Chapter

Need for a Collaborative Natural Resource Management Strategy for the Marine Environment—The Case of Plastics in the Mediterranean

Michel Soto Chalhoub

Abstract

Natural resource management issues are at the heart of sustainability and are seldom limited to a localized community. We address marine plastic pollution which not only infests local beaches, but is found in the present research to have high mobility, a serious impact on human health, and a damaging effect on ecosystems. Plastics have reached the deepest points of our oceans and while all oceans are affected, the Mediterranean Sea is particularly vulnerable to pollution because of its high biodiversity density, its enclosed geometry, and its bathymetry. We collected primary and secondary data and drew on separate studies performed by the author. We gauged public attitudes towards plastic waste management in Lebanon and found that the public is aware of the issue and supports the formation of a Mediterranean Rim consortium to address both remedial and preventive strategies. A regression analysis is introduced where a dependent variable represents the need for regional natural resource strategies. It was found to be positively and significantly correlated with the establishment of national policies, engineering innovation as a preventive strategy, and the adoption of local implementation. Our case study in Lebanon unveiled lack of public policies for solid waste management and marine plastic litter, causing implementation challenges. We recommend that the problem of plastic pollution be tackled with cross-border cooperation among neighboring countries around the Mediterranean.

Keywords: natural resource management, plastic pollution, Mediterranean Sea, regional environmental collaboration, policy development, private sector advocacy

1. Introduction

Environmental problems have a deep impact on public health, the economy, and society at large. Plastics top the list among other types of solid waste pollutants due to their properties and tenacity [1]. Plastic littering is a violation of several local and international agreements; it travels in sea water spreading its damaging effects on marine fauna and flora. Environmental valuation requires

accounting for environmental damage and the resulting social costs. In many countries, the absence of environmental valuation combined with lack of policies exacerbates the problem. Weakness in public management, at both levels of legislation and implementation, are other salient factors of major concern. To compensate for weaknesses in local policies across nations and to combat negative littering practices, international agreements were created to impose prohibitions against plastic littering in the marine environment. The London Dumping Convention created in 1972 (MARPOL Convention, Annex V) and MARPOL Protocol of 1978 declared plastics in international waters as unlawful. The 1982 Law of the Sea Convention mandates preservation of the marine environment. Several other United Nations agreements ban dumping plastic substances in the ocean. Many states committed themselves legally to such agreements. The weakness, however, resides in implementation and enforcement [2–5]. In a country like Lebanon where data were collected in the present research, non-governmental organizations and ecological movements took the lead over public sector services to close this policy gap. International organizations and environmental activists argue that the establishment of dump sites and landfills on the shore, as it has been practiced in Lebanon in the last two decades, is a straight violation of the Barcelona Convention, a 1995 legislation designed to protect and preserve the marine environment in the Mediterranean [6].

Previous studies by the author gauged public attitudes towards marine plastic litter with an emphasis on the nexus between engineering and public policy. It was argued that engineering solutions on their own could be developed and may prove to be effective. However, such solutions cannot be implemented if they are not supported by public policy. The separate study by the author is briefly reviewed to emphasize the results of a linear regression model with a dependent variable, Y, which represented the need to develop regional strategies for natural resource management. The independent variables were defined as (1) the establishment of national policies specific to marine protection against pollution, (2) use of technology as remedial solutions, (3) use of engineering innovation as preventive solutions in the private sector, and (4) local enforcement. The third variable was based on the premise that radical innovative solutions would be required to transition into a plastic-free end-use. A statistically significant and positive correlation was found with the first, third, and fourth variables, while there was no statistical significance with the second variable. In the following sections, we illustrate the dire need for policies focused on solid waste management and in particular marine plastic litter. We then draw on policy examples from other countries and recommend local adaptation and adoption. Still, local policy development may be solely a small component of the problem offering only a patchwork of piecemeal solutions. Plastic pollution requires a broader and long-term outlook where teamwork, cooperation, and scientific knowledge-sharing in the Mediterranean region are a firm prerequisite.

2. Plastic pollution is a regional and global problem

Literature shows that coastal areas of developing countries which lack waste management policies and remedial infrastructure are of primary concern. However, the status of plastic pollution in the world's oceans poses a challenge to both industrialized and developing countries alike. Large plastic items released in the ocean do not degrade but rather degenerate into very small pieces—microplastics—which are particles smaller than 5 mm. These particles are mobile over hundreds of acres on the ocean surface and within lower layers. The spread of microplastics is caused

by currents and oceanographic mixing processes. The Mediterranean is particularly vulnerable to polluting activities including plastic debris [7, 8].

In the last few decades, plastic accumulation reached remote offshore areas and formed trash gyres, islands, and vortexes [9]. Harmful effects of plastics on marine life include starvation, suffocation, and entanglement. Thousands of marine fauna and hundreds of species have been affected thus far. Floating plastics help transport non-indigenous marine species to intrude on other native colonies, causing a threat to marine biodiversity and the food chain. Floating plastic particles become vehicles to toxic pollutants that stick on their surface causing concentrated sources of environmental pollution in ocean gyres. With this visible recognition that drifting plastic debris cause adverse effects on ecosystems, innovative techniques are required [10]. A major challenge is to quantify plastics in the oceans because there is a lack of accurate information about sources, quantities, trajectories, accumulation, and final status.

3. Vulnerability of the Mediterranean

3.1 History and biodiversity

The Mediterranean Sea is considered to be the cradle of civilization. This pond is seriously affected by marine litter because its geometry forms a closed basin with limited mixing with other oceans. Due to their weather, beauty, and history, countries around the Mediterranean are densely populated with an active tourism industry. Lebanon's coast houses some of the most ancient cities including Tyre (2750 BC), Sidon (4000 BC), Beirut (3000 BC), and Byblos (5000 BC). Other countries on the Mediterranean rim have long-standing history, heritage, and ancient landmarks. Historic monuments on the coast are vulnerable to pollution, whether spills, solid, or plastic waste.

The Mediterranean is recognized for its natural diversity. It makes less than 1% of the world's ocean area and 0.3% of the world's total ocean water volume, and yet it is home to over 11% of marine species. This constitutes a high biodiversity density in terms of water volume and ocean area. NOAA's (2010) literature provides comparative data about oceans and seas including their geometric properties (**Table 1**).

This eco-diversity includes endemic species knowing that the Mediterranean's moderate temperature and salinity provide a favorable breeding medium for many endangered species. Online literature and blogs tweets provide ample documentation and pictures of marine animals entangled in plastics, or thwarted from motion, or starved from plastics filling their stomachs mistaken for nutrients. All such popularized evidence is conclusive about the harmful and deadly effects of microplastics on marine life. There is evidence that living organisms across the Lebanese coast are threatened directly by marine litter which made the Mediterranean Sea a global priority for conservation [11].

In recent years, the issue of plastic pollution escalated and became visible to most international organizations whereby this enclosed sea, which used to top the list of tourism attraction and maritime activity, was called in 2018 the Mediterranean Plastic Trap (**Figure 1**). Weak or no policies, dense human activity, and polluted rivers all contribute to the problem. A glaring issue pertains to rivers carrying debris of all sorts, including plastics, from land to sea. The Nile for example takes place in the top 10 polluting rivers according to various studies in literature. As will be seen in later sections, the counterclockwise prevailing current around the Mediterranean rim carries waste from coast to coast exhibiting a highly mobile pollution. The problem is a shared problem and therefore requires a shared solution.

Table 1: Volumes of the World's Oceans from ETOPO1

	Area+ (km²)	% Ocean Area	Volume (km³)	% Ocean Volume	Avg. Depth (m)	Max Depth (m)
Arctic Ocean	15,558,000	4.3	18,750,000	1.4	1205	5567
Atlantic Ocean	85,133,000	23.5	310,410,900	23.3	3646	8486
Baltic Sea	*406,000*	*0.1*	*20,900*	*0.0*	*51*	*392*
Mediterranean	*2,967,000*	*0.8*	*4,390,000*	*0.3*	*1480*	*5139*
North Atlantic	*41,490,000*	*11.5*	*146,000,000*	*10.9*	*3519*	*8486*
South Atlantic	*40,270,000*	*11.1*	*160,000,000*	*12.0*	*3973*	*8240*
Indian Ocean	70,560,000	19.5	264,000,000	19.8	3741	7906
Pacific Ocean	161,760,000	44.7	660,000,000	49.4	4080	10,803
North Pacific	*77,010,000*	*21.3*	*331,000,000*	*24.8*	*4298*	*10,803**
South Pacific	*84,750,000*	*23.4*	*329,000,000*	*24.6*	*3882*	*10,753*
South China Sea	6,963,000	1.9	9,880,000	0.7	1419	7352
Southern Ocean*	21,960,000	6.1	71,800,000	5.4	3270	7075
Total:	361,900,000◊	100.0	1,335,000,000	100.0	3688	10,803
Error Estimates:	0.1%		1%			

+ Boundaries between oceans vary depending upon agency, making comparisons with other published estimates difficult.
◊ Total surface area of Earth is 510,072,000 sq. km. The oceans cover ~70.9%.
* Southern Ocean area and volume calculated from ETOPO1 Bedrock version (includes Weddell and Ross seas without ice cover).
* Deepest ocean depth is in the Marianas Trench, measured at 10,911 meters. Maximum depths from ETOPO1 are not expected to exactly match known measured maximum depths as ETOPO1 represents average depths over ~4 sq. km areas.

Eakins, B.W. and G.F. Sharman, Volumes of the World's Oceans from ETOPO1, NOAA National Geophysical Data Center, Boulder, CO, 2010.

http://www.ngdc.noaa.gov/mgg/global/etopo1_ocean_volumes.html

Table 1.
World oceans and Mediterranean data (source: ETOPO1 and NOAA, 2018).

Figure 1.
Mediterranean map summarizing status. Source: [7].

3.2 Physical properties: waves and currents

Contrary to popular perceptions, the Mediterranean commands significant water depths up to 5000 meters, with a bottlenecked exchange of waters with the outside world through the Gibraltar Straight—a shallow orifice on seabed about 300 m below free water surface. The Mediterranean replenishes fresh water from rivers having estuaries around its basin, keeping its salinity at about 38 parts per thousand, while the Atlantic varies from 33 to 37; North Sea 34. Any form of intrusion on its natural status, pollution by spill or litter, accidental or not, may prove irreversible and catastrophic for such an enclosed basin (**Figure 2**).

The vulnerability of the Mediterranean to any polluting agent have been underlined by the author in previous publications including the quest and race for fossil fuel oil and gas extraction off the Lebanese coast. In recent years, extraction operations were launched in the region while Lebanon is considering the prospects of becoming an oil and natural gas producer in its waters. However, environmental

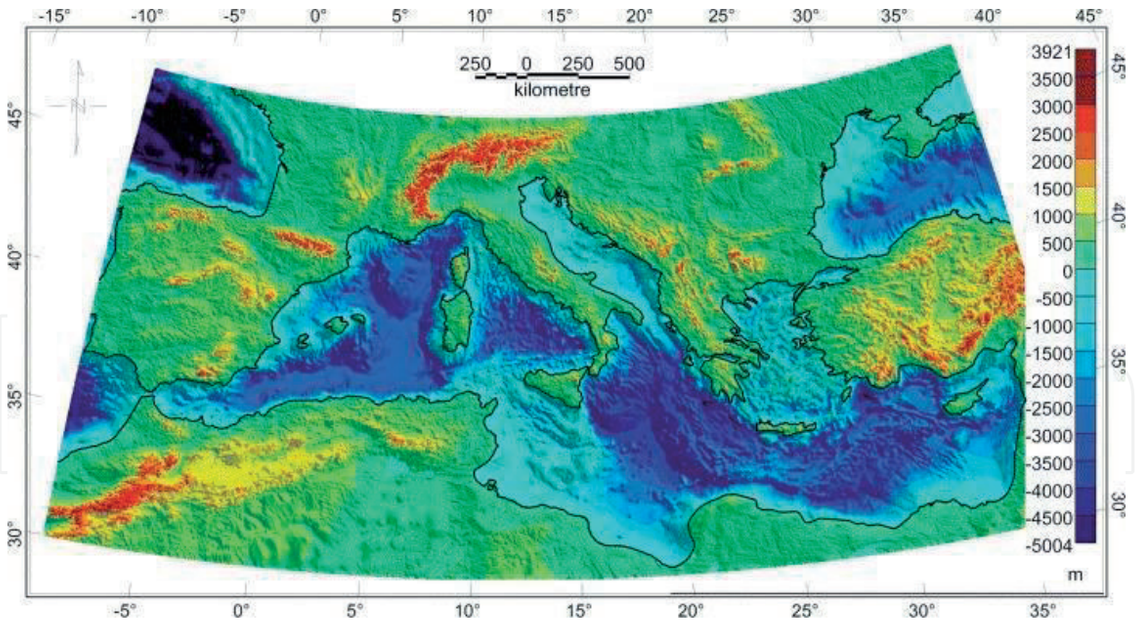

Figure 2.
The Mediterranean—water depth distribution.

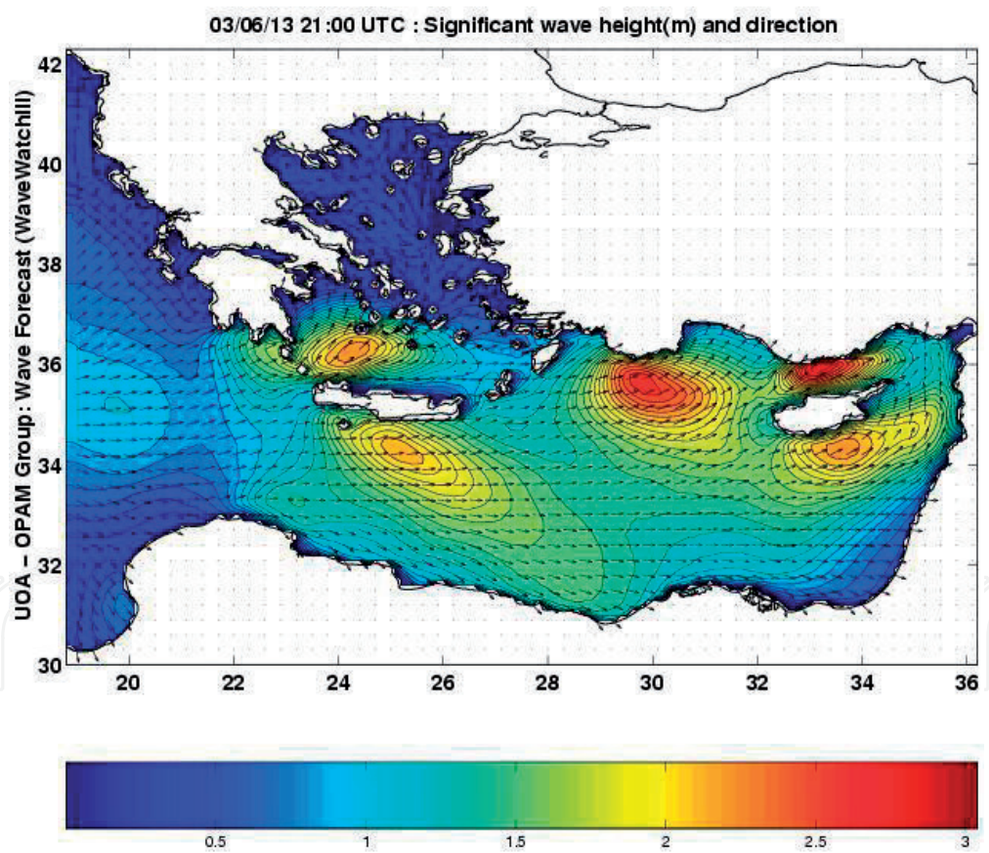

Figure 3.
The Mediterranean. Wave height, distribution, and surface current direction.

concerns are directly related to operational leaks, accidental spills, or deliberate damage to storage facilities due to potential conflicts. If such environmental concerns are properly accounted for in the social cost-benefit appraisal, a regional agreement would turn towards clean renewable energy and away from offshore fossil fuel production.

Hydrodynamic data about the Mediterranean is shown in **Figure 3**. A differentiation is in scope between the Mediterranean and open oceans in terms of

mixing and suspended matter transport processes. Water current velocity in the Mediterranean averages 0.6 m/s while it exceeds 2.5 m/s in open oceans. Knowing that the energy generated by wave motion is proportional to the square or cubic power of the water particle velocity, depending on flow regime, ocean waves can generate 17–72 times the energy generated in a closed basin like the Mediterranean. Therefore, the absorptive and abrasive capacity of the Mediterranean in decomposing or breaking down waste is much lower than the one of open oceans [12].

The fact that the Mediterranean is surrounded with sovereign countries offers opportunities of cooperation among those nations to establish a program against plastic littering. According to the United Nations Convention of the Laws of the Seas, "… States of this area have a general obligation to cooperate when facing a disagreement…" (UNCLOS, Part IX, Art. 123). A preventive approach is recommended in the long term, but a swift remedial clean-up program is necessary through the establishment of a Mediterranean cooperative for that purpose [12].

4. Case of the Lebanese coast

4.1 Plastic is the predominant pollutant on Lebanon's shores

On Lebanese shores, in nearby seafloor and sea surface, plastic constitutes the litter component of highest proportion, making over 90% of total solid waste. This environmental problem has public health and economic consequences that need to be addressed with urgency.

During the July 2006 regional conflict, Lebanon suffered oil spills due to damage to its crude oil reservoirs in its southern territory. Such toxic matter travels on microplastics and exacerbates the danger of disrupting natural marine habitat. Local experience during municipal solid waste (MSW) crises shows that plastics may not constitute the largest proportion of MSW, but once it reaches the sea, it become by far the predominant component. This is due to the fact that organic MSW components disintegrate while plastics remain. UNEP/MAP (2015) studies on the Mediterranean showed that plastics make-up over 85% of floating litter, of which 45–95% lay on seafloor [1]. Categories of plastic litter in the Mediterranean were also identified and it was found that the largest percentage pertains to packaging plastic including bottles and drink containers, food boxes, bags, in addition to single-use disposable items including cotton sticks, lighters, and plastics dining utensils.

4.2 Lack of public policies related to plastic pollution: public awareness and fatigue

There have been some early efforts in establishing anti-plastic pollution policies in Lebanon, starting with policy proposals for solid waste in general [13]. Despite the passing of some laws, violations in implementation are originating from within local governments (municipalities) that undermine efforts expended by NGOs and environmental activists [14]. This problem is linked to Lebanon's solid waste crisis which has been recurring over the last decades [15]. The landfill at Costa Brava in Beirut, Lebanon, attests to a complex combination of blurred policies, self-interest, marginalization of public rights, and violation of fundamental concepts of public goods [16]. Following the 2015 solid waste crisis and the shutdown of the Naameh landfill in May of that year, Costa Brava was opened in 2016 as a temporary fix or alternative. Public opinion followed immediately protesting against this project. Activists established a physical presence on location and assisted local communities to petition to the UNEP. The project estimated at USD 60 million went against

any rational environmental assessment, or lack thereof, and violated the Barcelona Convention [17].

The issue of plastic littering in Lebanon goes beyond a traditional awareness building campaign because the local population is already well-informed about plastics litter and its negative consequences. There is an overall lethargy in Lebanon about several environmental problems and lassitude among the Lebanese regarding their livelihood, health, and safety as a result of public sector mismanagement over several decades [18]. Problems of immediate concerns—economic slump, badly defined projects with mega budgets such as misplaced water dams, among other societal problems—all compete on the "attention span" of the Lebanese citizen [12, 19, 20]. We highlight these facts for two reasons. First, an advocacy campaign on plastics amidst an economic slump is challenging. Convincing a plastics producer to fundamentally change its product line requires engagement at a corporate strategy level. Second, awareness campaigns in local communities are also challenging as they require a message crafted well beyond the unaesthetic scene of a plastic-saturated shore (**Figure 4**). There is a need for product innovation or process development to combat plastic litter. Reluctance within the private sector to invest in innovative techniques and actionable solutions, and a fatigued local public that has gone through tough cycles of social unrest, have contributed to getting Lebanon in an unfavorable situation in relation to plastic littering among other problems [21].

4.3 Need for evidence-based advocacy and multidisciplinary collaboration

To combat plastic littering in Lebanon, both awareness-building and advocacy are recommended in parallel. The first may be performed with the general public, educational institutions, municipalities, and other entities. The second can be implemented with the private sector, including the major local plastic manufacturers. Cases from other countries provide evidence about the role of manufacturers [22]. Organizations such as The Lonely Whale has been encouraging companies to form teams and collaborate to scale down plastics volume across the entire supply chain; from raw material orders, to processing, manufacturing, and distribution. Member companies include so far some global manufacturing giants such as General

Figure 4.
Zouk Mosbeh beach cleanup, January 23, 2018, as garbage washed ashore in a storm. Source: J. Eid/AFP/Getty images, adopted by [21].

Motors, Hewlett Packard, Dell, Bureo, and Herman Miller. Similar possibilities could be explored for advocacy in Lebanon.

Plastic pollution gives rise to multi-faceted problems that require multidisciplinary collaboration. A deep understanding of the severity of the situation related to solid waste in general, and plastics in particular, requires a diligent approach that establishes a clear link between plastic pollution on one hand, and engineering, public policy, health, economic, and technical implication and potential solutions on the other hand. Advancing towards solutions must include prevention and remediation measures that should be planned for and implemented in tandem. Technical solutions must be backed by public policy design. Academic institutions, industries, and public sector entities are expected to work hand-in-hand to achieve tangible outcomes.

Recent studies showed that microplastics are eaten by fish, which are consumed by humans, causing unsafe food. This serious impact on marine life and infiltration in seafood has direct implications on public health. Numerous diseases have been reported to be on the rise in Lebanon. Various research projects at a global level established that plastics contain chemical and hazardous substances that cause a wide range of health problems including eye irritation, liver dysfunction, and cancer [23, 24]. Microplastics follow us to our kitchens and dining rooms as they were found in our food including table salt.

5. Plastics from land to sea Mediterranean subbasins and currents

Past studies of the Mediterranean subbasins showed a complex system of eddies, gyres, straights, and channels within a relatively small enclosed sea. Plastics were found in the deepest spots of oceans and are floating in the shape of islands as well, posing quantification challenges. Understanding Mediterranean bathymetry and dynamics is essential to capture how plastics are traveling from source to destination. Some of the early maps provide a simplified model of the subbasins and currents. An overall counterclockwise motion persists in the Mediterranean [25]. This motion is characterized by a south–north movement along the Lebanese coast. The 11 subbasins within the Mediterranean; numbered 1, 2a, 2b, 2c, 3 through 9, are shown in **Figure 5**.

A better understanding of traveling plastic trash can be developed from key concepts in fluid mechanics applied to subbasins. For instance, eddies transport debris in a circular or semi-circular motion and can be categorized into small eddies ranging up to 50 km; medium eddies from 50 to 150 km; large eddies between 150 and 250 km. The Mediterranean has the Gibraltar and Messina traits, the Otranto, Sardinia, and Sicily channels. Gyres in the Mediterranean run clockwise primarily due to the orientation of the Strait of Gibraltar, but they are elsewhere counterclockwise due to Coriolis effects.

Advances in satellite imaging technology offer a more sophisticated means to track sea water motion and facilitate the detection of existing and potential gyres of plastic waste islands. These technological advances further confirm the need for a concerted regional effort whereby several countries plan, operate, and cooperate on fighting plastic pollution in the Mediterranean. There is no evidence that the Mediterranean carries a permanent trash island but litter accumulation areas have been reported. Historical data collected in the Mediterranean Sea was used to compute the probability of debris particles to reach subbasins, in an attempt to identify possible retention areas. If retention areas are identified, the prediction of the potential location of floating trash islands becomes more manageable.

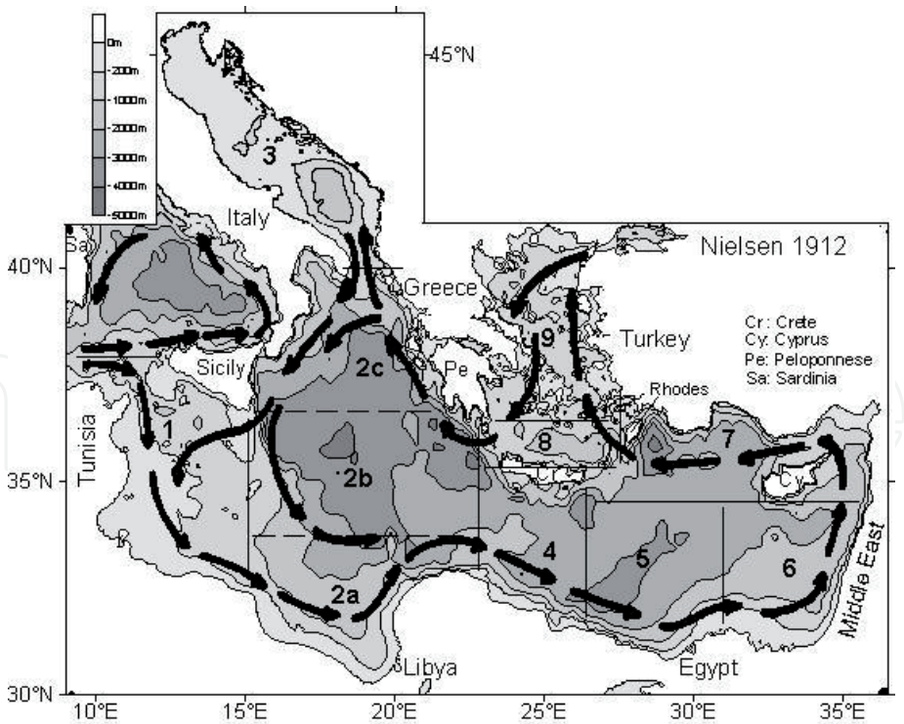

Figure 5.
Mediterranean subbasins 1: Channel of Sicily, 2a: Southern Ionian, 2b: Central Ionian, 2c: Northern Ionian; 3: Adriatic; 4: Southern Cretan; 5: Western Levantine (deeper than 3000 m: The Herodotus trough); 6: Southeastern Levantine; 7: Northern Levantine; 8: Northern Cretan; 9: Aegean. Source: ifremer.fr, February 25, 2019.

The evolution of litter based on climatological reconstructions shows a tendency of floating litter to collect in the southern portion with a long-term accumulation in the Southeastern Levantine Basin. Data analyzed by Zambianchi et al., show that drifters start from a dispersed status and end along coasts on the East Mediterranean including Lebanon as well as some North African countries for both summer and winter seasons [26].

6. Mathematical model, empirical analysis, and results

We formulated and performed a linear regression to gauge public attitudes in Lebanon by defining a dependent variable, Y, representing the need to develop regional strategies for natural resource management. The independent variables were defined as (1) the establishment of national policies specific to marine protection against pollution, (2) use of technology as remedial solutions, (3) use of engineering innovation as preventive solutions in the private sector, and (4) local enforcement. The selection of these variables was based on preliminary focus interviews and on evidence from the collection and analysis of secondary data. The variables were designed to gauge public attitudes towards regional collaboration to team up on protecting the environment. Focus interviews showed a predisposition of the community for regional collaboration because these issues affect human health beyond ecosystem protection or territorial claims. The outreach used a 1–5 Likert scale and included 750 recipients, of which 426 responded with 281 replies that covered the above variables.

Regression results showed a statistically significant and positive correlation with the first, third, and fourth variables at 5% significance level, there was no statistical significance with the second variable. In a previous analysis, we found positive correlation between the "willingness to contribute at a local community level" and

remedial actions such as beach cleanup, but the present analysis addresses a regional strategy. Public attitudes show that it would be very important to start with local public policies that would be carried to regional cooperative summits during which a strategy for the whole Mediterranean would be drafted, refined and agreed upon.

In our previous analysis, we also found that respondents were skeptical about prospects of regional collaboration in the East Mediterranean whereby focus interviews at the time showed that 46% of interviewees expressed disappointment about the lack of regional collaboration in public policy design. Nevertheless, both analyses show agreement between the qualitative and quantitative results indicating that communities are eager to see policies established at a local level, and implemented regionally in collaboration with Mediterranean rim countries. Community inputs were positive about regional treaties but this prospect was described by many as wishful thinking as evidenced by many respondents in the process of qualitative data collection during focus interviews.

7. From remedial reactions to preventive strategies: innovation against plastic pollution

7.1 Remedial reactions are necessary but not sufficient

There is no doubt that remedies need to be implemented urgently such as beach cleanup, collection, sorting, recycling, and re-use. In almost all environmental problems, remedial actions evolve as a result of a damage that was already done, and therefore the author considers them as mere reactions. The case of plastic pollution and littering in a closed pond-like sea is no different. There is a large amount of research literature on plastic recycling with a call for the establishment of an industry cycle to put plastics in a "closed loop" from first-time manufacturing to re-processing to new products—but again, made of plastics in their present chemical formulation. In that context, a brief description of recyclability may shed light on the shortcomings of remedial reactions. In fact, not all plastics are easily recyclable, let alone requirements for energy and carbon footprint. Plastics come in different materials, and various levels of recyclability. All plastic containers carry at their bottom a triangular sign inscribing a number; a recycling code. The recycling code corresponds to the type of plastic used to manufacture the item. There are many types of plastics, but it is customary to summarize them in seven types that are known to carry these code numbers for recycling purposes.

Polyethylene terephthalate (PET or PETE)—PET is part of the polyester series and is typically used to manufacture bottles for water or soda. Sometimes they are used for clothing and for containers of traysthat can be heated in a microwave. PET is widely recycled as it lends itself to the process and is commonly reused.

Low-density polyethylene (LDPE) is a polymer used in many applications such as bags, gas pipes, water pipes, bottles, toys, and plastic wrap. It is not common to recycle LDPE using simple home-based programs. However, LDPE plastic bags and other containers can be reused and therefore are not classified as single-use items.

High-density polyethylene (HDPE) is a polymer used in many applications such as garbage bags, liquid soap and shampoo bottles, caps, lids, and common grocery bags. HDPE used for items other than bags can be recycled in most places. Bags can be reused or can be returned to grocery stores for collection and recycling.

Polyvinyl chloride (V or Vinyl or PVC) is used for a variety of applications but most commonly in construction, namely plumbing installations. Other applications include bathroom curtains, garden or service hoses, raincoats and waterproof boots. It is not common to recycle PVC collected from used or dismantled plumbing

networks. However, PVC containers and bottles can be recycled and manufactured as exterior rainwater drainage pipes or road cones and vehicle barriers.

Polypropylene (PP) is used for outdoor furniture, medicine containers, food boxes, diapers, and rope.

Polystyrene (PS) is used to make disposable picnic items, compact disk cases and cassettes. PS could be used as foam—referred to as Styrofoam—for packaging, disposable plates, egg trays, delivery or take-out boxes. PS can be recycled but it consumes more energy than other plastics and is therefore uneconomical.[1]

Other plastics are marked "O" which is a group that includes various mixes of polymers. Examples of this group include (1) polylactic acid used to manufacture containers, (2) polycarbonates, used for eye glasses, DVDs, construction greenhouse panels, (3) acrylonitrile butadiene styrene or ABS, used for games, such as Legos and puzzle pieces, and (4) nylon, used for rope, wire, clothing, components in car tires.

7.2 Need for preventive strategies

In light of these facts, and given that most respondents seem to be well-versed in terms of the pros and cons of recycling, the statistical analysis showed that public attitudes clearly support the use of engineering innovation in fighting plastic pollution. Overall, there is a belief that the private sector—whether manufacturers or traders in plastic import and export—can play a fundamental role in the process. Relevant to the regression analysis, the third independent variable in the mathematical model reflects a potential engagement by major plastics manufacturers and traders. There is an urgent need to introduce innovative products such as bio-degradable substitutes to plastics, and innovative processes such as plastic-to-fuel operations. In that spirit, advocacy with local manufacturers, importers, and exporters of plastics from raw materials to finished products would set a track for preventive strategies and an anticipation of consumer behavior. Advances in product development such as bio-degradable plastic-like materials, and in manufacturing techniques as it has been the case in the USA, Japan, and Europe, must be explored for local adaptation and application in Lebanon. Engineering innovation is expected to play a major role in preventive strategies, along with the development of policies that are specific to plastic pollution.

7.3 Preventive strategies need to be regional

While research aimed at new product development support preventive strategies, other types of research grew in parallel to manage existing plastic waste, or remedial strategies. The subject of plastic pollution does not lack public attention, but it has been tackled in piecemeal solutions and in disparate geographic areas. The Regional Activity Centre for Sustainable Consumption and Production (SCP/RAC) developed a compilation of solutions that they termed as innovative and inspiring. The project was done as part of the EU-funded SwitchMed Programme.[2]

Out of dozens of attempts and campaigns in different countries, SCP/RAC selected the top 25 solutions that were hoped to be replicated in other geographies. Each of these solutions requires consideration as part of a potential roadmap for Lebanon. The subsequent phases of this program could elaborate a subset

[1] In the United States, several cities banned foamed PS.

[2] SwitchMed coordinates between the European Union, the United Nations Industrial Development Organization (UNIDO), the UN Environment and Action Plan for the Mediterranean and its Regional Activity Centre for Sustainable Consumption and Production (SCP/RAC), and the UN Environment located near Santa Barbara, California, USA.

of these solutions and include them in an organized advocacy campaign during implementation. The proposed solutions are classified under products or processes and are identified as being private business initiatives or public sector action. For example, the EcoOcean is a new product developed through funding from the EU; the EcoOcean material. This is a trademark of EcoCortec which introduced a bio-based polymer to make bags and wrapping from polyhydroxyalkanoate (PHA). According to the company, its composition includes 77% bio-based resins with sugar cane at its base. When in contact with the marine environment or a natural terrain, EcoOcean biodegrades by anaerobic digestion. Anaerobic digestion is a technique that was introduced in the United States in the 1960s and fully implemented in California in the 1980s [27]. The intended use of this product is not to dispose of it in the ocean. However, in case it reaches the ocean, full-scale experiments conducted by the company showed that it biodegrades within a few weeks or a few months, depending on water particle dynamics. This is a critical improvement over classical plastics that remain for hundreds of years. The experiments targeted microbial action breaking the bag down to microcosms. Testing included detailed studies through microscopic examination and molecular investigation to identify microbial communities and compare them with the effects of classical plastics. It was found that some of the sea animals were feeding on this biodegradable material. As for practical use, the material was tested against moisture, heat, and tensile stress and was found usable for daily choirs. However, it is the opinion of the author of the present roadmap report that such material requires a long-term follow-up to ascertain the nature of microbial communities that would develop. Countries like Lebanon that are not as endowed in research funding and facilities as the originating countries, could be an end-user that would adopt such techniques once fully proven against any potential side-effects.

Each proposed solution, when considered on its own, seems to contribute to combating litter in the Mediterranean. Those solutions could be considered for other locations as well. However, they fall short of having a coordinated program across countries for a mobile pollutant that travels in the waters similarly to air pollutants that have a negative externality. Given the facts at hand, there is a case for coordinated public policies backed by local advocacy campaigns.

8. Movements towards policy against plastics

We turn to a few examples in the State of California, which is considered as one of the most innovative states in pro-actively developing policies against plastic pollution. The approach is done in a combination of awareness-building, advocacy, legislation, and enforcement. Consider the sign in **Figure 6** posted by the US Forest Service in Los Padres National Forest that explain in a very few words how harsh it is to litter plastic bottles into the environment. This forest is renowned for its pristine status and ecosystem (**Figure 7**).

Additionally, the State of California currently charges the highest littering fines. Such fines are used to deter the resident or the visitor from littering (**Figure 8**).

There are many geographic similarities between California and several Mediterranean countries including Lebanon, Cyprus, Turkey, Greece, and Croatia to name a few. The old saying that in Lebanon you can drive to ski then drive back to the beach on the same day is applicable as you can go east, enjoy cooler weather and mountains covered with snow then drive back west to the shore. Lebanon and California are both active in terms of sports, outdoors, healthy cuisine, eating habits, and enjoying the beach by both locals and visitors. California residents boast about the nice weather all year round where the lifestyle is loaded with hiking,

Figure 6.
Sign posted by the US Forest Service in los padres National Forest.

Figure 7.
Los Padres National Forest.

Figure 8.
State of California posts the highest fines in the USA for littering.

picnics, beach volleyball, wind surfing, and beach camping. Both Lebanon and California have the same latitude or distance north of the equator.

In November 2016, California voters passed Proposition 67. *The proposition requested a ban on single-use plastic bags*. Thousands of volunteers who provided

community service by collecting plastic trash during California's coastal cleanup day reported back that they saw a substantial decrease in plastic bag refuse. Further data collected in California showed that plastic bag litter dropped by 72% between 2010 and 2017. By November 2017, plastic bags made less than 1.5% of all litter, down from 10% in 2010. In 2017, volunteers found in Monterey County only 43 plastic bags (in number) during the clean-up campaign, compared with almost 2500 bags in 2010. In a 2010 ranking about most frequently littered items, plastic bags ranked third after cigarette butts and fast food packaging. By late 2017, they fell out of the top 10 most littered items (Phillips, 2017). The importance of natural resource management cannot be more emphasized and this is exemplified by having a dedicated position as a State Secretary for Natural Resources.

> *"For decades, plastic bags were one of the most common items collected during the annual California coastal cleanup, ... This year, as California continues to transition to reusable bags, we are seeing a substantial decline in plastic grocery bag litter on beaches, rivers and parkways." John Laird, California Secretary for Natural Resources*

Another example is worth mentioning at the local [city] government level—also termed "municipal level" in most countries. Over 100 cities across the State of California passed their own bag bans before the statewide policy was enacted. As decentralization is discussed in Lebanon, local governments, or municipalities, can take the initiative in establishing a local city code against plastic disposal, sorting, and even management at the source.

> *"When I took on the problem of plastic bag pollution four years ago, California retailers were distributing more than 19 billion single-use plastic bags every year," "Today, that number is zero. Once again California is leading the way, creating cleaner communities for all."*
>
> *Alex Padilla, California Secretary of State -.*

The policy evolved in certain cities such as San Francisco to combine curbside collection and recycling booths along with plastic bag bans. This policy combines remediation with prevention.

Since the passing of anti-littering legislation in California, 40 other countries have taken action through taxing single use plastic bags, or by banning them fully or partially. In 2016, the European Union announced that by end of 2019, the consumption of plastic bags in member states would not exceed 90 bags per person per year. France implemented a full ban on lightweight plastic bags at checkout counters. Research by the Earth Policy Institute showed that one trillion single-use plastic bags are used each year, and most of them ultimately make it to the ocean through waterways. Overall, over 8 million tons of plastic per year are thrown into oceans (Earth Policy Institute, 2018). However, such policies must be studied for a potential downside as well. Upon further consideration, for a cotton bag to have a more favorable environmental footprint than a plastic bag, it needs to be reused 130 times (KQED). Nevertheless, most Mediterranean countries are in need for local and regional policies as part of a marine anti-pollution grand strategy.

9. Conclusions

Plastic pollution in the marine environment grew into a global and regional concern threatening ecosystems and human health. Private sector entities

including manufacturers and traders are expected to play an essential role in the design process of public policies and actively partake in their implementation. The Mediterranean is particularly vulnerable to plastic pollution due to its enclosed geometry, its disproportionate depth in comparison with its shallow strait, and its population density around its rim. Our linear regression analysis on public attitudes in Lebanon shows that the readiness of local communities to actively fight plastic pollution is positively and significantly correlated with an appeal to establish national public policies specific to plastic littering, and a request for advocacy with the private sector. There were concerns about sorting MSW at the household level given that contractors remix and dump them in open land. Respondents support regional collaborative treaties to protect the environment, but there is a perception that chances of success for such prospects are dim. Regional policies need to be explored further with the possibilities to form joint teams of experts, and develop innovative techniques across borders.

Radical change cannot happen without engineering innovation and advocacy with the private sector. Transitioning into a plastic-free end-use requires plastics manufacturers and traders to adopt novel techniques. There is an urgent need to introduce innovative products and processes such as plastic-to-fuel operations, as part of long-term preventive strategies. Future research is recommended to further develop public policies, both locally and regionally to handle this shared problem and its negative externalities.

Author details

Michel Soto Chalhoub
Department of Civil and Environmental Engineering, Notre Dame University, Zouk Mosbeh, Lebanon

*Address all correspondence to: mchalhoub@live.com

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