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Authors: Williams, A.T., and Rangel-Buitrago, Nelson

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REVIEW ARTICLES

Marine Litter: Solutions for a Major Environmental Problem

A.T. Williams† and Nelson Rangel-Buitrago‡*

†Faculty of Architecture, Computing, and Engineering
University of Wales Trinity Saint David, Swansea
Swansea, Wales, U.K.

‡Departamentos de Física-Biologia
Facultad de Ciencias Básicas
Universidad del Atlántico
Barranquilla, Atlántico, Colombia

ABSTRACT

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A current major environmental problem is that marine litter is being deposited in increasing amounts on the world's beaches and oceans. This is especially true for plastics, which form the bulk of the litter and which can last for an unknown number of years in the oceans. This article concerns itself with some solutions that can be applied to this problem. The standard responses involve cutting down plastic waste at the source, beach cleanups, use of the circular economy, education, and a reduction in packaging, among other solutions. Knowledge, prevention, mitigation, removal, and behavioural change are the key mandates involving a host of measures, ranging from politics, behaviour change, and radiation of plastic by gamma rays in order to strengthen concrete, to turning plastics into fashion items, furniture, bedding, and clothes, amongst many others. Collaboration is the key.

ADDITIONAL INDEX WORDS: *Marine litter, prevention, mitigation, behaviour change*.

INTRODUCTION

Marine litter can be defined as all persistent, manufactured, or processed solid material disposed of or abandoned over coastal and marine environments (Bergmann *et al.,* 2015; Coe and Rogers, 1996; Tudor and Williams, 2018). Marine litter is an issue that affects coastal areas and sea-floors worldwide. Its impact is of global significance, and the threats posed by marine litter to humans and the environment have been recognized for around 58 years (Ryan, 2015). However, despite its importance, it has only gained real recognition during the past few years.

It can have land-based (*e.g.*, direct from rivers and beaches, which is where the bulk comes from) as well as sea-based sources (*e.g.*, waste disposal from shipping, oil rigs). Depending on composition, size, buoyancy, ocean characteristics, and other factors, marine litter can drift, sink, and accumulate at different ocean depths. Its distribution ranges from the remotest world beaches (Lavers and Bond, 2017), floating in the middle of the ocean (Thompson *et al.,* 2004), the deep sea bed (Woodall *et al.,* 2015), and inside marine animals (Gregory, 2009) to frozen within polar ice (Bergmann and Gutow, 2015).

Currently, marine litter generation, especially the plastic issue, is a problem that has grown out of hand. Its costs to society and marine environments are immeasurable and irreversible. Its impact encompasses local, regional, national, and global scales and includes adverse effects on human health (Campbell, Slavin, and Grage 2016), aesthetics (Rangel-Buitrago *et al.,* 2017; Rangel-Buitrago, 2018; Williams *et al.,* 2016b), the economy (Gilbert, 1996), public perception (Corraini *et al.,* 2018; Williams *et al.,* 2016a), and biologic interactions (Gracia, Rangel-Buitrago, and Florez, 2018; Rech, Borrell, and Garcia-Vazquez, 2016).

Transport and accumulation regimes of marine litter are related to oceanic and climatic conditions (Carson *et al.,* 2013), as well as, amongst others, geomorphological characteristics, such as slope, beach morpho-dynamic state, and level of sheltering (Araujo and Costa, 2007). Similarly, its magnitude and composition are related to land use, socioeconomic activities, and littering behaviour (Carson *et al.,* 2013; Lechner *et al.,* 2014; Willis *et al.,* 2017).

Within marine litter, plastics typically constitute the dominant pollutant item and sometimes can account for up to 100% of marine litter pollution in a specific area (Galgani, Hanke, and Maes, 2015; Williams and Simmons, 1997; Worm *et al*., 2017). Processed wood and rubber are also common marine litter types that usually are transported by rivers before deposition in coastal environments (Rangel-Buitrago *et al.,* 2017; Viehman *et al.,* 2011; Williams and Simmons, 1997). Some nonbuoyant or nonpersistent litter items, such as glass, metal, and organic litter, are frequently attributed to non-riverine sources, *e.g.*, direct litter dumping (Bravo *et al.,* 2009; Rangel-Buitrago *et al.,* 2018; Williams *et al.,* 2016a,b). The use of plastics is so predominant that they have become a significant part (and are erroneously considered essential) in

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*Corresponding author: nelsonrangel@mail.uniatlantico.edu.co

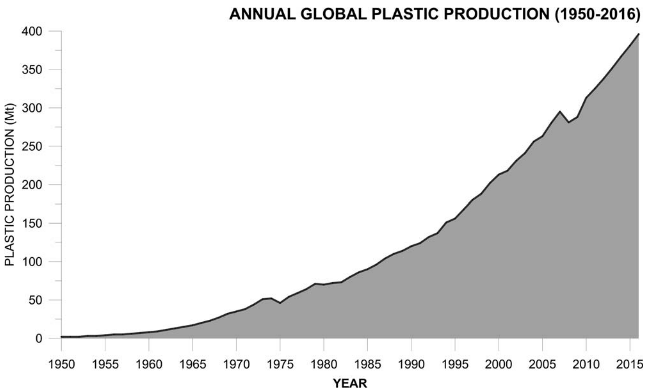

Figure 1. Annual global production between 1950 and 2016 (Data Source: Geyer, Jambeck, and Lavender, 2017).

the world consumer marketplace. Its invention (a mixture of formaldehyde and phenol) in 1907 by Leo Baekeland produced the first purely synthetic material—Bakelite. Its growth accelerated in the 1930s. Today plastic consumption is so high that production has ramped up from 2 million metric tons in 1950 to 381 million metric tons in 2015 (Figure 1; Geyer, Jambeck, and Lavender, 2017; Jambeck *et al.,* 2015).

Geyer, Jambeck, and Lavender (2017) estimated that some 8300 million metric tons (Mt) of virgin plastics were produced in 2015, with approximately 6300 Mt of plastic waste generated. Of this amount, around 9% has been recycled, 12% incinerated, and 79% accumulated in landfills or the natural environment. If these trends continue, roughly 12,000 Mt of plastic waste will be in landfills or in the natural environment by 2050. Just in 2016, global plastic's production reached record values of 396 Mt, which meant it grew by 4.04% compared with 2015, with Asia and Europe being the production leaders, with 167.5 Mt (50%) and 63 Mt (19%) produced, respectively. Plastic packaging and single-use items enter the waste stream immediately after use, contributing to a cumulative total of 6.3 billion Mt of plastic waste generated worldwide. Management of this large increase and quantity of plastic waste has been challenging, particularly in areas of rapid economic development and population growth (Geyer, Jambeck, and Lavender, 2017).

The impacts of plastics are related to their excessive abundance in all natural environments, their high persistence (because complete mineralization takes place after hundreds or perhaps thousands of years), the formation of toxic substances, and their ability to act as a vector for contaminants, including persistent organic pollutants (POPs) and heavy metals. They have displaced other materials, such as glass, and are used as an essential component in an uncountable variety of products that humanity uses daily, *e.g*., into polyesters for use in fabrics and textiles, polyvinylidene chloride for food packaging, and polycarbonates for eyeglasses and compact discs.

All of the above makes clear that marine litter management is an urgent necessity. This approach must be dynamic, multidisciplinary, and interactive as a strong response to avoid, prevent, or mitigate environmental, economic, and social losses derived from poor marine litter management practices. This management requires detailed knowledge of magnitudes and sources of marine litter as well as its interchange within the marine environment (offshore, shore, and inland). The cycle of management begins with magnitude quantification and source identification. This basis then guides planning, preparation, and decision making regarding the appropriate response, considering the time frame of expected results, including monitoring whether or not the solution is working.

Marine litter management is one aspect of overall ocean and coastal management and usually follows the objective of informed involvement and cooperation of all stakeholders to assess the societal goals in a given area and to take actions to meet specific objectives. It should be based on strategies to eliminate or at least reduce the source input. If marine litter can be adequately reduced, reused, and recycled, the chance of it entering into the marine environment can be substantially abated. The current environmental climate has made plastic litter a major environmental issue with the general public. Society must capitalise on the momentum generated.

Table 1. *The complexity of the situation.*

The Complexity of the Situation
1. Plastic use is deeply ingrained in our daily lives.
2. Society has moved to a disposable model.
3. We have increasingly on-the-go lifestyles.
4. Recycling many types of plastic waste is often difficult.
5. What are the social barriers to limiting plastic consumption and creating new social norms, *i.e*. stopping pollution at source?
6. What can we do about the pollutants already there?
7. Starbucks: September 1998, first shop in the U.K. It now has 884 shops.
8. Costa: in 1995 had 41 shops and it now has 2121 across the U.K.
9. Pret a Manger: in 1992, had three shops and in 1997, 53 shops. Now they have 500 and sell 1.4 million coffees per day.
10. In 1998, Starbucks offered a reusable cup discount of 10p, upping it to 25p in 2008, doubling it to 50p in 2016, reducing it to 25p in 2017.

SOME SOLUTIONS TO CURBING THE INEXORABLE RISE IN MARINE LITTER

Curbing marine litter is a complicated but not impossible task, and searching for solutions has become an issue of widespread worldwide concern (Table 1). Having ideas is easy, but turning them into reality is hard, and turning them so that they are deployed at scale is even harder. It even takes longer when one considers Hofstadter's Law, a general rule applicable to all complex tasks, which states that any process always takes longer than one expects, even when taking into account Hofstadter's Law (Hofstadter, 1999).

Solutions to be implemented include all available processes, techniques, knowledge, and instruments designed to eliminate or at least reduce marine litter related impacts. In the same way, solutions must have an optimal benefit to lowering environmental vulnerability due to related hazards.

Considering current and future population scenarios, all solutions must allow society to avoid or minimize adverse impacts, while at the same time obtaining some extra benefits from any potential positive consequences. *Homo sapiens* has lived for half a century in a throwaway society, but no away exists. Things have to change (Marine Solutions, 2018), and

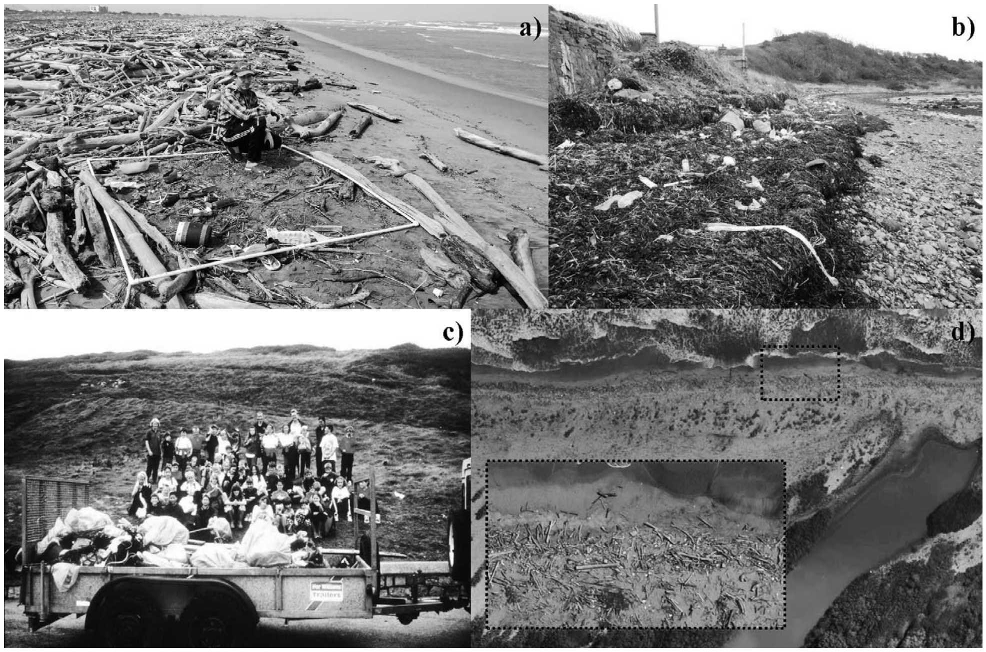

Figure 2. Methodologies used to classify marine litter. (a) Transect line quadrats, randomly dispersed, (b) strand line counts, (c) number of plastic bin bags/trucks, and (d) aerial surveys using drones.

although many solutions exist, there is no one-size-fits-all. The typology of marine litter solutions can be divided into five general categories.

KNOWLEDGE

Adequate management begins with satisfactory characterization of magnitudes, extension, sources, and impacts of marine litter (detailed knowledge of the problem). Once the typology and dynamics of marine litter are known, stakeholders may correctly intervene in the management practices to be developed, for example, developing intensive cleanup campaigns and establishing and reinforcing existing environmental education plans in a specific area. The measures to be applied may be summarized *via* two specific solutions.

An Appropriate Universal Methodology to Classify Marine Litter

Many different methods are used to assess beach litter, and no universal methodology exists (Figure 2; Earll *et al.,* 2000). It is an axiom that the use of many methods can lead to confusion and inaction about a specific problem. Several international guidelines exist (Cheshire *et al*., 2009), *e.g*., The Ocean Conservancy (OC, 2016a,b) and OSPAR (2007 and 2009), but cross checking is difficult. Some methodological examples are as follows:

(1) Beach surveys from water's edge to splash zone: This is logistically very hard, especially if there is a large tidal range, but it is one advocated by Dubsky (1995).
(2) Varying width transects to find the optimum: In the 1990s a transect width of 5 m was the norm for this research. However this could cover only 20–30% of the litter found on a beach (Tudor and Williams, 2001). Work carried out by the U.K. National Aquatic Litter Group (EA/NALG, 2000; Williams, Randerson, and Alharbi, 2014) showed that a transect width of 100 m covered >90% of any beach litter present.
(3) Transect line quadrats, randomly dispersed (Dixon and Hawksley, 1980): This methodology originates from the ecology world. With this method, litter items along a transect are recorded along 1 m randomly selected spots. This method has fallen out of fashion (Figure 2a).
(4) Offshore and riverine water columns (Simmons, Fricker, and Williams, 1993).
(5) Strand line counts: This method involves recording litter items along a strand line; it has been a useful indicator of litter, and it can also indicate sources (Figure 2b; Williams *et al.,* 2017).
(6) Number of plastic bin bags/trucks, *etc*.: This method is favoured in many local environmental beach cleanups (Figure 2c).
(7) OSPAR (2009) and Ocean Conservancy (2016): These organisations record each litter item found on an area of beach, and can attribute sources by using sophisticated statistical techniques (Tudor *et al.,* 2002).
(8) Aerial surveys using drones (Figure 2d; Moy *et al.,* 2017).

Research

In his famous novel *Twenty Thousand Leagues under the Sea*, Jules Verne (1870), described the first marine litter descriptions along the North Atlantic Ocean convergence zone. Since then, a great deal of water has flowed under the bridge, and a plethora of research has attempted to address the marine litter topic. Recent literature, *e.g.*, Galgany, Hanke, and Maes (2015) and Ryan (2015), stimulated from the first science reports in the 1970s, has underlined the scientific community's focus on four specific issues:

(1) Evaluation of sources and inputs (*e.g.*, Tudor *et al.*, 2002).
(2) Transport and distribution at sea (*e.g.*, Barnes and Milner, 2005).
(3) Plastics within the food web (*e.g.*, Duis and Coors, 2016).
(4) Rafting processes (*e.g.*, Gregory, 2009).

A focus on plastic chemistry, design, sourcing, and methods is sorely needed. The discipline of waste management needs a thorough overhaul. A whole range of questions can be asked, but answers are sparse. However, with the right political will, this can drive the process of cutting waste.

PREVENTION

Preventive solutions focus on avoiding generation of marine litter or preventing litter from entering the marine environment. Measures of this type include the reduction of plastic input focusing on nano-plastics and improvements in product design.

Attacking the Main Source: Reduce Plastic Input and Change to Degradable Plastics

Trillions of plastic particles are floating on the surface of the global oceans, and it is expected that the total amount of plastic waste entering the ocean will increase by an order of magnitude by 2025 (Rochman, 2015). One strategy to stop this is focusing on source reduction (Sherman and van Sebille, 2016). This can be achieved in many ways, including (1) improving waste management performance, infrastructure, and ability to stop large items of plastic waste from entering the oceans (Jambeck *et al.,* 2015); (2) preventing microfibres from clothing and small plastic fragments and beads from entering wastewater by putting filters on washing machines (Browne, 2015); and (3) removing plastic microbeads from personal care products (Rochman *et al.,* 2014).

Similarly, the use of degradable/compostable plastics must be encouraged. Degradable plastics use alternate materials or specialized enzymatic or chemical reactions to break down the material quickly once exposed to the elements. The above is important because once plastic entry to the marine environment occurs, it takes an extremely long time for it to break down, posing a danger to the environment. The use of degradable plastics offers many advantages, such as

(1) Reducing waste
(2) Reducing source material
(3) Saving energy
(4) Allowing use of plastic-eating bacteria

Examples of this are bottles made from polylactic acid (PLA). Manufacture of these bottles produces some 60% fewer greenhouse gases, and since corn, sugar beets, *etc*., are the raw materials, the result is fully biodegradable and compostable. However, there is still an issue of degradation times that must be solved, as well as research on whether the presence of PLA in the recycling scheme has a negative effect on the physical properties of extruded recycled polyethylene terephthalate (Asfa-Wossen, 2010).

Small Size, Big Problem: The Nano- Micro-Plastics Issue

Nano- and micro-plastics have recently become a hot research issue. Since enormous quantities of plastics break into smaller and smaller particles, it becomes hazardous in ways that are still unknown to humans and wildlife (Galloway, 2015). These sizes of plastics attract and bind toxic chemicals from the water and can travel through cell membranes. Several studies (Duis and Coors, 2016) revealed that current methodologies used to extract, quantify, and characterize nano- and micro-plastics would require adjustments to enable equivalent information. Similarly, standardization of the units of measurement concerning weight, number, and volume should be prioritized to allow comparison of results from different experiments (Ng *et al.,* 2018).

Source prevention is the ultimate aim, but to date, the tide of microparticles (<5 mm in diameter) flowing into the oceans continues, especially from sewage treatment plants, since the micro-plastics are too small to be filtered out. Estimates state that between 4594 and 94,000 microbeads are released with each use of a cosmetic product and 1600 plastic microfibres with every wash of a synthetic fibre garment (Daniels, 2016). They are nonbiodegradable and will absorb chemicals, pesticides, and other toxins.

To tackle pellet loss, best practices must be exercised throughout the plastic value chain and within the supply chain. International programmes such as the Wilson Center (2018) or Operation Clean Sweep (2018; Wiplinger, 2018) aim to help every plastic resin handling operation to reduce plastic pellet loss to the environment. In the U.K. it is led by the British Plastics Federation, and standards must be kept high. For example, cosmetic firms, such as L'Oreal, have banned microbeads from their products; the U.K., France, and Sweden will ban micro-plastics in face creams in 2018, Belgium 2019. Hopefully, others will follow.

Product Design

Along with design and production of a product, there must be an environmentally sustainable viewpoint focused on the creation of value for customers and consumers. This gives rise to a tremendous potential for companies to create new business opportunities, where sustainable development and value creation are integrated early into the design of new products and services. Environmental impacts can happen along all stages of a product's lifetime. However, the nature of environmental impacts derived from a product can be minimized and even avoided during the early design phase of product development: The design stage has a vital influence on the product's life cycle and also on subsequent occurring environmental impacts (Figure 3). It is this stage where materials, technologies, and product lifetimes are defined. It is essential that product developers incorporate environmental considerations carefully and systematically into the development project.

The above makes clear the necessity of adopting a so-called life cycle approach to development from the same conception of the product. The question here is a real challenge: 'How can one adopt a radically different approach to product design and manufacture to achieve real environmental improvements?' During product design the following six steps can be useful as a solution-oriented process towards environmental improvements (McAloone and Bey, 2009).

(1) Use context: How is the product used? By whom? For how long? The central issue here is to uncover the environmental impacts related to the product's functionality for the user.
(2) Overview: How is the product manufactured, distributed, and disposed of? Which environmental impact does this lead to?
(3) Eco-profile: What are the origins of the environmental impacts?
(4) Quantification: Create scenarios for alternative processes, materials, and life cycles. Consider the likelihood of the scenarios.
(5) Conceptualization: Try to remove or reduce the environmental impacts by creating solutions towards product or life cycle changes. The use of ecodesign principles can help to provide and sketch ecoconcepts.
(6) Ecostrategy: Make an action plan for the environmental efforts of the company, especially for product development.

Design for product life and end of life, with waste cut to a minimum or even zero, is crucial, along with correct labelling, since the current business model is inefficient and outdated. For example, pigmentation with deep pigment colouring of clear plastic bottles due to brand imaging makes recycling problematic. However, use of removable ink techniques now available helps recycling of rigid plastic packaging, and removing colour makes recovery of mixed plastics more manageable and attractive for recycling (Wrap, 2018).

One current big issue is coffee cups, which eventually are sent to landfill. U.K. coffee drinkers use around 3 billion disposable cups per year, but only one in 1000 is currently recycled (Lavalle, 2018). The paper degrades, but the plastic lamination lining, which makes the cups impermeable, is very resistant to degradation. Coffee shops are currently trying to counter this by reducing the cost of a cup of coffee if it is served in a reusable cup (Rice Way £18; SAS bamboo £12; Keep Cup, £10). Starbucks currently gives a 25 pence (p) discount if reusable cups are used; Costa gives a 25p donation to charities; and Frugalpac (2018) is close to developing a 100% compostable cup. Multiple materials in packaging cause huge problems, and much current packaging is difficult to recycle, *e.g.*, vacuum packed meat trays with multiple layers of different plastic have a cost that is too large for the market; they become unsustainable and obsolete. Pringles crisps contains a cardboard tube, metal lining and bottom, plastic lid, foil, and paper. Similarly the polymer shrink sleeve wrap of Lucozade Sport drink means it cannot easily be recycled. A typical crisp packet is a metallised plastic film, and after eating the contents should be put in a rubbish bin. The U.K. Campaign Organisation 38 Degrees has pointed out that U.K. customers consume approximately 6 billion packets per year (38 Degrees, 2018). A single manufacturer, *i.e.* Walkers, is set to produce 28 billion by 2025, when the company has pledged to make packets 100% recyclable. Currently it produces 11 million, *i.e.* 7000 nonrecyclable packets each minute. On October 6, Walkers announced that crisp eaters could deposit packets at many collection points or post them free to the recycling firm TerraCycle, as they were now technically recyclable. The packets would be cleaned, shredded, and turned into plastic pellets, which can be used in the production of fence posts, benches, and other items.

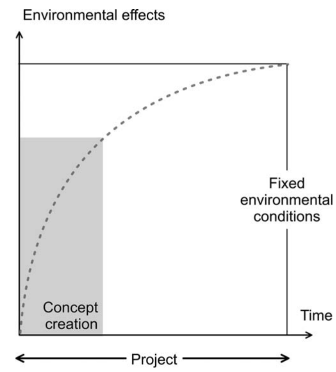

Figure 3. Existing relations between concept creation, project life cycle, and environmental effects. The design stage (concept creation) has a vital influence on the product's life cycle and also on subsequent occurring environmental effects. This stage is crucial because the product lifetime is defined.

MITIGATION

Mitigation solutions are focused on all actions that allow reduction of marine litter issues through revision, adaptation, and reorganization of specific human activities. Measures of this type include enhancement of the circular economy, strengthening of cooperation, and change of product design including the use of novel approaches.

Enhancing the Circular Economy (Go beyond the Concept)

The circular economy is an economic system that wants to retain as much value as possible of products, parts, and materials by approaches such as optimal reuse, refurbishment, remanufacturing, and recycling (Figure 4). The concept recognizes the importance of the economy needing to work effectively at all scales—for large and small businesses, for organizations and individuals, globally, and locally (MacArthur Foundation, 2016).

The linear economy is no longer an optimal model to follow because it is based on high demands of materials (most hazardous), which is unsustainable from an environmental, social, and economic point of view. The multiple problems derived from use of a linear economy (*i.e.* price volatility, interconnectedness, degradation) highlight the necessity of an alternative model, which can be interpreted as opportunities for the circular economy. A shift from a linear economy to a circular economy not only amounts to adjustments aimed at reducing negative impacts, it also represents a systemic change in human behaviour that can build long-term resilience, generate new economic opportunities, and provide environ-

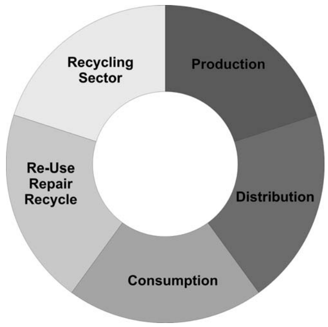

Figure 4. The concept of circular economy. The circular economy (CE) is a concept in which growth is decoupled from natural resource consumption and ecosystem degradation. CE can be achieved through five stages that include: production, distribution, consumption, reuse–repair–recycle, and recycling sector. CE is in contrast to a linear economy, which is a take–make–dispose model of production.

mental and societal benefits. The ideal is maximum value from all materials and reducing/eliminating waste in the oceans, a far cry from the current situation, and a new philosophy of closing the loop for product lifecycles is called for (Lacy and Rutqvist, 2015). Currently many items cannot be recycled, *e.g.*, drink cartons, polystyrene, crisp/food wrappers. What can be recycled are steel/aluminium drink cans, plastic bottles, clean paper, rinsed out food tins, yogurt pots, cardboard, unbroken glass, and empty aerosol cans, for example.

The conundrum is that demand for recycled plastic in Europe is about 6% (EC, 2018). It is noteworthy that every second, more than 20,000 drinks in plastic bottles are purchased globally (Global Citizen, 2018), *i.e.* >1 million bottles per minute—nearly 500 billion bottles per year. Coca-Cola, the largest beverage manufacturer, manufactured >110 billion plastic bottles in 2016, *i.e*. 3400 per second. As a result, in the U.K. they agreed to increase recycled plastic in its bottles to 50% by 2020. Pepsi Cola also aimed to make 100% of its packaging recoverable or recyclable by 2025.

In the U.K., the Plastics Pact is the first of a global network of such pacts enabled by the Ellen MacArthur Foundation's New Plastics Economy initiative and has governmental support (EC, 2018; Ellen MacArthur Foundation, 2018). It is an innovative packaging project that will deliver most significant impacts in the short and long term, such as overcoming barriers to increasing the amount of recycled content used in new packaging, developing reusable packaging, and reducing the total amount of plastic packaging, together with working with partners to overcome the issue of unrecyclable black plastic. Individual firms, *e.g*., COLPAC (2018), have developed ovenware suitable for noodles, stir fry, pasta, and rice dishes compatible with EN 13432 certification, one that is entirely biodegradable and composts within 90 days in a specialist facility. It can stand high (210°C) oven temperatures, is made 100% from sugar cane, and is a ready alternative for the takeaway trade to aluminium/polystyrene trays. On this point, it behoves governmental thinking to accept the Kahneman (2011) System 2 model, slow, hard, conscious, and analytical, rather than the current System 1 model—intuitive, easy, unconscious, and fast.

Some big U.K. stores are also showing interest in this matter. John Lewis will buy back old clothing from customers to try to reduce the 300,000 tonnes of fashion waste that ends up in landfill each year. A special app reveals what has been bought over a 5 year period, customers choose what they have to sell, and a price is given. When this reaches £50 a courier collects the goods, and the customer gets a gift card. In 2017, the store took back for upcycling >27,000 electrical products and 2000 sofas. They also sell bath towels made from 35% recycled plastics bottles (10 one-litre bottles per towel) and regenerated cotton. Similarly, Marks and Spencer's 'schwopping' scheme, which donated clothes to Oxfam, has prevented some 7.7 million clothing items from being thrown away. They have also recently launched a pack-away-mac made with 50% recycled polyester sourced from plastic bottles.

Some 60% of the total polymers in municipal waste are made of polyethylene (PE; >100 million tonnes produced per year, whose molecules are extremely hard to break down) and propylene. As an example of plastics that can be recycled into fuel and waxes a new, as yet a not commercially available, process can use a catalytic cross alkane metathesis method to break down the alkanes and hydrocarbons that are entirely converted into liquid fuels (diesel) and waxes (Xiangqing *et al.,* 2016).

Dematerialisation

Dematerialisation involves a reduction of materials used in a product or service whilst retaining the same level of user functionality. It is in its infancy and does confront the limitations of current circular economy thinking. From an energy viewpoint, remanufacturing keeps the product whole, slows entropy, and reduces the amounts of product being disassembled, repurposed, or remelted. With less material being used, pressure on the ecosystem is reduced. To meet United Nations (UN) Sustainable Development Goals, a better material value chain for housing, industry, infrastructure, and manufacturing is needed.

Thinking Outside the Box

The marine litter problem demands new perspectives, and below are some of today's innovative solutions. Many are not commercially available due to economics, others are sound. There exist many other, outside the box ideas that are fairly unusual and have not been mentioned, *e.g*., breeding caterpillars. The larvae of the greater wax moth (*Galleria mellonella*) devour plastic bags; one worm eats 2 milligrams per day, so trillions would be needed. Perhaps the answer lies in the bacteria that enables the moth to eat plastic, so could a future way out be large fermenting vats of bacterial froth into which plastic litter is poured?

Slat (2018) has argued that some 40% of the North Pacific Gyre plastic can be taken away within 10 years. Six hundred metre length drifting booms having a 3 m skirt could be linked to 24 platforms with 12 m metal suspended towers hanging in the water column where current speeds are one fifth lower than the surface one. As a result of the speed differential, litter would be collected on the boom and later recycled. His organisation has already raised U.S.$30 million to construct an ocean sweeping machine, and trials commenced in summer 2018. Models show that a full-scale cleanup system roll-out (approximately 60 systems) could clean 50% of the Great Pacific Garbage Patch in just 5 years (Ocean Cleanup 2018), and the Ocean Cleanup projects hope to be able to remove 90% of the ocean's plastic by 2040.

Bakey's India (2018) make cutlery from sorghum blended with rice and wheat, *i.e*. no chemicals/preservatives/emulsifiers *etc*.; they are 100% natural, biodegradable, vegetarian, and even vegan. The spoons come in three flavours, plain, sweet, and savoury and disintegrate within 3 days when mixed with water. They are even introducing other cutlery products, such as chopsticks. Herald (2018) has a range of items, such as plastic straws made of sugar, corn starch, and jelly. In the U.K., Loliware (2018) now makes edible straws with various flavours, *e.g*., vanilla, since the U.K. throws away >8.5 billion standard straws per year. One can even get straws made from pasta (Coco di Mama, 2018), wheat (EcoStrawz, 2018), or sugar (Sorbos, 2018); and for the fashion conscious a set of six Murano glass straws can be had from designers Duncan Campbell and Charlotte Rey (2018) for £50, whilst the jeweller Stephen Webster (2018) can sell a sterling silver one (The last Straw) for £145. A question: what is wrong with using lips? They have worked over a very long time span. The U.K. superstore Iceland (2018) can make ready meal trays and pulp packaging for vegetables, chicken, and fish and bags from bamboo and sugar beet, and it intends to eliminate plastics by 2023. Skipping rocks (2018) make edible water Ooho pouches from seaweed—a drink and snack!

Bottletop's London store features an interior that was three-dimensionally (3D) printed from 60,000 recycled plastic bottles and 5000 cans. They specialize in manufacturing expensive handbags (~£395) made from bobbin tabs, can pull rings, *etc*. and work with the Mulberry leather goods firm.

Fishy Filaments, U.K. (Creative Metallurgy Concept; 3ders, 2018; IndieGogo, 2018) plan to repurpose used fishing nets as filament for high priced 3D printers and are currently raising funds to move the project from an initial research phase into a commercial operation. The 3D printing industry creates a demand for cheap nylon/plastic, and nets are collected for the project, which is run by the Newlyn Pier and Harbourmaster Authority. A simple mechanical process thermally re-forms them to larger diameter filaments for high-value 3D printers. They use crowdfunding in order to raise the capital to further finance the process.

Strengthening concrete/bitumen: Exposing plastic (polyethylene terephthalate—standard bottle plastic) to high doses (100 kGy) of gamma radiation in the Massachusetts Institute of Technology's cobalt-60 irradiator changes the material's crystalline structure, making it stronger (an increase in compressive strength), stiffer, and tougher by 20% when mixed with Portland cement and fly ash, since the crystalline structure blocks the pores within the concrete (Schaefer *et al.,* 2018).

Burning/burying plastics affects the environment, but banning plastic would severely affect quality of life. Hospitals could not currently get by without plastic for, *e.g*., heart valves and catheters, and banning it would have a devastating effect on low income families, especially in the third world. Molten plastic, derived from strips of bin bags, water bottles, notebook liners, *etc*. is an excellent binder, and, if added to a stone/bitumen mix, the plastic sticks fast to the other materials, increasing the tensile strength—ideal for paved roads. Heated (170°C) asphalt has shredded plastic (<70 microns, 12% of the mix is the optimum amount) sprinkled over it followed by heated bitumen, producing a tar like surface. No toxic gases are released as plastic decomposes, releasing such fumes only if heated to >270°C. Over 9900 miles of road have been paved in Tamil Nadu State, India, by this method (Singh and Yadav, 2016; Vasudevan, 2004, 2006)

Clothing/bedding/fashion: Smoothshell's Ocean Discovery Underwear is made from flotsam, jetsam, and nets. Clothes from Henry Holland (2018) are similarly made, and the manufacturer makes a donation from profits to the U.K. Marine Conservation Society (MCS); Trutex (2018), using polyester yarn from 31 plastic water bottles, can make one school blazer. They make 300,000 blazers per year, saving >9 million bottles from landfill. Take, make, use, reuse, is the new motto. The MCS has entered a partnership (2018) with the Silent Night (2018) bed maker firm. Each mattress filling uses eco comfort fibres manufactured from 150 plastic bottles, which is estimated to prevent 105 million plastic bottles from entering oceans and landfills. Sunglasses made from recycled ocean plastic are on sale at £230 (Net-a-Porter, 2018); recycled £95 bags are available from Corner the Market (French Connection, 2018). For more than a year, Adidas has been teasing the release of a shoe made almost entirely from discarded plastic fished out of the oceans. It revealed its first prototype of the sustainable sneaker, created in collaboration with environmental organization Parley for the Oceans, in June 2015. In mid-November of the same year, the first mass-produced quantity (7000 pairs) were put up for sale, and according to Adidas, that is just the start. The homeware retailer Lakeland (2018) makes antislip door mats from 100% recycled materials (including plastic bottles). Rothy's (2018) have turned 13 million water bottles into ladies' shoes, and when they are worn out, Rothy's will take them back for recycling. Adidas, in association with Parley, are sponsoring a kit made from recycled plastic waste from the Maldives for one-off football games in November 2018 involving Real Madrid and Bayern Munich, with the aim of emphasising the importance of cleaning up the oceans.

Bioplastics (Plastic Industry Association, 2018): These are either made from a renewable resource, *e.g*., corn or sugarcane (biobased); break down completely *via* a natural process (biodegradable), or are both biobased and biodegradable. They cost some 50% more to produce than conventional plastics but will come into their own with economies of scale when large plants for organic polymeric packaging, *etc*., are set up and when regulations on nondegradable plastics will become increasingly stringent at a time when oil extraction costs increase annually. These new packaging materials can reduce carbon emissions by 25% over the product lifecycle. Biodegradables, such as EN 13432, ASTM D6400-99 preshredded plastic, degrade in commercial composting plants in 180 days, 56–71°C, 50–60% humidity, and pH 7–8. These are prototypes and not yet an industrial reality. They are durable for several months in dry conditions but degrade in a few weeks in soil or water and would be used in nonfood packaging. The total market for consumer and industrial flexible packaging was almost $230 billion in 2017 and is projected to grow at an annual rate of 4.3%, reaching a total value of $283 billion in 2022 (Smithers Pira, 2018).

Enzymes: *Ideonella sakaiensis* (201-F6, Yoshida *et al*., 2016), eats polyethylene terephthalate (PET), since it uses PET as its major energy and carbon source. Work carried out by Yoshida *et al*. (2016), the University of Portsmouth, and the U.S. Department of Energy's National Renewable Energy Laboratory (Sci News, 2018) engineered an enzyme whilst examining the structure of a natural enzyme in a waste recycling centre and suggested that these enzymes can play a part in the plastics problem (Sci News, 2018). The enzymes could nearly completely degrade a thin film of PET after 6 weeks at a temperature of 30°C. Two enzymes were used to hydrolyse PET, but these are very early days.

Coalitions

The United States hosts 'The Plastic Pollution Coalition' with >500 members and 90 nongovernmental organizations under the 'Surfrider umbrella' (Plastic Pollution Coalition, 2018; Surfrider Foundation, 2018). In the U.K., the Marine Litter Action Group established in 2014 brought different sectors together (>60 organisations), all working in the marine litter field. To date >1.7 million individuals, 39,000 volunteers, and <11,000 organisations and companies are involved, and *ca*. 355 marine litter projects have been planned, completed, or implemented (Marine Litter Solutions, 2018).

The U.K. Plastics Pact is a collaborative initiative led by WRAP (2018) and enabled by the New Plastics Economy initiative of the Ellen MacArthur Foundation (2018). It is the first of a global network of such pacts that will create a circular economy for plastics by 2025 that can build a stronger recycling system. This will transform the U.K. plastic packaging sector by bringing the entire plastics packaging value chain together *via* having a common vision and ambitious target set to stimulate innovative new business models to reduce the total amount of plastic packaging. Its aim would be to identify priority projects to deliver the greatest impacts in the short and long term, such as overcoming barriers to increasing the amount of recycled content used in new packaging, developing reusable packaging, and working with partners to overcome the issue of unrecyclable black plastic. Pure black plastic (often technically recyclable) is rarely picked out by recycling facilities, since the infrared technology cannot see the chemical spectrum of the polymer; thus it is usually rejected. Morrisons, a U.K. 493 outlet super store and a launch signatory of the Plastics Pact, is reviving traditional brown paper bags (100% recyclable) for loose fresh fruit and vegetables, which will save 150 million currently used plastic bags per year. It is intended to introduce these by September 2018. Waste resource management is the key to avoiding marine litter.

Some 29% of plastic packaging used at 10 big U.K. supermarket chains is either nonrecyclable through standard collection schemes or difficult to recycle and creates about 800,000 tonnes of plastic every year. Between 71% (Lidl) and 81% (Morrisons) of the total packaging (by weight) was widely recyclable at kerbside (Simmons, 2018). Huge inconsistencies abounded in the labelling of recycling information (Figure 5), since different systems of labelling are used and some items are not labelled at all. A recent Which survey report (2018) found that 48% of people thought that Figure 5d (common on much packaging) meant the item could be recycled; 73% knew that Figure 5a meant that something can be recycled. Government and manufacturers could simplify and clarify current recycling labels, together with compulsory recycling labelling on all plastic packaging, so that consumers know what can and cannot be recycled. A U.K. survey (n = 2155) in May 2018 showed that 67% agreed that packaging recyclability was important, but only 15% did not buy because the packaging could not be recycled (Simmons, 2018).

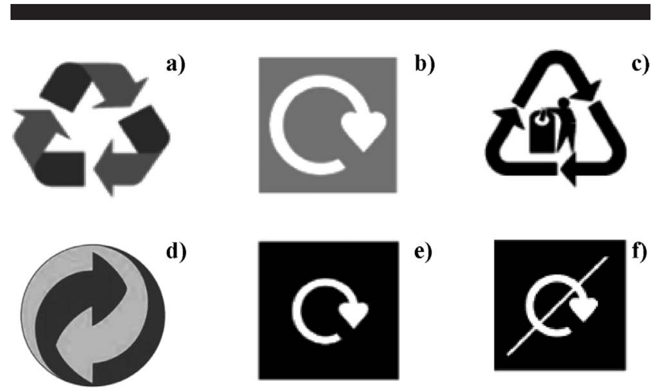

Figure 5. Some packaging symbols: (a) Mobius loop—it can be recycled; (b) recycled by >75% of local authorities; (c) be tidy and dispose here; (d) green dot, contribution to packaging recovery scheme by the producer; (e) not collected by all local authorities; (f) less than 20% of local authorities recycle this.

A 64% (2017) reported proportion of U.K. packaging waste, increased from 31% in 1998, exceeded a European Union (EU) target of 55%, but analysis involved complex methodology and a number of assumptions, so the reported recycling rate for plastic packaging could be overstated (DEFRA and EA, 2018). In 2017 local authorities spent some £700 million on collecting and sorting packaging waste, *i.e*. the tax payer paid some 90% of the cost of recycling (DEFRA and EA, 2018), with most of the recovery revenue coming from recycling of either glass (£18 million) or plastic (£47 million). The U.K. Environment Agency did not in general view packaging as a priority, but it is now creating a national team.

The U.K. Packaging Society is one of the oldest established bodies for packaging professionals, and in 1970 had >170 cardboard packaging mills in the U.K.; today it has <40. The rise of the supermarkets destroyed this, since they consistently drove prices down, forcing manufacturers to find the lowest cost materials to be used for packaging, resulting in PET, plastic, and metal packaging for beverages, which gave rise to a large part of the litter problem (Davis, 2018). Beverage deposit schemes have been recently been mooted (April 2018), and in the U.K., government has set up a scheme to ban disposal of items, such as straws, cotton buds, and drink stirrers. For example, in the U.K., Weatherspoons, McDonald's (currently using 1.8 million straws per day in Britain), Pizza Express, and Costa Coffee have announced plans to eliminate plastic straws by substituting paper straws from a dedicated paper straw factory at Ebbw Vale, Wales, run by Transcend Packaging, which could help create 200 jobs. It is hoped that the factory will be in full production in 2019. Costs currently are 10p/1000 plastic straws, compared with 14–15p/1000 for paper. Five main issues have been highlighted by plastic coalitions (Davis, 2018).

(1) Plastic waste management: A lack of recycling alignment exists, and a cultural shift is needed, stressing the importance of recycling.
(2) Plastic options: Reduce unnecessary packaging and eliminate plastics that are not easily recyclable, *e.g.*, black meat trays. Development of bioplastics and biodegradable/compostable ones must be supported.
(3) Substitution: Use more materials based on paper, paperboard, cellulose, *etc*. The latter option lacks the barrier functionality of plastic films, but new developments will overcome this issue. Cups, boxes, sachets, flow wraps, meal trays, *etc*., all can use this technology.
(4) Market alignment: Supermarkets are a major contributor to waste problems. Plastic free aisles now can now be found in Ekoplaza, Amsterdam.
(5) Economics: Existing plastics are cheaper than today's alternatives. Economies of scale can reduce this gap, but cost is a big deterrent. Perhaps a tax on hard-to-recycle plastics and a tax incentive given to supermarkets to adopt new technologies would be an answer.

Strengthening Regional Cooperation for the Marine Litter Reduction

Regional cooperation is crucial to achieving marine litter reduction targets because it strengthens collaboration and harmonizes common efforts to maximize results. Cooperation opens new perspectives for concrete contribution and partnerships with the principal actors in the field of marine litter management, such as fisheries, shipping, industries, local authorities, and civil society, including the scientific and academic sectors, private and public sectors, *etc*.

A common source of litter that affects the marine environment is ocean based (Bergmann *et al.,* 2015). This litter source includes offshore installations, dumping of refuse at sea, shipping cargo, and fishing (industrial and artisanal) and has persisted and remains a concern despite the plethora of international agreements, such as MARPOL.

Strengthening of regional fisheries management is urgently required to tackle fishing industry related litter. The maritime industry, especially fisheries, suffers from excessive damage related to marine litter. For example, McIlgorm, Campbell, and Rule (2011) estimated marine litter related damage to cost fisheries U.S.$1.26 billion per year in 2008 for 21 countries in the Asia Pacific Rim; Edyvane and Penny (2017) showed that between 2003 and 2008 on Australia's northern shores, foreign fishing litter (nets, rope, and gear) was the primary source of marine litter (63%) with 2305 derelict fishing nets washed ashore (89% were of foreign origin, *i.e.* manufacture); other sources include ghost fishing (Butler *et al.,* 2013) and propeller entanglement (Sheavly and Register, 2007). Wallace (1990), reported clogged cooling systems by plastics affected 45% of commercial fishers in the eastern United States; container loss estimated for the period 1990 and 2005 was 16,625 containers (ISL, 2009); issues such as amenity loss contribute to overall container loss.

REMOVAL

Removal measures are focused on removing and eliminating litter already present in the marine environment, *e.g*., Slat (2018). Cleanups are commonly employed for this, but they are time-consuming, costly (Newman *et al.,* 2015), and only capture a fraction of the overall litter (macro litter). However, they do have an immediate positive impact on the environment by removing litter before it infiltrates into coastal and ocean waters (Figure 6). This activity is a direct way to prevent litter effects and also can serve to involve the affected community. Also, it can be useful to collect data that can be used in monitoring the environmental quality of marine environments. Environmental groups, such as Surfrider Foundation, Coastkeeper, Ocean Conservancy, amongst others, have been conducting beach cleanups on a regular basis for over 20 years around the world. These cleanup activities have two primary goals:

(1) Cleaning the beach.
(2) Shifting human behaviour and creating a beach ethic, so that beach cleanups eventually become unnecessary.

Litter-free beaches, either cleaned by hand or by machines (Public works/private companies/organised volunteer groups) are worth their weight in gold to the tourist industry. Ballance, Ryan, and Turpie (2000) working on South African beaches found that a drop in beach cleanliness standards reduced tourism revenue by up to 50%. Eighty five percent of beach users would not visit a beach with three litter items/m^2, whilst 97% stated they would not visit a beach with 10 or more litter items/m^2. Beach cleanups must be incorporated and implemented as a conventional management strategy. For example, in Orange County, California, a travel cost model study showed that millions of dollars each year are lost to residents by tourists avoiding littered, local beaches, preferring farther away cleaner beaches that can cost more to reach. Reducing marine litter by 75% at six popular beaches generated over $40 million in additional benefits to Orange County residents over just 3 months (Leggett *et al.,* 2014). Krelling, Williams, and Turra (2017), working at two Brazilian beaches (Pontal do Sul, PS, an estuarine beach; Ipanema, an open-ocean beach), showed that >85% of beachgoers would avoid a beach visit if a worst case scenario (>15 items/m^2) occurred, and most users would choose a neighbouring state beach destination. Stranded litter could potentially reduce local tourism income by 39.1%, representing losses of up to U.S.$8.5 million per year.

In the U.K., approximately 5000 items of marine plastic pollution occur per mile of beach; 150 are plastic bottles (www.sas.org.uk). The Marine Conservation Society (GBBC, 2014; MCS, 2017; Marine Conservation Society, 2018), together with a host of organised local cleanups, has led to many volunteer-based surveys and cleanup schemes in helping clear up this litter. Volunteers for beach cleanings tend to be a biased audience of people who do not litter, and that audience

Figure 6. Examples of beach cleanups. (a) Colombia, (b) Turkey, (c) Spain, (d) Bonaire.

should reach out to the masses that do so, but the cost-effective data gathered does give a badly needed full brush report of litter in the surveyed regions. The cost of removing beach litter to all U.K. coastal municipalities (mainly labour) was estimated to be in the region of €18–19 million (Lozano and Mouat, 2010; Mouat, Lozano, and Bateson, 2010), an average cost per municipality of €146,000 (Mouat, Lozano, and Bateson, 2010). In Belgium and the Netherlands, the total cost was estimated to be €10.4 million per year, at an average of €200,000 per municipality per year (Mouat, Lozano, and Bateson, 2010). The Ocean Conservancy (OC, 2016a,b) coordinates international action in this field.

BEHAVIOR CHANGE

No matter what measures exist to collect, recycle, and process waste, humanity will never achieve a truly clean marine environment unless there is a fundamental shift in human mindsets and behaviour towards producing less trash and not littering. Behaviour-changing solutions attempt to influence behaviour such that people engage in activities that help to eliminate, remove, or at least reduce the amounts of litter into the marine environment (Figure 7; Table 2). Behaviour-changing schemes are cross-cutting and aid the development and implementation of the previously mentioned solutions (knowledge, prevention, mitigation, and removal).

Below are three solutions on how to get people on board in this difficult endeavour with efforts to keep marine environments clean and free of waste.

Use of Economic Instruments

Economic Instruments encompass a range of policy tools, from pollution taxes and marketable permits to deposit-refund systems and performance bonds (UNEP, 2000). The common element of economic instruments is that they can change or influence behaviour through their impact on market signals. This tool can be designed in a variety of ways, and for a variety of applications, but in general terms are focused on:

(1) Increasing prices of goods and services that can be harmful to health and environment.
(2) Increasing financial returns on products/activities that are used with more sustainable approaches that foster more environmentally friendly production and consumption schemes.
(3) Decreasing compliance costs through flexibility to polluters or users of natural resources to choose the most cost-efficient and environmentally effective measures.
(4) Giving incentives for investments in innovation and improved environmental technology.
(5) Achieving environmental and health goals by specific tax policies that can help raise revenues.

There exist two primary objective economic instruments to tackle marine litter: Minimizing marine litter production and the harm caused, together with avoidance of unintended consequences from its application (Newman *et al.,* 2015). A wide range of economic expenditure (*e.g.*, loss of fishing gear)

Figure 7. Examples of behaviour changing as strategy for marine litter reduction. (a) Advice to discourage littering behaviour in Bonaire (left) and Colombia (right), (b) use of deposit-refund systems in Sweden.

and economic loss of output/revenue (*e.g.*, income from tourism loss), as well as environmental and social costs (health issues related to litter), arranged against a vast sector range and geographic spread make measurement of the economic impacts of litter very complicated. Direct costs, *e.g.*, beach cleaning, *vs*. intangible ones, *e.g.*, ecosystem impact (biodiversity, services, regulatory and cultural) and deterioration of life quality, are much harder to estimate. Most studies do not take into account the social and ecological impacts, *e.g.*, Mouat, Lozano, and Bateson (2010), McIlgorm, Campbell, and Rule (2011). For example, Costanza *et al*. (1997) estimated that the cost to marine ecosystems alone was €16.5 trillion.

In addressing marine litter, specific economic instruments can be used to reduce the impacts of such litter in a variety of ways, these instruments are as follows:

(1) Grant incentives to industries that use less plastic (packaging) either through economic disincentives or subsidies (internalizing external cost).
(2) Target waste generation using instruments such as a landfill tax.
(3) Target specific types of waste, such as plastic bags, cigarettes, or straws—single-use items. For example, Kenya banned plastic bags in 2017, and Samoa has recently announced that it will ban all single-use plastic bags and straws by January 2019. A recent study (Brooks, Wang, and Jambeck, 2018) showed that 89% of exported waste has been single-use items.
(4) Target sources of waste most problematic for marine litter, such as shipping.
(5) Target individual types of marine litter to reduce ghost fishing.
(6) Pay or elevate payments for the collection of litter.
(7) Target the toxicity of litter.
(8) Discourage polluting behaviour (Figure 7).
(9) Impose fines for littering: Laws exist for this, but implementation is sadly lacking, and this should be a MUST.
(10) Charge for effluents, *i.e*. require companies that pollute to pay fees.
(11) Encourage the use of deposit-refund systems (Figure 7). This means that if the consumer returns specific litter items, the consumer gets a deposit back. Countries such Sweden and Norway have machines called Pantmaskin or Pantstation that return a 1 to 2kr deposit for each can or bottle deposited. Its use is highly encouraged by social media, and even famous singers compose songs advertising its use (*e.g*., Linda Pira and De Vet Du). The Scottish Government in 2017 commissioned detailed work on how a potential deposit–return scheme might operate in Scotland.
(12) Auction/tender the right to create pollution.
(13) Offer tax incentives, *i.e*. give a tax rebate for collection/litter prevention: In many third world countries, litter simply accumulates on roadsides, river banks, and streets and is collected on a sporadic basis by garbage trucks. If this is gathered on a regular basis for landfill, burning or recycling, it at least stops it entering rivers and ultimately oceans.
(14) Levy a sales tax on specific items, *e.g*., plastic bags: Shoppers took six billion fewer plastic bags home in England and £29 million donated to good causes thanks to a 5p charge. It reduced plastic bags found on English

Table 2. *Some Individual and systemic changes.*

Individual Changes	Systemic Changes
1. Continuous awareness raising (cleanups/campaigns)	1. Reframing the lens—from marine litter to plastic pollution
2. Focus on behavioural change/targeting social norms to reduce consumption at source	2. Plastic manufacturers, producers and retailers to take a lead
3. Refuse all single-use items	3. Ghost gear
4. Pilot innovations	4. New legislation—single-use charge, *e.g*., EU; UN
	5. Recycling overhaul

beaches by half. One trillion plastic bags are produced each year (2 million every minute), and each bag has an average use of just 12 minutes.

(15) Levy tourist taxes, *e.g*., voluntary or imposed by authorities: This economic instrument is applied in vulnerable areas such biodiversity hot spots, *e.g*., Great Barrier Reef, or islands, *e.g.,* the Lesser Antilles. Many U.S. states have these automatically added to tourist bills, *e.g.,* Florida.

(16) Create port reception facilities: low/no cost, which encourages disposal. Cleanup costs of ports, harbours, and beaches and marinas are the significant costs to the maritime industry in the U.K. (Lee, 2015).

Some 50% of plastic waste earmarked for recycling is exported to countries around the world, especially China, which has imported 45% of the world's plastic waste since 1992, and after this has imported 106 Mt of plastic waste (Brooks, Wang, and Jambeck, 2018). China's new policy of prohibiting eight types of plastic waste demands an increased domestic management policy for plastic waste.

This can change the culture of litter, and litter studies must be part of a school curriculum, so that is becomes imbued in young people. Some schools have Litter Education programmes that attempt to spread a message about the harmful effects of littering and the importance of reducing, reusing, and recycling. Programmes are offered to any form of educational institution, including private, public, and home school. The Australian or Rapa Nui ethics of respect for beaches are good starting points. There, having a good time at the beach is the norm, but litter is disposed of in bins or taken home. People's attitudes can be changed; the very successful, 'Do not drink and drive', 'Click clunk, fasten seat belt' campaigns in the U.K. being a case in point. The U.K. Surfers against Sewage (SAS, 2018; www.sas.org.uk) in 2017 made a replica military boat from plastic bottles and exhibited it along the south coast in order to raise litter awareness to educate beach users about the problem. A move is currently afoot to forbid smoking at U.S. state beaches in order to eliminate the amount of cigarette butts found along their beaches (Leatherman, pers. comm.). A novel idea, conceived by three design students from the National Taiwan University of Arts, New Taipei City, Taiwan, to educate the public regarding the litter problem has been pollution ice popsicles (made from cigarette butts, dirty water, dead fish, *etc*.). These popsicles were created to raise awareness and highlight steps to be taken to combat litter, and hopefully they can lead to changed behaviour. Serious commentaries written in widely read popular magazines can resonate with the general public, *e.g*., *National Geographic*, whose June issue had a 50 page article on plastics in the oceans (Parker, 2018). Finally TV documentaries, such as the one narrated by David Attenborough, *Blue Planet 11*, can seriously influence people's views on the plastic issue (Attenborough, 2017).

The Political Agenda

Decisions taken by government are influenced by many factors, *e.g*., the media, public opinion, the party platform, crises, lobbying, culture, timing, science, *etc*., but it behoves one to consider the words written by Ibsen (1883). Ibsens' superb play is a criticism of democracy and is the tale of how a brave man can survive even against great odds. It poses the question as to whether the concept of "the government of the people by the people for the people" exists. One of its two great themes is how leaders can manipulate the majority, asking questions such as: are choices made by leaders in the interests of the people or the few that benefit from them and make people believe the reverse? Is society deceived in choosing an option that is the opposite to its interest, but excellent for the privileged minority? With media control, and hence public opinion, can political leaders do whatever they want? If a people make a choice, is it by their own free will, or have they been subtly misled into it? Ideas that are very pertinent today.

The rising tide of public protest against plastic pollution has, for example, influenced the U.K. government, resulting in a drastic reduction of plastic bag use in several countries, *e.g*., the 5p charge in England resulted in a 6 billion drop in numbers of plastic bags used. The Colombian government banned the distribution of plastic bags smaller than 30×30 cm in an attempt to promote a greener lifestyle. This decision was approved on April 28, 2016, through the 0668 resolution, which 'rules the rational use of plastic bags and adopts other resolutions.' This new policy makes part of the Soy ECOlombiano project (I am ECOlombian), together with a collaboration between the Colombian government and World Wildlife Fund Colombia. To follow up the unfolding of the measure, the Ministry of Environment demands that distributors present an annual plan on the sustainable use of plastic bags and asks them to publish their advances in the *VITAL* platform, which was created especially for this project.

In May 2018 the U.K. government set up a consultation committee to ban straws, stirrers, and cotton buds. In the same month, the EU lunched restrictions on single-use plastics as part of its plan to ensure 55% of plastics are recycled by 2030, by banning plastic straws, chopsticks, cutlery, cotton buds (except for medical swabs), stirrers, and balloon sticks. Companies making such items will have to cover the costs of waste management and the cleanup of marine waste along with measures to raise awareness regarding litter prevention. They would also like member states to use bottle deposit schemes to ensure that 90% of plastic bottles are collected separately by 2025.

WHAT IS NEEDED

Marine litter management must be developed within a policy framework that sets clear objectives and in an institutional environment where stakeholders have different defined roles. Minimum requirements for its adequate operation are as follows.

(1) Manage litter in a sustainable and informed fashion that accounts for the full range of factors involved in the coastal decision making.

(2) Promote compatibility and balance of coastal uses to minimize litter generation.

(3) Apply precautionary and preventative approaches.

(4) Account for both environmental and economic costs and benefits of marine litter management strategies to ensure optimal use of the coastal zone.

(5) Provide the scope and complexity of the marine litter issues selected as priorities for management measures that are appropriate to the capacity of all institutions involved.

Specific fundamental principles must be used to implement an integrated approach to litter management. The following principles can be a starting point:

(1) Keep close to a broad, holistic approach, considering all alternatives available.
(2) Take into account a long-term perspective.
(3) Always think of adaptive management.
(4) Try to give specific solutions and flexible measures.
(5) Always work taking into account natural processes.
(6) Include participatory planning.
(7) Integrate, support, and involve all relevant administrative bodies.
(8) Use of a combination of instruments.

Importantly, litter issues are a reality that needs urgent solutions, but this can be a slow process, so expected results are likely to be met in the medium to long-term time frame. Being proactive is the key. Flexible strategies instead of reactive measures should be adopted to strengthen litter management and thus improve the coastal environmental quality.

National policies and local actions need to take an integrated and holistic approach to address and counteract the downward spiral of increased marine litter impacts. The current conditions could trigger a broad shift towards a sustainable global civilization if humans started evaluating the past from a broad perspective and placing greater emphasis on planning for the future rather than only sticking to the present (Rangel-Buitrago *et al.,* 2017).

World coastal countries should try to manage marine litter problems with fresh and innovative strategies, or at least known successful approaches if applicable. At the same time they should plan to replace old and less efficient management processes, particularly those that are known to generate more problems (*i.e*. plastic generation). Here evaluation of the changes that occurred in consumption behaviour is the key to possible successful management. Devices that focus on solutions were outlined previously and include integrating ecological, economic, and social aspects, as follows.

(1) Combination of indicators and integrating tools: Data from very diverse fields are required for a framework to guide the optimal management.
(2) Conceptual assessment design of the strategy to follow: A precise definition of the strategy properties, problems, and goals for achievement is necessary.
(3) Embedding fresh approaches in the spatial and temporal knowledge related to the area of interest: It is of utmost importance to know human-driven behaviour and economic conditions of the full area because of the need to accept that some solutions can be better than others.
(4) Development of social and economic analysis with the help of decision support systems: Where meaningful, it might be necessary to place monetary values on the benefits provided by a particular marine litter management strategy.

Developing integration among all aspects involved (*i.e*. ecological, economic, and social): Weak coastal governance, inadequate financial support, poor or zero political practices, lack of commitment, and the nature of public participation could hinder the formation of Integrated Coastal Zone Management (ICZM) regulations. The above is a challenge when looking to incorporate litter management into unstable ICZM regimes.

Marine litter management is not an easy process and requires a holistic view to finding practical solutions that often go beyond national issues (Rangel-Buitrago *et al.,* 2018; Williams and Micallef, 2009; Williams *et al.,* 2016a,b). Under current consumption conditions, litter management is a worldwide imperative because for every day that passes, the problem becomes more intricate, and solutions require investments of large amounts of money. As the world coastal population increases, high pressure is applied to governments at all levels to resolve the marine litter issue. Unfortunately, many litter management solutions fail due to a weak institutional framework, sometimes nonexistent, accompanied by diluted and compromised regulations.

An optimal marine litter management can be introduced if the following steps are taken.

(1) Building-decision support systems help communities visualize litter impacts and possible solutions.
(2) All stakeholders are firmly engaged.
(3) Policies are enacted to ensure environmental integrity.
(4) Proven management interventions are incorporated.
(5) Capacity for implementation is reinforced.
(6) The required broad overall system knowledge as the basis for litter management is available.

The above should be included in policies supporting strategies and, above all, must be constructed with enough robust scientific research for decision makers to make rational decisions. Political support that helps integration of this strategy into policy frameworks and practices is required.

Finally, optimal allocation of financial, knowledge, and technological resources are required. Marine litter management must be included in national policy-setting and raise awareness in planning, practices, and capacity building.

CONCLUSIONS

Marine litter has been around for a very long time, but its impact on the environment has accelerated during the past 50 years, especially with the mushrooming growth of plastics. Plastics, the dominant marine pollutant (in 2016 global plastic's production reached record values of 335 Mt) negatively affects human health, aesthetics, economy, and marine life. Tackling the litter issue involves many stakeholders, including governments, as litter pays scant regard to international boundaries. Curbing it is a complicated task, and this paper identifies five key areas that could help to lessen the amounts of litter found on beaches and in the seas.

Knowledge: A universal methodology to classify litter is badly needed, as is further research especially into the chemistry of plastics in order to produce biodegradable and completely compostable new plastics,

Prevention: Stopping litter generation at the source is the key, which in turn means less waste produced. This is vitally important in the production of micro- and nano-plastics, *e.g.*, in face creams. Product design is also a crucial component, since current product designs are not geared for end-of-life materials. A life cycle approach is seemingly not included in the current conception of product design, but this is slowly changing.

Mitigation: The circular economy must be enhanced, since the current linear one is outdated and unsustainable from an environmental, social, and economic point of view. Demand for recycled products (6% in Europe) must be increased. The formation of associations should be encouraged, such as the Plastic Pact in the U.K., an innovative packaging that delivers significant short- and long-term impacts, such as overcoming barriers to increasing the amount of recycled content used in new packaging, developing reusable packaging, and reducing the total amount of plastic packaging. Thinking outside the box has produced a host of new technologies that use discarded plastic items, *e.g.*, Loliware, Bakeys, Herald, who are all replacing plastic cutlery, straws, stirrers, with items made from sugar, corn starch, and jelly. Other companies are replacing 3D printer filaments, creating stronger concrete, and using recycled plastic to create clothing and fashion accessories, to name but a few. Additionally, strengthening regional cooperation is a must, especially for fisheries.

Beach cleanups are a successful way of educating the public regarding the litter issue, as are newspaper and magazine articles and TV programmes, and hopefully a behavioural change can come about *via* education. Use of a raft of economic instruments can also reduce litter impact.

Finally political will is essential, as final decisions inevitably involve governmental action. Litter management must be included in national policy-setting, and awareness should be raised in planning, practices, and capacity building.

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