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Plastic debris on Pacific Islands: Ecological and health implications

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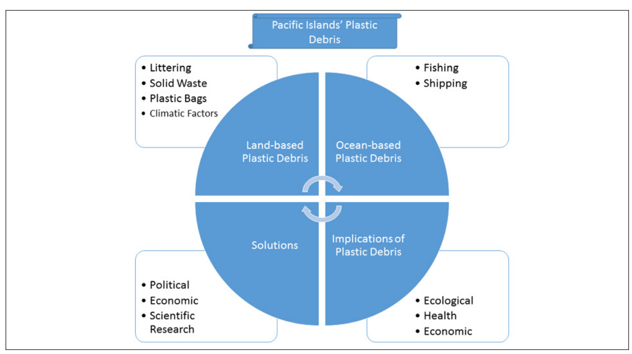
HIGHLIGHTS

- Substantial amounts of plastic are found in the Great Pacific Garbage Patch.
- Littering and solid wastes are major sources of land plastic debris in the Pacific.
- Commercial fishing and shipping contribute to the problem.
- Plastic debris negatively impact the environment, economy and human health.
- Political, economic and scientific interventions are needed to solve the problem.

GRAPHICAL ABSTRACT



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ABSTRACT

Plastic debris is a worldwide problem. This is particularly acute in the Pacific region, where its scale is a reason for serious concerns. There is an obvious need for studies to assess the extent to which plastic debris affects the Pacific. Therefore, this research aims to address this need by undertaking a systematic assessment of the ecological and health impacts of plastic debris on Pacific islands. Using pertinent historical qualitative and quantitative data of the distribution of plastic debris in the region, this study identified pollution and contamination trends and risks to ecosystems, and suggests some measures which may be deployed to address the identified problems. The study illustrates the fact that Pacific Island States are being disproportionately affected by plastic, and reiterates that further studies and integrated strategies are needed, involving public education and empowerment, governmental action, as well as ecologically sustainable industry leadership. It is also clear that more research is needed in respect of developing alternatives to conventional plastic, by the production of bio-plastic, i.e. plastic which is produced from natural (e.g. non-fossil fuel-based sources) materials, and which can be fully biodegradable.

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1. Introduction: plastic debris and waste management in the Pacific Region

Since the discovery of polyurethanes (PU) by Bayers and his co-workers in 1937, leading to the first introduction of plastic materials in 1955 (Feldman, 2008), the global production of plastic has increased considerably. The use of plastic is manifold: from packaging to the production of toys and straws, to plastic cutlery. In many countries, plastic materials are not properly disposed of. As a result, the world's ocean and land are infested with plastic pollution, represented by debris (Rudduck et al., 2017; Lebreton et al., 2018; Bond et al., 2018; Le Guern, 2018), including the Pacific region (Chowra, 2013; Jambeck et al., 2015; Forrest and Hindell, 2018; Lavers and Bond, 2017).

Increase in marine plastic litter, which can be found in the ocean gyres of the North and South Pacific, a waste intensive tourism industry, as well as difficulties in adequate waste collection and management all contribute to the increasing deposition of plastic litter in the Pacific region (Lachmann et al., 2017). The most prominent accumulation of marine garbage and plastic waste, the so-called Great Pacific Garbage Patch, comprises a span of 1.6 million square km (e.g. about the size of Texas or three times the size of France) (TheOceanCleanup, 2018; Pyrek, 2016) and is influencing the Pacific islands coastal ecosystems by the presence of solid waste (e.g. bags, fish nets, toys) which are transported by wind and surface currents (Lebreton et al., 2018). The highest amount of plastic litter contributes from domestic (e.g. household or people litter plastic into the sea), industrial (e.g. plastic waste from industries) and fishing activities (e.g. litter from plastics longline fishing nets, nylons and bottle into the ocean) (Li et al., 2016). As such, plastic pollution poses a significant threat to the coastal ecosystems of the Pacific Island States, directly and indirectly affecting marine and terrestrial environments, life on land and life below water.

The following questions are addressed in this paper:

- What is the extent and significance of the problem of plastic debris on the Pacific Islands?
- What are their ecological and health implications?

Before going any further, it is important to state some facts. Firstly, it should be noted that plastics are the most widely used disposable material globally (de Scisciolo et al., 2016). They are nondegradable petroleum-based products that lack the ability to decompose or mineralize at measurable rates (Leslie, 2015). Secondly, their diversity, versatility, relatively inexpensive manufacture processes, durability and practical applications are some of the reasons for their indispensability in several aspects of modern life (Monteiro et al., 2018; APME, 2014). Unfortunately, the present unsustainable usage of many plastic items, coupled with its highly durable nature, generates substantial quantities of waste with environmental and socio-economic implications (Debrot et al., 2013; Ryan et al., 2009). 80% of anthropogenic debris littering the oceans are plastics (Landon-Lane, 2018), threatening the safety, integrity, and sustainability of oceans. Moreover, the ubiquity of plastics in oceans has resulted in a critical situation for ocean ecosystems (Vince, 2015). In 2015, approximately 322 million tonnes of plastic were generated with over 10 million tonnes being deposited in the oceans (Landon-Lane, 2018). From 1950, 8.3 billion metric tons of plastic has been produced globally and half of that has been produced in the last 13 years (Georgia, 2017; Geyer et al., 2017). According to Raynaud (2014), a 5% increase in global plastic production is documented annually and this figure is projected to increase significantly in the near future. This underlies recent projections of an increase in marine plastic debris (Van Sebille et al., 2015) since over 80% of plastic debris are produced terrestrially. If the current pollution rates are sustained, the quantity of plastic in the oceans will surpass that of fish by 2050 (Simon and Schulte, 2017).

Whereas the problems posed by plastic products and the role of extended producer responsibility in Europe have been investigated (Leal Filho et al., 2019), this is not so in the Pacific region.

There are two main historical sources of plastic debris in the Pacific region: land-based and ocean-based. About 80% of this plastic debris is attributed to land-based sources, with the remaining 18% from the fishing industry including aquaculture (Hinojosa and Thiel, 2009) and an estimated 2% from land-ocean-based sources, such as shore-based plastic debris and incidental losses (e.g. via ocean transportation and run-off from processing facilities) (Andrady, 2011; Norrman and Soori, 2014; Le Guern, 2018). The impacts of plastic debris include harm to the environment, marine life, economy and human health (Timmers et al., 2005; Watson et al., 2006; O'Hanlon et al., 2017). Oceans are highly susceptible to diverse sources of plastic pollution due to long-distance movement of debris by wind, water bodies, superficial or ocean currents (Eriksen et al., 2013; Cózar et al., 2014). Land-based debris originates from the activities of local populations such as the improper disposal of wastes by manufacturing companies and tourists' activities while ocean-based debris consists of debris originating from anthropogenic ocean activities and pelagic sources such as shipping or fisheries (de Scisciolo et al., 2016).

Based on literature review, document analysis and survey, the authors present herewith a set of historical data and evidence of plastic debris from 2008.

The two main categories of sources of plastic debris (land based and ocean based) will be further examined separately below:

Land-based plastic debris

Evidence in the Pacific suggest that the plastic debris from land-based sources can be attributed to four processes: (1) littering, (2) solid waste disposal around coastal and undervalued areas (e.g. areas that are abandoned or considered less significant), (3) plastic debris induced by climate change and disasters caused by natural hazards (4) plastic debris from discarded plastic bags (Tables 1–2), (Chowra, 2013; Norrman and Soori, 2014; Gee, 2018).

Ocean-based plastic debris

In the region, commercial fishing and shipping are the main causes of ocean-based plastic debris. The commercial fishing debris includes nets, ropes, strapping bands, bait boxes, plastic bags, and gillnets (Sheavly, 2010). The commercial-based shipping debris is the illegally dumped waste or littering from shipping activities (Chowra, 2013; Thevenon et al., 2014; Le Guern, 2018; Kiln et al., 2012). A study on Sand Island on Midway Atoll between 2008 and 2010 found a total of 740.4 kg of beached marine-based litter made up of 32,696 objects, of which 91% were mainly plastic debris (polyethylene and polypropylene) (Ribic et al., 2012). The NGO "Ocean Clean Up" which specifies that more than 1.8 trillion pieces of plastic are found in the Great Pacific Garbage Patch, that weigh an estimated 80,000 t (Ocean Clean UP, 2019).

In order to provide some context to the currently grave problem of land based and ocean based plastic waste in the Pacific islands region, it is necessary to look at island waste management.

1.1. The challenges facing waste management: an example from Tuvalu

Taking Tuvalu as an example, chosen because concrete actions are taking place there, it is clear that Pacific island nations cannot look at plastic waste management in isolation. The first national strategy-related document on waste management for Tuvalu was the 1993 Tuvalu State of the Environment Report (Lane, 1993). This report lists solid waste management as "perhaps the most obvious environmental issue in Funafuti" it also states that: "Tuvalu at present does not have a significant or insoluble pollution problem, despite the volume and

Table 1
Record of land-based plastic debris in the Pacific island countries.
Source: Authors, Hemstock et al. (2006), Chowra (2013), Lavers and Bond (2017), Captain Cook Cruises (2018).

Source	Country	Year	Amount	Types
Litter Clean-up	American Samoa	2012–2013	1960 kg	Fast food, beachgoers, sports/games, festivals, and litter from streets/storm drains
	Henderson Island	2017	15,966.45 kg	Plastic debris. Henderson Island is a small Pitcairn island, uninhabited in the South Pacific Gyre. According to Australian researcher Dr. Jennifer Lavers, it contains an estimated 37.7 million items of debris together weighing 17.6 t.
	Fiji	2018	788.20 kg	Plastic bag and bottle, plastic wraps, diapers, cigarette butts, plastic pipes
Solid waste disposal	Fiji, Kiribati, Marshall Islands, Palau, Solomon Islands, Tokelau, Tonga, Tuvalu	Throughout Annual average for household and office waste 2003–2015	Varies 1000–1400 t per year total (50–70 t per year of plastic)	Dumpsites – coastlines, undervalued areas (swamps and mangroves forests). High tide events, storm surges, and other extreme weather events can release and transport light plastic debris. By weight, household waste is 65–70% of total solid waste, and office waste from commercial and Government of Tuvalu offices is 30%. Solid waste is composed of 70% organic materials (12% of organic waste is paper and cardboard); 5% plastic; 20% glass and metal; 5% other.
Climate change and natural hazard	Affected islanders	Dry-wet seasons	Varies	Provide avenues for plastic debris to enter the marine environment from the land.
Plastic bags	Affected islanders	Throughout	Varies	Plastic bags are lightweight and sturdy, so winds and currents can easily carry them. Its buoyant and durable making them get caught in trees, bushes and to block storm pipes, causing flooding or breeding grounds for mosquitoes. They can easily litter and be carelessly discarded if waste litter bins are not available.

variety of solid waste dumped indiscriminately around Funafuti." Lead contamination from discarded batteries was identified as a major waste management issue and plastics are conspicuous by their absence in that plastics were not identified as a land or marine pollutant.

From Table 1, Tuvaluan households contribute a maximum of 70 t per year of plastic waste to the environment – this is an insignificant amount in global terms. For Tuvalu, population pressures and the impacts of external pollution have led to increasing waste management issues. For Tuvalu, over a decade ago (Hemstock et al., 2006, Rojat et al., 2006), the major waste management gaps were identified as:

- A lack of an agreed national set of waste sector objectives that are applicable at a "country level", as well as possible additional legislation to ensure their effectiveness, either nationally or at a Kaupule (By-Law level). International agreements and frameworks have not improved waste management in the Pacific least developed states.
- The need to achieve consistency in the standards of operation, scope of activities, and waste management service provision with a management and finance structure that ensures fair and equitable payments for services.
- A severe (critical) shortage of labour and equipment for waste service provision, even at a basic level.
- A worsening situation in respect of waste disposal.
- The need to provide support and capacity building to Tuvalu waste organization(s).
- A general lack of community interest and awareness in relation to waste issues.

Despite the mention of waste management in the current National Environmental Management Strategy, there is still no coherent waste management plan for Tuvalu. The situation for waste management in Tuvalu is now critical, despite a plethora of technical assistance and feasibility studies costing US$600,000, (Smith and Hemstock, 2012), as well as efforts under the European Development Fund (EDF) 10 and (EDF) 11. The South Pacific Regional Environment Programme, SPREP, is the regional intergovernmental environment organization with the lead responsibility for regional coordination and delivery of waste management and pollution control action. SPREP is guided by the strategic management framework, Cleaner Pacific 2025, in facilitating regional cooperation and collaboration. For Tuvalu, despite over a decade of strategy development and feasibility studies, waste management in Funafuti – the most populous atoll – is in crisis.

Table 2
Types of land-based plastic debris, time of degradation, entering pathways and health effects.
Source: Norrman and Soori (2014), NJDEP Science Advisory Board (2015), Vethaak and Leslie (2016), Forrest and Hindell (2018), Ecology Center (2018), Metz (2016).

Plastic debris	Degradation time (years)	3 pathways plastic pollutants entering the human body	Health effects due to foodborne chemicals
Cigarette butt Disposable diaper Fishing line Food wrapper PET-bottle Plastic bag	10 450 600 20–30 300–500 30–60	1) Chemical toxicity: Plastic pollutants may enter the human daily diet through ingestion of contaminated fish, mammals and other edible sea creatures who consume plastic polluted food; inhalation; and air- and -waterborne hydrophobic contaminants. 2) Pathogen and parasite vectors. 3) Particle exposure toxicity.	Cancer, birth defects, immune system problems, childhood developmental issues, lung & gut injury, oxidative effects (oxidative stress, cell damage, inflammation, and impairment of energy allocation functions), male infertility

2. Ecological and health impacts of plastic debris

The unabated accumulation of wastes in the ocean constitutes a global pollution issue affecting several coastal countries, cities, and islands (Van Sebille et al., 2015). The proximity of coastal environments to terrestrial plastic sources makes them highly vulnerable to the impacts of plastic debris pollution (Jambeck et al., 2015). Oceanic insular environments are equally vulnerable to plastic pollution, whereas, in turn, populated islands are also potential sources of plastics. Moreover, various meteoceanographic mechanisms support the retention of plastics from the surrounding sea on islands (Monteiro et al., 2018). Based on a brief review, Table 3 summarizes some of the most relevant risks caused by plastic debris on human health and well-being as well as environmental and animal health consequences, with attention to the Pacific region.

2.1. Changes in ecosystems and biodiversity

Although plastic pollution affects both terrestrial and marine habitats, most of the work assessing the environmental impacts of plastic debris focuses on marine environments (Thompson et al., 2009). According to Raynaud (2014) as reported in Landon-Lane (2018), marine ecosystems are devalued to the tune of $13 billion/annum globally. Furthermore, plastic waste may cover areas of marine and insular flora and fauna, leading to hypoxia induced by limitation of gas exchange between pore waters and overlying sea water (Gregory and Andrady, 2003; Gregory, 2009). All this is, in addition, undesirable for economic reasons: plastic debris devalues recreational spaces by diminishing their aesthetic appeal thereby resulting in a significant drop in revenue from tourism; disrupts ecosystem services and are hazardous to maritime activities such as shipping and fishing (Moore, 2008; Koelmans et al., 2017).

The occurrence of plastic debris pollution in the deep sea has more recently been documented, with deep-sea organisms discovered entangled in plastic bags. Areas with proximity to densely populated regions, such as the Mediterranean Sea, are particularly vulnerable (Chiba et al., 2018) Previously, many islands were thought to be insulated from ocean-based sources of plastic marine debris, but recent studies have discovered millions of stranded plastic items on island beaches in relatively short time ranges (Lavers and Bond, 2017). Even the most remote localities of both Northern and Southern hemispheres are no longer immune from littering by marine debris, including the Pacific islands (Gregory, 2009). Despite the impacts of plastic debris on tropical and sub-tropical islands due to their vulnerable ecosystems (de Scisciolo et al., 2016), the number of studies that have assessed the impacts of plastic debris in insular environments are relatively few (Monteiro et al., 2018). This is despite the tendency to accumulate stranded plastics on depositional habitats such as island beaches. It is noteworthy that different studies on selected Caribbean and Pacific islands observed significant differences in both volume and content of debris found in these locations. Therefore, the impact of different island's exposure to debris vary spatially and temporally (de Scisciolo et al., 2016). This gives credence to the claim that environmental pressures exerted by debris are not the same on all islands. It is thus plausible that the ecological and health impacts of plastic debris also vary between islands. Although plastic pollution has been established as a source of transboundary environmental harm, there is limited knowledge on the specific damage and impacts of plastic pollution due to its relative newness (Landon-Lane, 2018).

Considering the side effects of micro- and nanoplastics, the leaching of toxic pollutants from fragmented plastic is assumed to negatively impact the environment and may affect the biological function of organisms. This is because plastics can transport contaminants as well as increase their environmental persistence (Teuten et al., 2009). Several contaminants leach out of plastics in the landfill environment, thereby contaminating surrounding areas (DeVries, 1991; Balakrishnan, 2017). For example, in the case of Tuvalu, a coral atoll, due to the porous nature of the coral bedrock tidal surges wash leachates from the municipal

Table 3
Potential ecological and health risks of plastic pollutants.
Source: 1 Baker et al. (2015), 2 Barboza et al. (2018), 3 Chiba et al. (2018), 4 Forrest and Hindell (2018), 5 Gregory (2009), 6 Halden (2010), 7 Jupiter et al. (2014), 8 Kühn et al. (2015), 9 Lachmann et al. (2017), 10 Li et al. (2016), 11 Moy et al. (2018); 12 Prata (2018), 13 Richards and Beger (2011), 14 Rist et al. (2018), 15 Sharma and Chatterjee (2017), 16 Smith and Hemstock (2012), 17 Thompson et al. (2009), 18 Verma et al. (2016), 19 Vethaak and Leslie (2016), 20 Werner et al. (2016).

Exposure	Environment	Animal health	Human health
Persistence in the environment for up to a century (primarily macroplastics)	Contamination of surface and deep waters, beaches, sediments, and shorelines, marine and terrestrial organisms[17,19]	Entanglement in floating litter and plastic materials at shorelines, beaches, and seabed with harmful and lethal effects[3,8,20] Ingestion of plastic with harmful effects on food intake, digestion, reproduction, and survival[8,20]	Contamination of marine and sea-based food as well as living environment causing adverse health effects[3,7,17] Contamination of marine and sea-based food causing adverse health effects[3,4,8,19]
	Surface abrasion, shading, suffocation, loss of marine biodiversity including seagrass, mangroves, and coral reefs[10,13,16,20,11]	Loss of biodiversity, nutritional base and living habitat; higher vulnerability to environmental hazards[11,16,20]	Loss of ecological balance and variability in marine/sea-based food; Higher vulnerability to environmental hazards[17,16,19]
Transfer of pollutants and chemicals	Introduction of alien invasive species, pathogenic micro-organisms and parasites[4,5,9]	Altering of marine and terrestrial habitat; Exposure to harmful pathogens and parasites causing sub-lethal and lethal health effects[2,5,8,9]	Loss of variability in marine/sea-based food; Exposure to harmful pathogens and parasites causing sub-lethal and lethal health effects[9,17,19]
Exposure to microplastics due to fragmentation of macroplastic or as part of certain products	Spreading of harmful pathogens and toxins; harassment of natural resources, including agriculture and fresh water/tap water[10,11,17]	Ingestion of microplastic particles and toxins may lead to physical damage and death due to starvation and disrupted metabolism, loss of mobility, loss of reproductive and development function, and damage of the nervous system[4,15]	Ingestion (including marine food) and inhalation of microplastic particles and toxins may lead to cell damage, endocrine and metabolic disruption, which are suggested to cause inflammation, developmental abnormalities, immune system suppression, damage of metabolic, reproduction and developing system, and increased risk of severe infection[6,10,14,17,19]
Burning of plastic waste	Release of dioxins, toxins and microparticles in the environment, including waterways, crops and air[1,12,18]	Inhalation and absorption of toxins (including contaminated food) affecting the metabolic and endocrine system; no effects could be identified in the literature, however, health effects are assumed to be similar to those described in humans[18]	Inhalation and absorption of toxins (including contaminated food) that may act as carcinogens, endocrine disruptor, and hazardous pollutants, which may cause rash, nausea and headache, and may lead to an increased risk of heart diseases, respiratory illness such as asthma and emphysema, cancer, endocrine disruption, and damage of nervous system, reproductive and developing system[1,12,18]

landfill into the lagoon (Fujita et al., 2014). The environmental problems caused by plastic debris are chronic in nature rather than acute (Gregory, 2009). The pollution of soil and terrestrial ecosystems by plastics and microplastics is another environmental problem (Chae and An, 2018; He et al., 2018) and there are growing concerns on the possibility of microplastics penetrating the soil profile and polluting the groundwater (Scheurer and Bigalke, 2018; Rillig et al., 2017; Liu et al., 2018). Presently, the leaching of chemicals from plastic products and the potential for plastics to transfer chemicals to wildlife and humans is one of the major concerns arising from plastic usage and disposal (Thompson et al., 2009).

2.2. Marine, insular wildlife and public health

Although there is a growing concern regarding the negative impacts of plastic debris, very little is yet known on the potential effects of plastics on plant, animal and human health (Koelmans et al., 2017; Keswani et al., 2016). To date, most adverse effects of plastic exposure could be observed in the gastrointestinal tract in wildlife such as fish, turtles and seabirds (Moore, 2008; Forrest and Hindell, 2018; Lusher et al., 2017) and have been mainly explored under experimental conditions. Human data, however, is limited and impacts on human health must be interpreted critically(Kumar, 2018; Barboza et al., 2018). According to Bouwmeester et al. (2015), three ways of toxic effects of plastics can be differentiated: the exposure to plastic particles, the release of organic pollutants that have been absorbed from plastic, and the leaching of additives.

Growing evidence can be seen on the harmful effects of plastic on wildlife (Gall and Thompson, 2015; Markic et al., 2018). Records show that over 180 species of animals have ingested plastic debris, including birds, fish, turtles and marine mammals and over 250 species have been affected by ingestion and entanglement as reported by Laist (1997) in Gregory (2009), and more recently by Werner et al. (2016). Large animals are particularly susceptible to accidental ingestion of plastic debris and entanglement in floating plastic (Chiba et al., 2018). In addition, organisms also consume plastic contaminants through inhalation and dermal sorption (Teuten et al., 2009; Tanaka et al., 2013). These frequent interactions have severe impacts on wildlife, with nearly 700 species known to be affected directly or indirectly (Gall and Thompson, 2015). Entanglement and ingestion of plastics poses several dangers, including gastrointestinal blockages (Baird and Hooker, 2000), ulceration (Fry et al., 1987) and internal perforation that are believed to cause starvation and debilitation (Gregory, 2009; Mascarenhas et al., 2004). In Gregory (2009), it was reported that 95% of dead fulmars in the North Sea have plastic in their guts, and large quantities of plastic were present in the guts of other birds. Exposed surviving organisms are afflicted with a reduced quality of life and impaired reproductive performance (Gregory, 2009).

Plastic debris may furthermore have the potential to enter the marine food chain and cause adverse health effects in marine mammals and humans through the consumption of seafood contaminated by organic and organometallic contaminants inherent in plastic debris (Chiba et al., 2018; Teuten et al., 2009). Recent research shows that microplastics have been found in economically important marine species such as lobster, mussels, and fish species, also in the Pacific (Forrest and Hindell, 2018), and could be detected in table salt and tap water (Eriksson and Burton, 2003; Kontrick, 2018; Lachmann et al., 2017). In this context, recent studies suggest the possibility of micro- and nanoplastic penetrating secondary tissues, such as liver, muscle, and brain, and attacking the immune system causing immunotoxicity and triggering adverse effects like immunosuppression and abnormal inflammatory responses (Lusher et al., 2017; Wright and Kelly, 2017). Besides humans, animals feeding from plankton, such as mysticetes (baleen whales), are vulnerable to plastic ingestion (Gregory, 2009), either by eating plankton contaminated with micro-plastic or direct swallowing plastic pieces. Although some evidence exists on the presence of microplastic in food destined for human consumption, this topic seems highly controversial and human health effects remain poorly understood (Rist et al., 2018; Wright and Kelly, 2017). Something similar applies to floating plastic debris, which are suggested to facilitate the spread and transportation of invasive species to new areas (Lachmann et al., 2017; Gregory, 2009). According to recent findings, plastics are assumed to be potential reservoirs of pathogens such as faecal indicator organisms, for example *Escherichia coli*, and may even contain multidrug resistant genes inside microbial communities colonizing plastic debris in the North Pacific Gyre (Barboza et al., 2018; Yang et al., 2019). However, these findings need to be considered with prudence and further critical investigation is required to establish a correlation between plastics and the public health risks.

As already highlighted by Talsness et al. (2009) and more recently reviewed by Kumar in 2018, additives and chemicals leaching from plastic debris, namely phthalates and Bisphenol A (BPA), have been detected in humans, with potential adverse effects. As plastics chemicals are assumed to function as endocrine disrupting compounds that modulate the endocrine system, they may play a role in the occurrence of reproductive abnormalities and endocrine dysfunction such as adult-onset diabetes. Further health outcomes have been reviewed such as musculoskeletal concerns, skin irritation or development abnormalities. Especially pregnant women and children seem susceptible to the adverse health effects caused by phthalates and BPA (Halden, 2010; Kumar, 2018; Lei et al., 2018). However, there is a paucity in research to further confirm these findings and no evidence could be found on cases in the Pacific Island region. In addition to leaching plastic chemicals, burning domestic plastic waste in the backyard is a common practice of land-based waste management in developing countries including Pacific Island States, with hazardous effects to human health through inhalation, such as dyspnea caused by airway and interstitial inflammatory response (Prata, 2018; Baker et al., 2015). The extent of chemical transfer and toxicological impacts of exposures to these chemicals, however, are uncertain and require further investigation (Thompson et al., 2009).

Taken together, the adverse health impacts resulting from exposure to macro- and microplastics remain controversial and largely unexplored, especially among humans (Keswani et al., 2016; Barboza et al., 2018). However, it remains a growing concern that plastic debris have the potential to compromise the balance of coastal and marine ecosystems, and to cause hazardous effects on human and wildlife health in different ways (Kontrick, 2018; Moy et al., 2018). Because Pacific islands' populations as well as marine and land-based animals share a similar exposure to plastic pollution, particular attention must be paid to the interlinkage between human, environmental, and animal health to fully understand the public health consequences of plastic pollution, which has yet mainly been illustrated by examples from plastics entering the food chain.

3. Coping with the problem

Sources and pathways of marine litter are diverse and exact quantities and routes are not fully known (Löhr et al., 2017). However, the amount of scientific data and practical knowledge on plastic wastes as a whole, and on plastic debris in the Pacific region in particular, means that a sound basis for action is available. Marine litter is a problem which can be avoided, provided proper policies are in place and are implemented to address it. Overall, three main categories of measures are needed to address the problem:

a) Political action to restrict the use of conventional plastic;
b) Economic sanctions to discourage the use of conventional plastic, coupled with incentives to use more bioplastic based materials;
c) More research on the generation and use of bioplastic so as to replace conventional types.

Table 4 outlines some of the measures which can be deployed to address the problem in the Pacific region, some of which may also be implemented elsewhere.

Table 4
Some measures to mitigate the problem of plastic debris in the Pacific region.
Source: Authors.

Measure	Impacts
Impose a ban on plastic bags	Reduced waste generation and drive for more environmentally-friendly means to carry good (e.g. bags made of natural fibres)
Avoid plastic packaging when possible	Reduced plastic debris generation
More efficient waste management systems	Better collection and processing of plastic and prevention of plastic debris
Engage the tourism sector in using recyclable or re-usable materials (e.g. plates, cutlery)	Reduced plastic debris generation in a substantial manner
Use education, outreach and regular clean-up campaigns	Foster the awareness and prevention of plastic use, and reduce the amounts of plastic debris produced
Encourage the use of bio-plastic	Prevention of plastic debris generation due to the biodegradation of the materials

These measures, when combined, can make a real difference in providing a basis upon which the problem of plastic debris can be kept under control. The potential can be especially conspicuous in respect of restricting the production and use of throwaway plastic products (e.g. cotton buds, cutlery, plates, straws, drink stirrers, sticks for balloons), plastic bags, plastic packaging (including packaging of cosmetics), plastic toys, shipping, fishing, and aquaculture equipment. In Europe, schemes such as the Horizon 2020 project "FORCE – Cities Cooperating for Circular Economy" aim to minimise the leakage of materials from the linear economy and work towards a circular economy. Whereas the Erasmus+ Project "Waste EI" (Waste Education Initiative) prepares education materials which allow the general topic of waste management to be tackled at universities. Similar initiatives are greatly needed in the Pacific region.

4. Conclusions

Although substantial advances in industry and in many sectors of society result from the use of plastics, there is an urgent need to regulate the use and disposal plastic materials, which are widely used through our daily activity. By doing so, we may also reduce the potentially hazardous exposures to human health. The main points of this article are: it has shown that sustainable management of plastic debris is one of the major environmental issues in the Pacific Islands. Also, the article reveals that land and ocean-based plastic debris account for a substantial amount of the solid wastes found in the region and only minimal success has been achieved to date in attempts to manage the plastic waste problem. The significance of this work lies in the fact that by outlining environmental and health aspects of the various problems caused by plastics as whole and macroplastics in particular, we have demonstrated that this is a matter of great social and political concern; the many negative impacts on the ecosystems of Pacific islands cannot be ignored.

Despite the need to address the problem and its many ramifications, a profound knowledge to provide detailed information on the extent of effects of both macro- and microplastics remains limited. And because of the many variables associated with the problem, designing robust studies remains challenging (Lachmann et al., 2017; The, 2017). Consequently, when monitoring at a public health level, pollution databases and environmental observations, including wildlife studies, may prove useful to assess the complex health burdens caused by the adverse effects of plastic debris from a One Health perspective. Therefore, with the growing plastic consumption worldwide and Pacific Island States being disproportionately affected, further studies and integrated strategies are needed, involving public education and empowerment, concerned government action, as well as ecologically sustainable industry leadership.

It is also clear that more research is needed in respect of developing alternatives to conventional plastic, by the production of bio-plastic, i.e. plastic which is produced from natural (e.g. non-fossil fuel-based sources) materials, and which can be fully biodegradable.

Finally, more substantial efforts are needed in the Pacific islands in respect of awareness-raising, so that public support to the prevention of plastic debris can be provided.

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