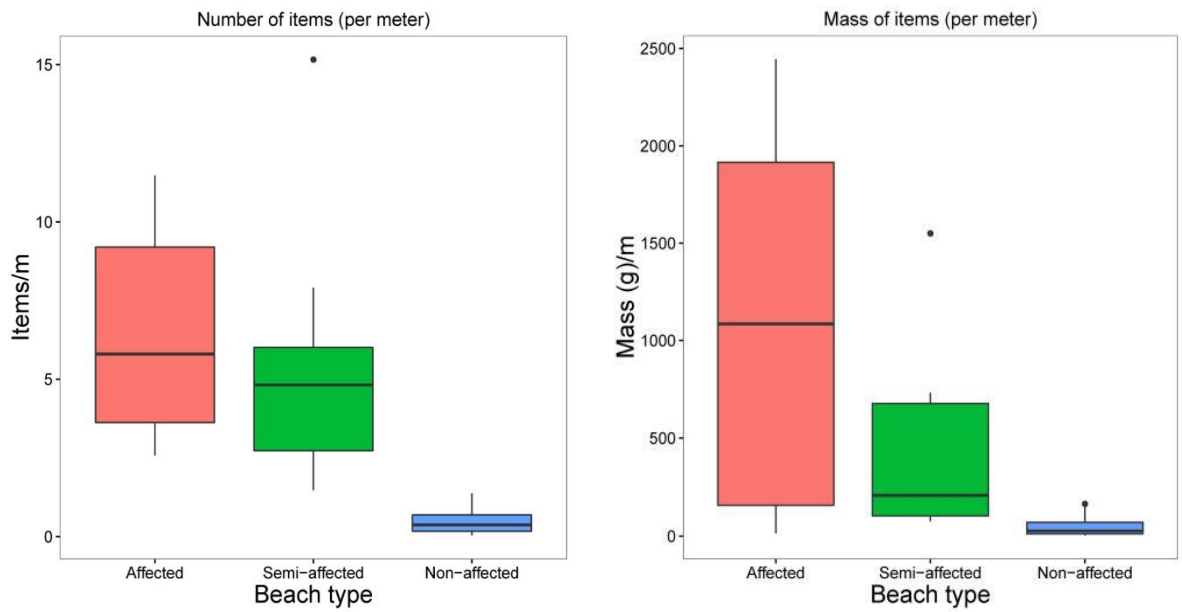

Figure3. Box-plots of the distribution of the number of litter items per beach length (left) and the corresponding mass per beach length (right) in affected, semi-affected and non-affected sites by the migrant influx in Lesvos. Data from one site (Korakas) are not shown in graph B for clarity (outlier with very high mass density). The horizontal lines in the boxes represent the medians. The coloured boxes represent the middle 50% of the distribution.

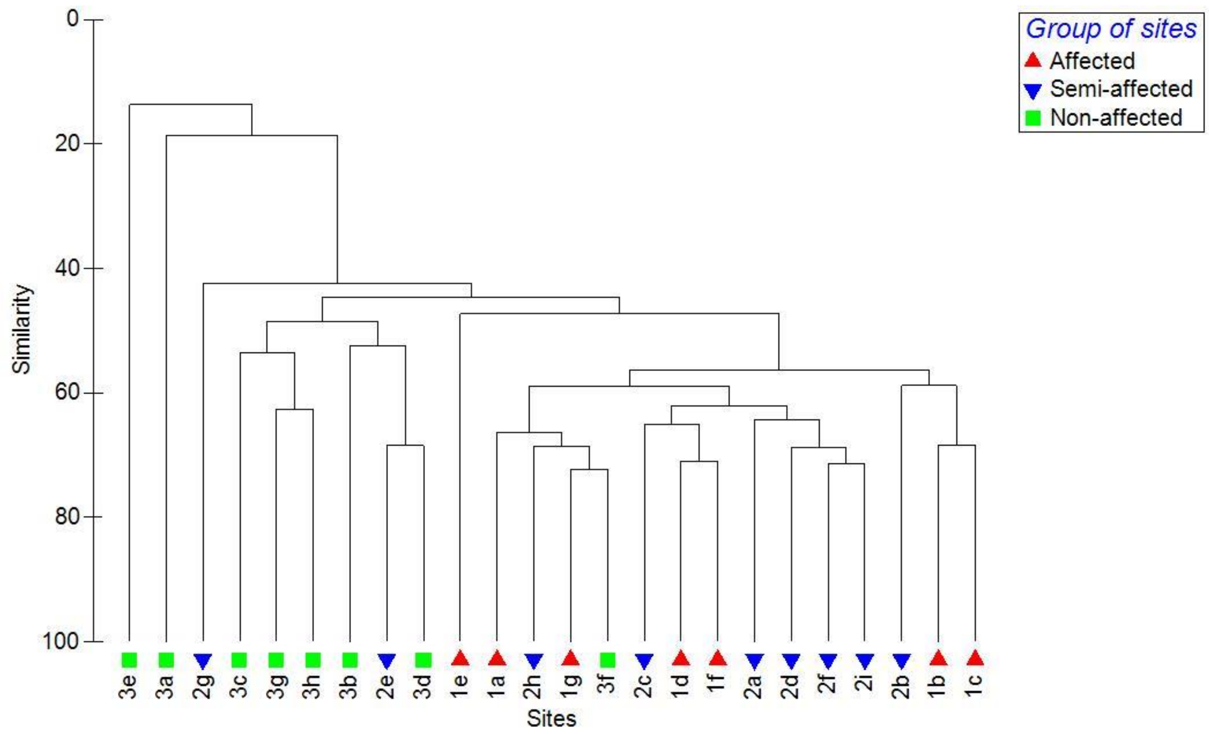

Figure4. Cluster dendrogram groups affected and semi-affected sites in a same group taking into account number of items on the sites, while non-affected group of sites constitute the group for themselves.

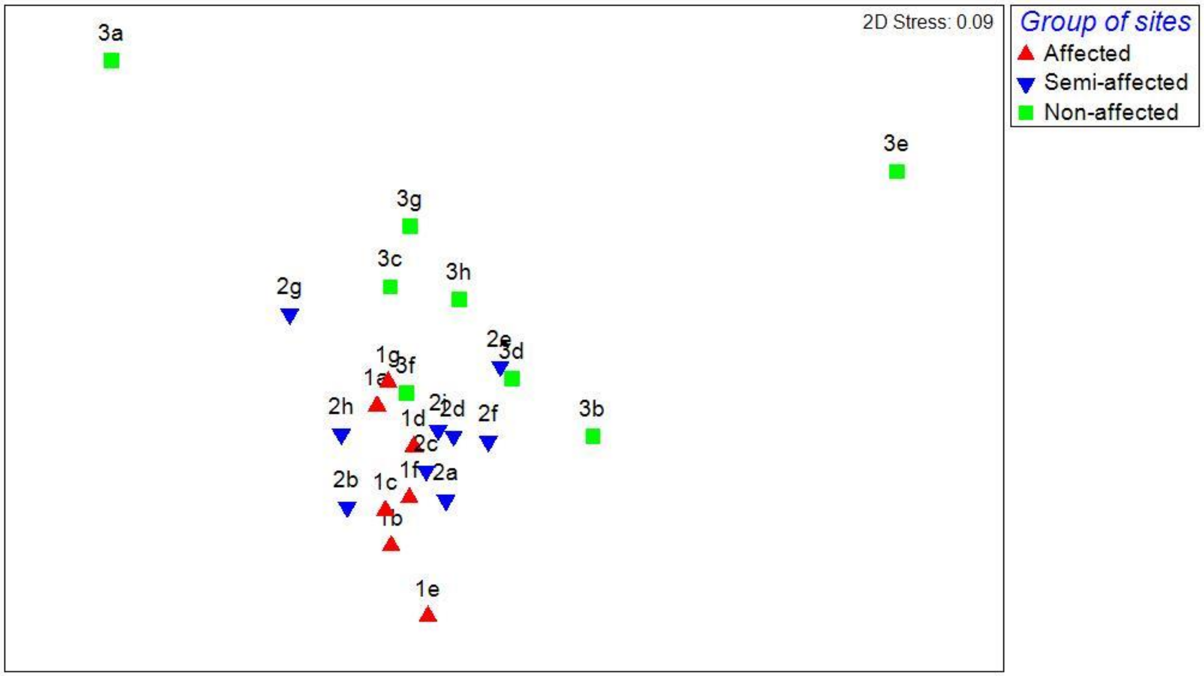

Figure 5. MDS plot of all beaches surveyed. The numbering denotes the three zones: 1: affected; 2: semi-affected; and 3: non-affected. The ordination was according to the similarity of the composition of the marine litter recorded in each site (log(1+x) transformation; Bray-Curtis similarity).

Suplementary File:

Table S1: Summary of the characteristics of surveyed locations (affected, semi-affected and non-affected) with type of harm that they could produce, considering environment and community.

Beach type *	Surveyed beach	Coordinates	Date of survey	Sampling Effort	Touristic area	Potential harm	Codes in Cluster and MDS
Affected	Abelia	26.126492E 39.307351N	26.05.2016.	100m (25m x 4)	Yes but visited mostly by locals	Ecological	1a
	After Skala Sikamineas	26.289533E 39.376350N	17.05.2016	100m (25m x 4)	Yes	Ecological, economic and social	1b
	Before Eftalou	26.250683E 39.378417N	17.05.2016.	75m (25m x 3)	Yes	Ecological, economic and social	1c
	Cihlanda (Kechrada)	26.118172E 39.305429N	26.05.2016.	100m (25m x 4)	Yes but visited mostly by locals	Ecological, economic and social	1d
	Korakas	26.341717E 39.389567N	17.05.2016	75m (25m x 3)	No	Ecological, social	1e
	Near to Archea Antissa	26.030071E 39.286453N	26.05.2016.	100m (25m x 4)	Yes but visited mostly by locals	Ecological, economic and social	1f
	Petra	26.181411E 39.335557N	28.05.2016.	100m (25m x 4)	Yes	Ecological, economic and social	1g
Semi-affected	Gavathas	25.978826E 39.277483N	30.05.2016.	100m (25m x 4)	Yes but visited mostly by locals	Ecological	2a
	Haramida I	26.572958E 39.016765N	06.06.2016.	100m (25m x 4)	Yes	Ecological, economic, social	2b

	Kampos	25.987590E 39.277481N	30.05.2016.	100m (25m x 4)	Yes but visited mostly by locals	Ecological	2c ▼
	St. Ermogenis church	26.545021E 39.017749N	06.06.2016.	75m (25m x 3)	No	Ecological	2d ▼
	Lapsarna I	25.920708E 39.281072N	30.05.2016.	100m (25m x 4)	Yes but visited mostly by locals	Ecological	2e ▼
	Lapsarna II	25.919500E 39.290031N	30.05.2016.	75m (25m x 3)	Yes but visited mostly by locals	Ecological	2f ▼
	St. George	26.493111E 39.191556N	27.07.2016.	75m (25m x 3)	No	Ecological	2g ▼
	University	26.570351E 39.086325N	25.06.2016.	100m (25m x 4)	Yes but mostly visited by locals	Ecological, social	2h ▼
	Xampelia	26.420528E 39.252083N	27.07.2016.	100m (25m x 4)	No	Ecological, economic	2i ▼
Non -affected	Skala Eresos	25.922048E 39.137559N	16.08.2016.	100m (25m x 4)	Yes	Ecological, economic and social	3a ■
	Plomari	25.987590E 39.277481N	19.08.2016.	100m (25m x 4)	No	Ecological, economic and social	3b ■
	Podaras	26.013174E 39.104771N	16.08.2016.	100m (25m x 4)	Yes	Ecological, economic, social	3c ■
	Limena	25.854493E 39.193938N	15.08.2016.	100m (25m x 4)	No	Ecological	3d ■
	Melinda	26.312685E 38.987203N	19.08.2016.	100m (25m x 4)	No	Ecological, economic, social	3e ■
	Tavari	25.989229E 39.108030N	16.08.2016.	100m (25m x 4)	Yes	Ecological, economic, social	3f ■

	Vatera II	26.230448E 39.016575N	19.08.2016.	100m (25m x 4)	Yes	Ecological, economic, social	3g
	Vatera I	26.184527E 39.017650N	19.08.2016.	100m (25m x 4)	Yes	Ecological, economic, social	3h

Table S2: Number of items per meter and mass of items per meter registered on surveyed sites

	Beach	Count (items/m)	Mass (kg/m)
Affected	Korakas	10.88	86.02
	After Skala Sikamineas	3.15	2.44
	Before Eftalou	4.10	2.00
	Ambelia	2.58	0.03
	Cihranda (Kechrada)	9.13	0.54
	Near Archea Antissa	9.27	1.63
	Petra	5.80	0.01
Semi-affected	Kampos	4.82	0.19
	Gavathas	1.48	0.20
	Lapsarna I	7.91	0.10
	Lapsarna II	3.32	0.67
	Haramida I	6.01	1.55
	St. Ermogenis church	15.16	0.07
	University	1.11	0.73
	St. George	2.55	0.09
	Xampelia	5.15	0.23
Non-affected	Limena	0.93	0.03
	Skala Eresos	0.10	0.15
	Tavari	1.38	0.01
	Podaras	0.43	0.008
	Vatera I	0.61	0.04
	Vatera II	0.32	0.01
	Melinda	0.04	0.003
	Plomari	0.20	0.16

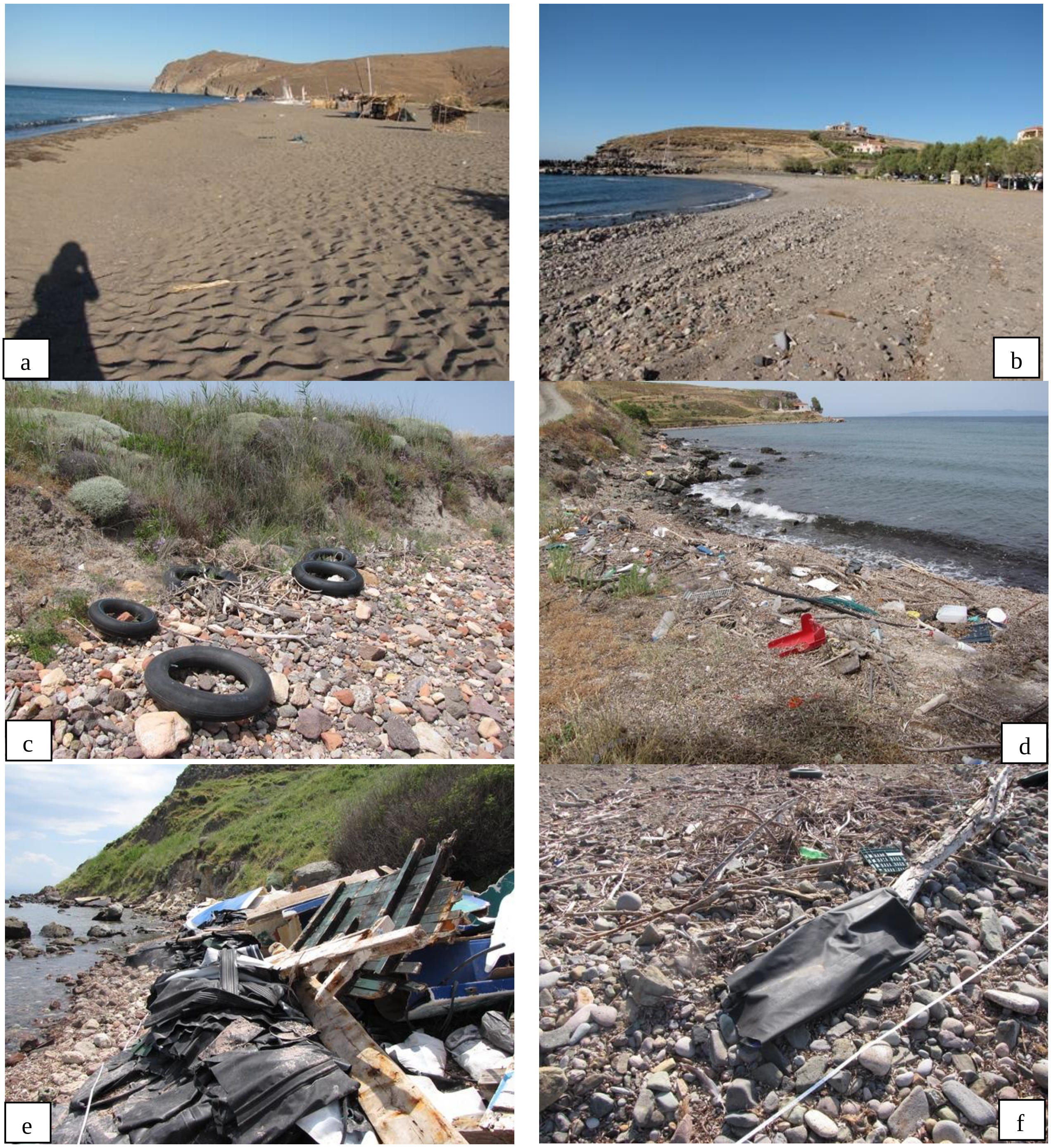

Figure S1. Polluted surveyed beaches. (a, b) Non – affected beaches (Skala Eressos, Tavari)(c, d) Semi-affected beaches (Gavathas, Lapsarna II); (e, f) Affected beaches (Korakas, Skala Sikamineas).

Figure S2. Items related to refugee crisis. (a) Remains of polyester boat; (b) life jacket; (c) swimming ring; (d) pieces of inflatable boats.

Figure S3. Comparison of one of the surveyed site (26.250683E, 39.378417N) with situation in 2015. Pictures made on survey 2015 (a, c); Pictures made on survey 2016 (b, d).