The economic impact of marine plastic debris in South Africa: A preliminary estimate

Final report

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EXECUTIVE SUMMARY

Introduction

Leakage of plastic waste into the environment is an issue of increasing global concern. In South Africa, an estimated 40 000 tonnes of mismanaged plastic waste enters the marine environment each year from land-based sources (Verster and Bouwman, 2020). In the absence of intervention, flows of plastic waste to the ocean will continue to increase (Jambeck et al., 2015; Tekman et al., 2022; Stafford et al., 2022).

In addition to its direct impacts on marine ecology and biota, marine plastic debris can potentially affect the delivery of ecosystem services, with resulting impacts on human well-being, society and the economy. It can also impact directly on industries such as fisheries, shipping and tourism; and lead to an increase in costs (e.g. costs associated with cleaning up plastic debris). However, policy responses must be informed by a sound evidence base. Quantifying the impacts of marine plastic debris on the economy can provide critical evidence to inform an appropriate response.

Marine plastic debris impacts on the economy in three ways (see Figure *i*):

1. Impacts on marine ecosystem services
2. Direct damage to affected industries, e.g. fisheries, shipping (marine transport), and marine and coastal tourism
3. Costs associated with clearing of plastic debris.

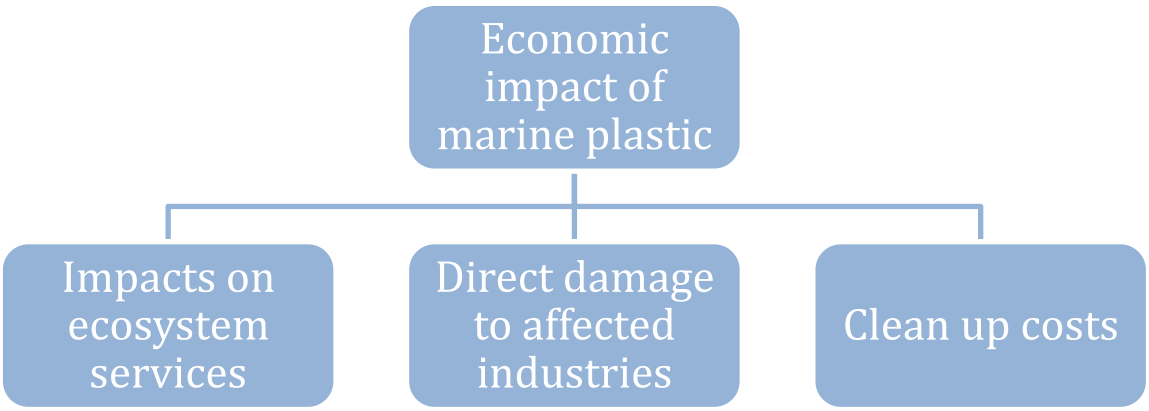

Figure i. Components of the total economic impact of marine plastic

This study provides a preliminary estimate of the economic impact associated with each of these three components; as well as an overall estimate of the economic impact of marine plastic debris in South Africa.

Methodology

Given the lack of local data and knowledge regarding the impacts of marine plastic on ecosystem services and on industry in South Africa, the study applied the 'benefits transfer' method in order to quantify the costs associated with each of the three components in Figure *i*.

This involved adapting the best available estimates of the impacts of marine plastic (in relevant units) from international studies, based on South Africa's specific context. Specifically, it involved the identification of relevant 'unit impact values' from global studies; i.e. estimates that are framed in units (e.g. impacts per tonne, or in percentage terms) allowing them to be adapted to the SA context based on relevant local variables.

It also involved consultation with relevant local experts and stakeholders to help adapt and refine the unit impact values from the global studies to the SA context. An online expert/stakeholder consultation workshop was conducted on 7 December 2022, with 40 participants from government, industry, civil society and academia. The refined unit impact values were then applied to the SA context in order to estimate the total economic impact of marine plastic in South Africa.

Results

In terms of **impacts on annual ecosystem service delivery** (first row of Table *i*), the **plastic entering South Africa's marine environment each year**[1] imposes a cost of **R3.4 billion to R34.1 billion per annum (mid-range estimate = R13.6 billion).** This is equivalent to **R68 142 to R681 423 per tonne of plastic (mid-range estimate = R272 569** per tonne), per annum.

Table i. Total economic impact of marine plastic in SA per annum (based on 50 000 tonnes of plastic entering the marine environment each year[1]*); and costs per tonne*

	Annual costs due to plastic entering SA's marine environment each year (R millions)			**Annual costs per tonne of plastic entering the marine environment each year (Rands per tonne)**		
	Low	**Mid-range**	**High**	**Low**	**Mid-range**	**High**
Impacts on ecosystem services (per year)	3 407	13 628	34 071	68 142	272 569	681 423
Direct damage to industry	64	269	475	1 272	5 390	9 507
Clean-up costs	61	203	363	1 221	4 069	7 256
Total	**3 532**	**14 101**	**34 909**	**70 635**	**282 028**	**698 186**

Direct damage to industry (2nd row of Table *i*) ranges from **R64 million to R475 million per annum (mid-range estimate = R269 million**); in terms of reductions in revenue or GDP in the fisheries, shipping and tourism sectors. This is equivalent to **R1272 to R9507 per tonne of plastic (mid-range estimate = R5390** per tonne).

Clean-up costs for marine plastic are estimated at **R61 million – R363 million per annum (mid-range estimate = R203 million** per annum) (3rd row of Table *i*). Note that the clean-up costs per tonne of plastic indicated in Table *i* refer to the costs per tonne of plastic *entering the marine environment* annually[1]; *not* the costs per tonne of plastic cleared.

[1] Estimated at 50 000 tonnes per annum; based on 40 000 tonnes per annum from land-based sources as per Verster and Bouwman (2020); plus an estimated 10 000 tonnes per annum arising due to episodic flooding (not accounted for in Verster and Bouwman's estimate) and from marine sources.

The total annual economic impact associated with the **plastic reaching the marine environment each year** ranges from **R3.5 billion to R34.9 billion per year** (**0.05% to 0.5% of annual GDP, or 4.7% to 46% of the SA plastics industry's direct contribution to annual GDP**). The mid-range estimate is **R14.1 billion** per year (**0.2% of GDP, or 18.6% of the plastics industry's direct contribution to GDP)**. The **total cost per tonne of plastic (per year)** ranges from **R70 635 to R698 186 (mid-range estimate = R282 028**) (last row of Table *i*).

Impacts on ecosystem services make up the bulk of the costs associated with marine plastic. Based on the mid-range estimate of annual impacts (R14.1 billion per annum), **impacts on ecosystem services account for 97% of the total**, with direct damage to industry (2%) and clean-up costs (1%) making up a much smaller proportion (Figure *ii*).

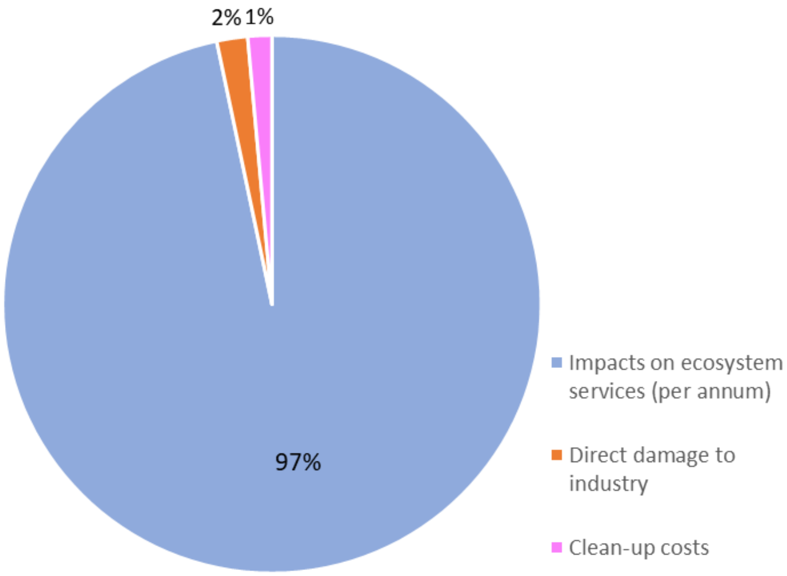

Figure ii. Percentage contribution of each component to the total economic impact

Furthermore, plastic entering the marine environment takes hundreds to thousands of years to break down, and will continue to impose negative impacts on ecosystem services throughout its lifetime. The **lifetime cost per tonne of marine plastic**, in terms of impacts on ecosystem services, **ranges between R3.4 million and R33.8 million (mid-range estimate = R13.5 million**) (not shown in Table *i*). This implies a total cost of **R169 billion – R1.69 trillion per year (2.5% to 25.5% of SA's annual GDP); with a mid-range estimate of R677 billion (10.2% of annual GDP),** in terms of **impacts on ecosystem services over the lifetime of the plastic entering the marine environment each year.**

Conclusions and recommendations

The results presented in this report should be seen as a *preliminary* estimate of the economic impact of marine plastic debris in South Africa. The intention was to develop an understanding of the order of magnitude of these impacts; so as to move the discussion forward. Owing to the uncertainties involved, and the lack of relevant South African information; a range of estimates has been provided, based primarily on adapting and adjusting unit impact values from international studies to the SA context as best as possible; while a number of assumptions have had to be made. The estimates provided in this report should therefore be seen in this context, and used with caution.

To summarise:

- **The total economic impact associated with the plastic reaching SA's marine environment each year** ranges between **R3.5 billion and R34.9 billion per year**, with a mid-range or "best" estimate of **R14.1 billion per year.**
- The **cost per tonne of plastic (per year)** ranges between **R70 635 and R698 186 (mid-range estimate of R282 028** per tonne).
- The **lifetime cost per tonne of marine plastic**, in terms of its impacts on ecosystem services over its lifetime, ranges between **R3.4 million and R33.8 million** per tonne (**mid-range estimate = R13.5 million** per tonne).
- The **plastic entering the marine environment each year** imposes a total cost of between **R169 billion and R1.69 trillion (mid-range estimate = R677 billion)** in terms of **impacts on ecosystem services over its lifetime.**

However, this report underestimates the total environmental impact associated with plastic:

- It only focuses on the impacts of plastic at end of life. Plastic gives rise to various other negative impacts across its life cycle, including greenhouse gas emissions and human health impacts associated with plastic production (WWF, 2021).
- It only focuses on *marine* plastic. The vast majority of mismanaged plastic waste generated in South Africa remains in the terrestrial or freshwater environment, or is subject to open burning (Verster and Bouwman, 2020; Stafford et al., 2022). The environmental and human health impacts associated with these forms of plastic pollution still need to be quantified.
- It only quantifies the impacts of marine plastic in terms of a reduction in ecosystem service delivery, direct damage to industry, and clean-up costs. Impacts on human health and on 'non-use' (existence and bequest) values are more difficult to quantify, and are excluded.
- The estimates are based on current rates of plastic waste generation, i.e. an assumed 50 000 tonnes of plastic reaching the marine environment each year. In the absence of significant intervention strategies, plastic production and leakage are both projected to increase in future (Jambeck et al., 2015; Stafford et al. 2022). This projected rise in plastic reaching the marine environment will in turn lead to an increase in the associated impacts.

Given the projected rise in plastic production and consumption in South Africa, **no single intervention strategy implemented in isolation will effectively reduce plastic pollution** (Stafford et al., 2022). Even with the Extended Producer Responsibility (EPR) Regulations in place, under the current targets for collection and recycling, 2040 levels of plastic pollution will be similar to current levels, given the projected growth in plastic production and consumption. Instead, **system-wide change is required, incorporating a broad range of upstream and downstream interventions; in line with the principles of a circular economy** (World Bank and CSIR, 2022).

At the same time, the negative impacts estimated in this report should be compared alongside the many benefits of plastic. There is a need for further research to assess the full set of environmental, social and economic costs and benefits of plastics, of alternatives to plastic, and of various types of intervention strategies; in order to inform the most suitable strategies for reducing the leakage of plastic waste to the environment. **However, the current lack of data should not be used as an excuse to delay action**. Making the transition to a circular plastics economy will require a concerted, collaborative effort among all role players, all working towards a shared vision.

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Acronyms

Acronym	Description
APEC	Asia-Pacific Economic Cooperation
CPI	Consumer Price Index
DFFE	Department of Forestry, Fisheries and the Environment
EPR	Extended Producer Responsibility
GDP	Gross Domestic Product
NPV	Net Present Value
RDI	Research, Development and Innovation
SDR	Social Discount Rate
TEEB	The Economics of Ecosystems and Biodiversity
UNEP	United Nations Environment Programme
USD ($)	United States Dollars
WWF	World Wide Fund for Nature
ZAR (R)	South African Rands

1 Introduction

Globally, the impacts of plastic debris on the marine environment have received increasing attention over the past decade. Jambeck et al. (2015) estimated that between 4.8 and 12.7 million metric tonnes of plastic waste entered the ocean from land-based sources in 2010. Overall, an estimated 70 to 150 million tonnes of plastic is believed to have accumulated in the world's oceans (Beaumont et al., 2019; Tekman et al., 2022). Furthermore, flows of plastic waste to the marine environment are likely to increase significantly in the absence of improved management (Jambeck et al., 2015; Tekman et al., 2022).

In Africa, the estimated total mismanaged waste in 2010 was 4.4 million metric tonnes (of which more than 10% was plastic), which is projected to increase to 10.5 million metric tonnes by 2025 if no significant changes are implemented (Hoornweg and Bhada-Thata, 2012; Jambeck et al., 2018).

Jambeck et al. (2015) ranked South Africa 11th out of 192 countries in terms of mismanaged plastic waste entering the marine environment, with 90 000 – 250 000 tonnes of plastic estimated to enter the oceans from land-based sources in South Africa each year. A more recent local study (Verster and Bouwman, 2020) shows that the amount of plastic reaching the ocean from land-based sources in South Africa is somewhat lower, in the range of 15 000 – 40 000 tonnes per annum. However, that study also highlights that the majority of total mismanaged plastic waste (estimated at 440 000 tonnes per annum) remains in the terrestrial or freshwater environment, or is subject to open burning (Stafford et al., 2022).

Nevertheless, there is evidence of an upward trend in marine plastic debris from land-based sources in South Africa, with plastic items making up a higher proportion of macro-debris found on South African beaches in more recent studies as compared to older studies (Chitaka and Von Blottnitz, 2019). Collins and Hermes (2019) predict that more than 60% of floating plastic entering the ocean from land-based sources in South Africa washes up on beaches along our coastline.

In addition to its direct impacts on marine ecology and biota, marine plastic debris can potentially affect the delivery of ecosystem services, with resulting impacts on human well-being, society and the economy. Furthermore, marine plastic debris can impact on industry directly (e.g. through damages to vessels), while additional costs are incurred in clearing up of plastic debris in order to avoid damages to industry and the environment.

Ecosystem services refer to the valuable goods and services provided by ecosystems to human societies. They include provisioning services (such as food, water and other resources), regulating services (such as climate regulation and nutrient cycles), and cultural services (such as recreation and education); as well as supporting services (such as habitat provision and biodiversity) (Millennium Ecosystem Assessment, 2005; TEEB, 2010; Haines-Young and Potschin, 2018). The delivery of such services to humankind is vital to human livelihoods and to sustained economic activity, and therefore has an intrinsic (although typically unaccounted for) economic value (Millennium Ecosystem Assessment, 2005; TEEB, 2010).

However, the by-products of human activities, such as pollution and waste, can have a negative impact on ecosystem structure and functioning, and therefore on the continued ability of ecosystems to provide these services. In turn, this leads to a reduction in the value derived from such services. For example, to the extent that marine plastic debris may have a negative impact on fish populations (provisioning services), or on the attractiveness of coastal areas (cultural services); the fisheries and tourism industries (respectively) could be negatively affected, which in turn has a negative economic impact. These negative impacts are referred to as *externalities*, that is, the side-effects of human activities which are not internalised in market prices.

To the extent that these impacts are not quantified in economic terms, the benefits of a policy response (in terms of avoided damages) are difficult for policymakers to assess. Policy responses to the plastic pollution crisis must be informed by sound scientific evidence relating to the economic, social and environmental costs and benefits of alternative mitigation strategies. 'Knee-jerk' responses that are not sufficiently informed by evidence can often do more than good. Quantifying the impacts of marine plastic debris in economic terms can therefore provide critical evidence to inform an appropriate policy response, by providing an indication of the benefits of intervention strategies aimed at reducing plastic pollution.

Arabi and Nahman (2020) identified significant gaps in the current knowledge base regarding the impacts of marine plastic debris on ecosystem services in South Africa, and on the South African economy. While the impacts of plastic debris on marine biota have been relatively well explored both globally and in South Africa; impacts on ecosystem structure and functioning, and the resulting impacts on ecosystem services (as well as on economic activities reliant on these services) are less well understood (Arabi and Nahman, 2020).

This research project aimed to address these gaps by providing a preliminary estimate of the economic impacts of marine plastic debris in South Africa; including its impacts on ecosystem services and on industry, and the costs associated with cleaning up of plastic debris.

2 Literature review

Internationally, the literature generally distinguishes between three main components of the economic impact of marine plastic (see Figure 1):

1. **Impacts on marine ecosystem services**
2. **Direct damage to affected industries**; such as fisheries and aquaculture, shipping (marine transport), and tourism (specifically marine and coastal tourism)
3. The **costs associated with clearing and removal** of plastic debris.

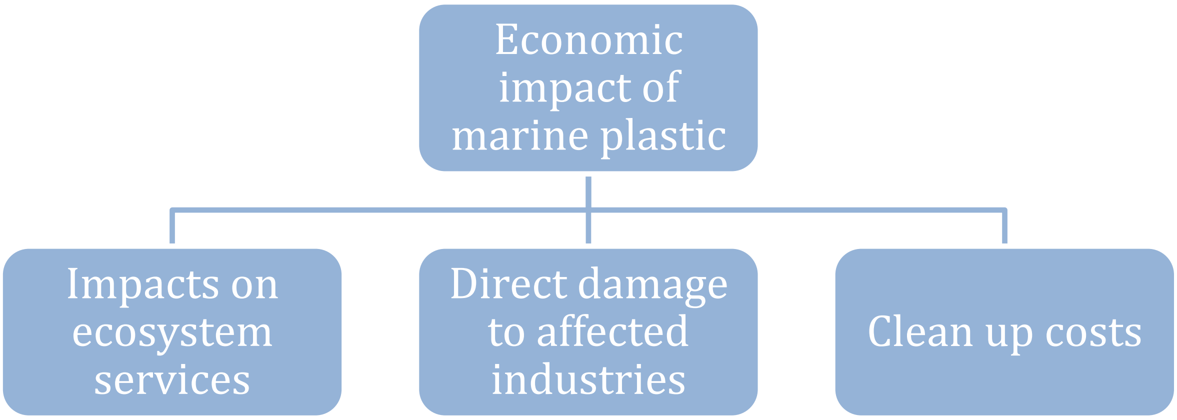

Figure 1: Components of the total economic impact of marine plastic

Some literature (e.g. McIlgorm et al., 2009; Arabi and Nahman, 2020) also refers to other types of economic impacts arising from marine plastic, including:

- impacts on human health resulting from marine life ingesting plastic and contaminating the food chain.
- Impacts on 'non-use' values, which refer to the values that humans place on the marine environment over and above the actual use of marine resources. These include 'existence' value, which refers to the value derived simply from knowing that a clean environment (or a specific iconic species) exists; and 'bequest' value, which refers to the value in knowing that a clean environment (or specific species) will still be around for future generations to appreciate.

These latter types of impacts are extremely difficult to quantify. For example, despite plastics being found in the digestive systems of some commercial fish species found in South African waters (Bakir et al., 2020), there is still a lack of research quantifying the human health impacts associated with ingestion of contaminated seafood (Hamid et al., 2018; Beaumont et al. 2019; Arabi and Nahman, 2020; see also Box 1). Existence and bequest values are also notoriously difficult to quantify in economic terms.

As such, this report will not focus on impacts on human health or non-use values. It should therefore be borne in mind that, in excluding these costs, the results presented in this report may underestimate the full economic impact associated with marine plastic.

Instead, this report will focus on quantifying the three components illustrated in Figure 1 (**impacts on marine ecosystem services**, **direct damage to affected industries**, and **clean-up costs**). Figure 1 will therefore be used as a framework around which this report is structured. In Sections 2.1 to 2.3, we summarise some of the relevant local and international literature on each of the three components. In Sections 3.1 to 3.3, we describe the methods employed in this study to quantify each component. Sections 4.1 to 4.3 present the resulting estimate of the economic impact associated with each component; while Section 4.4 aggregates across the three components to provide an overall estimate of the economic impact of marine plastic debris in South Africa.

2.1 Impacts on marine ecosystem services

2.1.1 Understanding ecosystem services

Ecosystem services refer to the valuable goods and services provided by functioning ecosystems to human societies. While a number of frameworks exist, ecosystem services are generally classified into four broad categories, namely:

- **provisioning services**: products or materials (such as food, water, energy and other resources) derived by human societies from living systems.
- **regulating services**: the role of ecosystem processes in maintaining environmental conditions favourable to all life on Earth; such as climate regulation, nutrient cycles, and the regulation of air and water quality).
- **cultural services**: the non-material benefits that we derive from ecosystems; such as recreation and leisure, aesthetic benefits, and education.
- **supporting services**: services such as habitat provision and biodiversity, which are necessary for the production of all the other categories of ecosystem services (Millennium Ecosystem Assessment, 2005; TEEB, 2010).

According to the Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2018), human society derives benefits directly from the first three of these categories (provisioning, regulating and cultural services; collectively referred to as "final" services); with supporting/intermediate services referring rather to the underlying processes necessary for the production of the final services (see Figure 2).

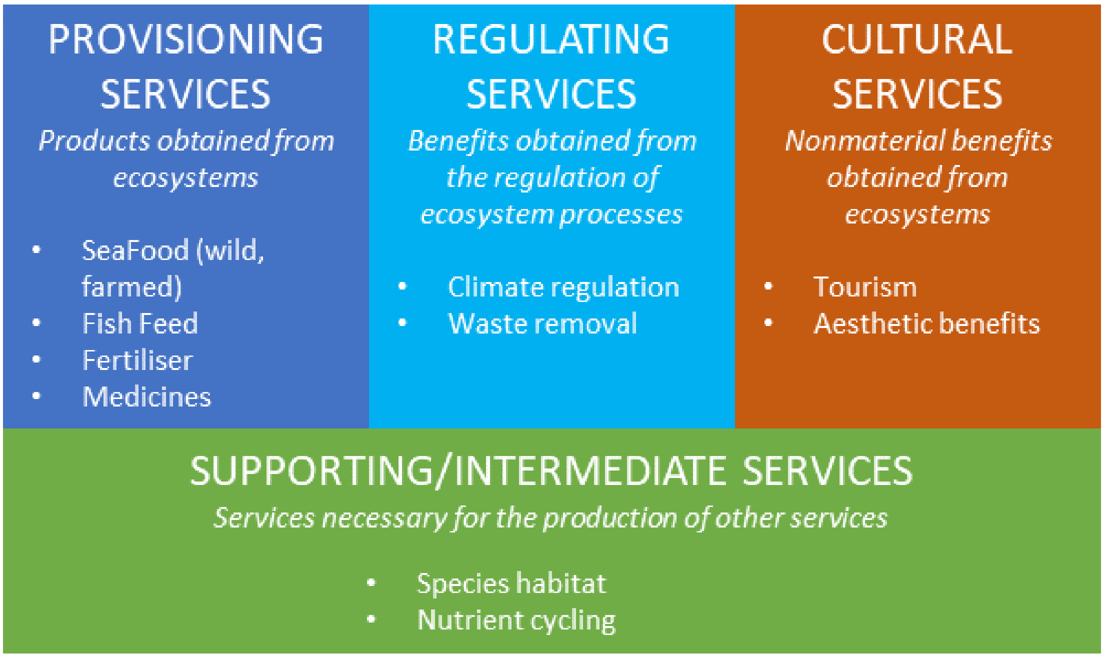

Figure 2: Summary diagram of the classification of ecosystem services (with examples), based on the CICES framework (Haines-Young and Potschin, 2018)

The provision of ecosystem services to humankind is vital to human livelihoods and to sustained economic activity; and therefore has an intrinsic (although typically unaccounted for) economic value, based on the ability of the environment to produce outputs that benefit society and human well-being (Millennium Ecosystem Assessment, 2005; TEEB, 2010) (see Figure 3).

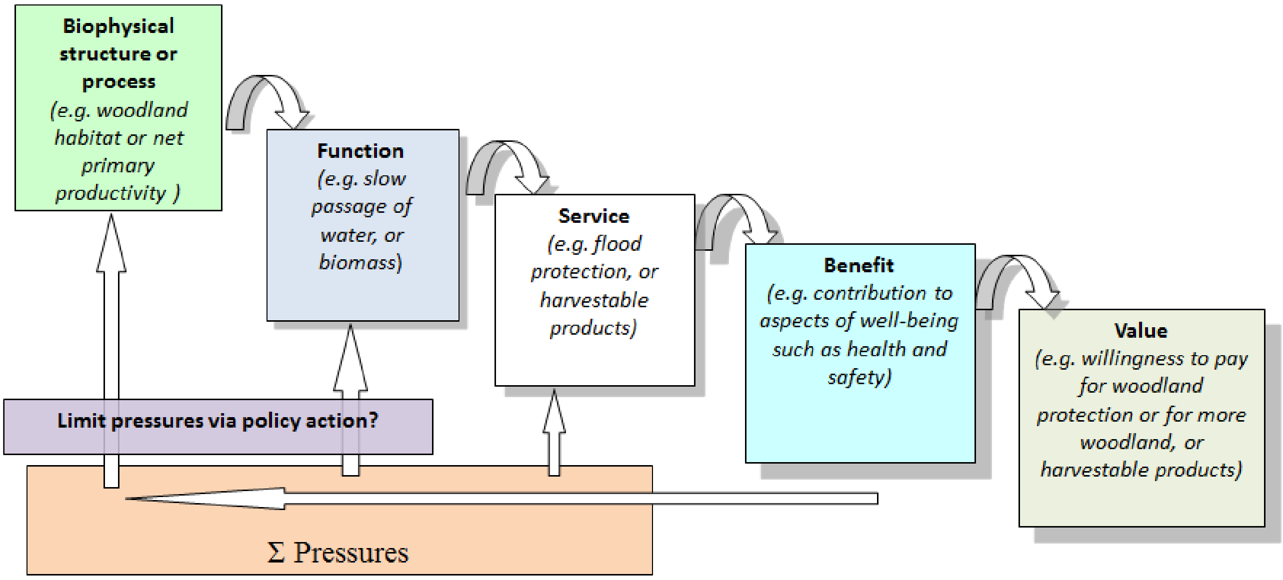

Figure 3: Ecosystem services cascade framework, highlighting the relationships between ecosystems' underlying structure and functioning, the services generated, and the benefits accrued for human wellbeing (Potschin and Haines-Young, 2011).

The ability of ecosystems to provide such services to humankind is dependent on their underlying structure and functioning (see Figure 3). The by-products of human activities (such as pollution and waste) place pressure on ecosystems, negatively affecting their structure and functioning, and impacting on their ability to provide ecosystem services. In turn, this can have a negative impact on the economic value derived from such services.

The following sub-section provides an overview of the various ways in which marine plastic debris can impact on ecosystem services in the marine environment.

2.1.2 Ecosystem services impacted by marine plastic debris

International literature suggests that all four categories of ecosystem services are impacted by marine plastic. Box 1 provides a high-level overview from the international literature of how marine plastic impacts on provisioning services (e.g. fisheries), regulating services (e.g. climate regulation and nutrient cycles) and cultural services (e.g. recreation, aesthetics and heritage); as well as supporting services (e.g. habitat provision and biodiversity); based on Arabi and Nahman (2020). In addition, Annexure 1 provides a more detailed review of how marine plastic impacts on the main types of ecosystems found in the South African marine environment.

Box 1: Impacts of marine plastic on the four categories of ecosystem services (adapted from Arabi and Nahman, 2020)

Provisioning services

Marine organisms are exposed to marine plastic debris through both ingestion and entanglement (Naidoo et al., 2020). While there is currently a lack of knowledge regarding the resulting impacts on populations (although some examples of impacts on communities are emerging in the literature); to the extent that fish stocks could be impacted by marine plastic debris, the efficiency of commercial fisheries and aquaculture farms could potentially be negatively affected.

Ingestion can take place directly from the marine environment, or through the food chain (Fazey and Ryan, 2016a; Hamid et al., 2018; Beaumont et al., 2019; Tekman et al., 2022). Studies have shown uptake of microplastics by filter-feeders, such as mussels; as well as vertebrates, such as fish and mammals. Impacts of exposure via the food chain can be detrimental due to possible accumulation and bio-magnification of microbial pathogens and toxic persistent organic pollutants in higher predators, although there is a lack of conclusive evidence in current research. The impacts of marine plastic debris on ecosystems – together with the cumulative impacts of climate change, ocean acidification and over-exploitation of marine resources – could potentially put the fishing and aquaculture industries at risk (Mouat et al., 2010).

Finally, there is potential for marine plastic to affect human health when entire contaminated organisms are ingested. This is further impacted by the accumulation of synthetic microfibres, toxic chemicals and persistent organic pollutants in shellfish and fish tissue, which have the potential to cause birth defects, cancer, and compromised immune systems, although there is currently a lack of scientific evidence regarding these health-related impacts (Hamid et al., 2018; Beaumont et al., 2019). While some studies suggest that the risks for human health due to ingestion of plastic in contaminated species are minimal (Hamid et al., 2018; Beaumont et al., 2019), the high dependency on seafood by a large part of the world's population suggests that further research is required to clarify the extent of these risks (Beaumont et al., 2019).

Regulating services

Emerging research suggests that plastic could reduce the effectiveness of the ocean as a carbon sink (WWF, 2021). Currently, the ocean removes more than 25% of carbon emissions from the atmosphere; e.g. through the actions of phytoplankton, which ingests carbon during photosynthesis; which then sinks to the ocean floor as part of the faecal matter of zooplankton and other organisms consuming phytoplankton. However, research suggests that microplastics are being ingested by zooplankton; reducing their feeding rate (thereby threatening zooplankton populations and their ability to perform this function); and making their faecal matter more buoyant (which reduces the speed at which it sinks to the ocean floor, and gives more time for the carbon to escape to the atmosphere) (WWF, 2021).

Cultural services

The presence of plastic debris in coastal areas has been found to be a key reason for visitors to shorten their visits or avoid a specific area (Beaumont et al., 2019). The presence of debris can also impact on both physical and mental health. Visitors and workers can incur physical injuries such as cuts due to sharp debris, entanglement in nets, as well as exposure to unsanitary items. Exposure to polluted coastlines has also been shown to have a negative impact on individuals' mental wellbeing and mood. Visiting beaches has important health benefits, such as promoting physical activity and social interaction, thereby improving physical and mental well-being. As such, in attempting to avoid plastic pollution by not visiting beaches, health and well-being is likely to be negatively impacted (Beaumont et al., 2019). In addition, marine debris can negatively affect peoples' quality of life by reducing the aesthetic appeal of the marine environment (Mouat et al., 2010).

The presence of marine plastic can also have negative impacts on the heritage of communities and individuals. People tend to have an emotional and/or cultural attachment to marine organisms such as turtles, seabirds and cetaceans. The expectation that these marine organisms exist and will continue to exist in future (existence and bequest values) has an impact on the well-being of humans, irrespective of whether they ever get to see or interact with these animals. The potential loss of these animals (e.g. through ingestion, entanglement, or reduced reproductive success), which has gained significant public attention in recent years, could therefore have a negative impact on the well-being of humans (Beaumont et al., 2019).

Supporting services

Approximately 70% of marine debris accumulates on the ocean floor, where it can significantly impact benthic organisms and habitats (Mouat et al., 2010). In particular, such debris can prevent gas exchanges and reduce the amount of oxygen in sediments, which impacts negatively on ecosystem functioning, benthic organisms and the composition of biota on the ocean floor. It can also physically damage benthic habitats through abrasion, scouring, and breaking; while derelict fishing gear has the potential to translocate organisms and seabed features (Mouat et al., 2015).

In addition, marine plastic has the potential to significantly impact marine ecology and biodiversity, which could in turn severely impact the resilience of such ecosystems in the face of global change (Beaumont et al., 2019). However, there is currently a lack of understanding regarding the extent to which impacts related to ingestion, entanglement, damage to benthic environments and loss of biodiversity will impact on marine ecosystems in the long term (Mouat et al., 2010).

Finally, marine plastic provides a habitat on which invasive species can become attached and be transported over long distances. Floating plastics allow for the attachment and transport of alien species and disease, thereby potentially modifying pelagic ecosystems. Plastic, unlike natural flotsam, is able to withstand UV exposure and wave action, and is able to remain buoyant for extended periods, thereby travelling great distances with the colonised species attached (Fazey and Ryan, 2016a and 2016b; Almroth and Effert, 2019; Beaumont et al., 2019).

2.1.3 Impacts of marine plastic on ecosystem services: South African research

South Africa's National Biodiversity Assessment (Skowno et al., 2019) identified plastic (including microplastic) as an emerging pressure across all realms; including land, rivers and the sea; as well as threatening biota across these environments. Annexure 1 provides an overview (mainly from international literature) of how marine species are exposed to plastic, and of the potential impacts on ecosystem services, for the main types of ecosystems (or habitat types) found in the South African marine environment (rocky shores; sandy beaches; kelp forests; tidal marshes, mangrove forests and seagrass; coral reefs; and deep sea ecosystems).

However, in their review on the state of knowledge regarding the impacts of marine plastic on ecosystem services and the economy in South Africa, Arabi and Nahman (2020) identified a significant lack of research specifically quantifying the impacts of marine plastic on ecosystem services in the South African context. While a number of studies have reported on impacts on marine biota through direct encounters with plastic (e.g. through ingestion and/or entanglement) (see Naidoo et al. 2020); there has been a significant lack of research regarding the impacts at a population/species level, or on ecosystems as a whole; nor on how these translate to impacts on ecosystem services.

Table 1 provides an overview of existing research quantifying the impacts of marine plastic on ecosystem services in South Africa, as per Arabi and Nahman (2020).

Table 1: Existing South African research quantifying the impacts of marine plastic on ecosystem services (Source: Arabi and Nahman, 2020)

Category of ecosystem services	**Impacts**	**South African research**
Provisioning services	Impacts on fisheries & aquaculture	None
Regulating services	Impacts on nutrient cycles	None
Cultural services	Impacts on recreation and aesthetics	Some research on the impacts on tourism; although in the current report this is discussed under direct damage to industry (see Section 2.2.2), or under the costs of beach clean-ups (Section 2.3.1).
	Impacts on heritage	None
Supporting services	Impacts on habitat provision	None
	Impacts on biodiversity	None
	Invasive species transport	Some studies on plastic as a vector for transport of species, but not for invasive alien species specifically.

2.1.4 Costs imposed by marine plastic on ecosystem services: International literature

Even internationally, there are few studies that have been able to quantify the costs associated with marine plastic in terms of impacts on ecosystem services. While many ecosystems and species are exposed to plastic (see Annexure 1), there remains a lack of detailed studies assessing the impact at larger spatial and temporal scales. In this section, we review two of the most widely recognised studies that have attempted to quantify the impacts of marine plastic debris on ecosystem services, namely Beaumont et al. (2019) and WWF (2021).

2.1.4.1 The Beaumont et al. (2019) approach

Beaumont et al. (2019) employed a three-step approach to quantifying the global impacts of marine plastic on ecosystem services, as follows:

1. quantifying the ecological impacts on biological subjects (based on a comprehensive review of global literature);
2. translating this to impacts on ecosystem services (by employing the CICES framework); and
3. translating this to a 'social cost of plastic'; by quantifying the extent to which plastic is impacting on the current value of global marine ecosystem services.

Beaumont et al. (2019) first reviewed published data from international literature (over 1000 data points) on the impacts of marine plastic on eight ecological subjects (bacteria, algae, zooplankton, invertebrates, fish, turtles, birds and mammals). This encompassed both observational and experimental empirical data, including data on ingestion, entanglement, colonisation of plastic, and toxicological effects on the eight subjects. These data were then systematically scored based on the extent, reversibility and frequency of the impact; where impact is defined as an effect on the lifespan and/or reproductive potential of the subject in question.

Beaumont et al. (2019) find that there is "global evidence of impact with medium to high frequency on all eight ecological subjects, with a medium to high degree of irreversibility". The majority of these impacts were found to be negative, except in the case of algae and bacteria, for which plastic increases the range of habitats available for colonisation, thereby increasing their range and abundance.

Impacts on the eight ecological subjects were then translated into impacts on ecosystem services, based on the CICES ecosystem services classification (see Section 2.1.1); and on an approach developed by Papathanasopoulou et al. (2015), who assessed the impacts of energy systems on marine ecosystem services.

Beaumont et al. (2019) then scored each subject's potential for providing each ecosystem service, based on previous global assessments and reviews (De Groot et al., 2012; Costanza et al., 2014). The impacts of plastic on the ecological subjects (as discussed above) were then combined with the assessment of each subject's potential for providing each service, to determine the impact of marine plastic on ecosystem services. Beaumont et al. (2019) find that all ecosystem services are negatively impacted (to varying extents) by the presence of marine plastic, with one exception ('regulation of the chemical condition of salt waters by living processes').

Based on these results, Beaumont et al. (2019) provide an initial assessment of the impacts of marine plastic on marine natural capital (the world's stocks of marine natural assets). They argue that, "based on available research, it is not yet possible to accurately quantify the decline in annual ecosystem service delivery related to marine plastic" (Beaumont et al., 2019). However, their results suggest "substantial negative impacts on almost all ecosystem services at a global scale" (Beaumont et al., 2019). They argue that, in light of this evidence, "**it is considered reasonable to postulate a 1–5% reduction in marine ecosystem service delivery as a result of the stock of marine plastic in the oceans in 2011**" (Beaumont et al., 2019). They further argue that this estimate "is conservative when compared to the reduction in terrestrial ecosystem services due to anthropogenic disturbances available in the literature" (Beaumont et al., 2019); such as an 11–28% decline in the value of global terrestrial ecosystem services arising from land use changes between 1997 and 2011, and a reduction in the value of ecosystem services of up to 31% due to urbanisation in China (Beaumont et al., 2019).

Finally, to translate this percentage reduction in marine ecosystem service delivery to an economic impact, Beaumont et al. (2019) draw on a well-known paper by Constanza et al. (2014), which estimates the value of all ecosystem services globally. For marine ecosystem services specifically, Constanza et al. (2014) estimated that, on a global scale, **marine ecosystem services provide benefits to society valued at $49.7 trillion per year** (in 2007 USD, as at 2011).

Then, Beaumont et al. (2019) calculate the annual reduction in marine ecosystem service delivery as a result of plastic; by applying the 1-5% reduction in marine ecosystem service delivery (see above), to the baseline value of $49.7 trillion. Based on the value of marine ecosystem services of $49.7 trillion, a 1–5% decline in marine ecosystem service delivery "equates to an **annual loss of approximately $500 billion –$2.5 trillion in the value of benefits derived from marine ecosystem services**" (Beaumont et al., 2019), as a result of marine plastic.

In order to translate this to a cost per tonne of plastic, Beaumont et al. (2019) look at the stock of plastic that is believed to have accumulated in the world's oceans, which was estimated at between 75 and 150 million tonnes in 2011. Dividing the lower-end estimate of the annual loss ($500 billion per year, see above) by the higher-end estimate of the amount of plastic in the ocean (150 million tonnes), gives rise to a cost of $3300 per tonne, as a conservative, low-end estimate of the cost per tonne of plastic in terms of its impact on ecosystem services. On the other hand, dividing the higher estimate of the annual loss ($2.5 trillion per year), by the lower estimate of the amount of plastic in the ocean (75 million tonnes), gives rise to $33 000 per tonne, as a higher-end estimate of the cost per tonne.

In other words, looking at the amount of marine plastic pollution assumed to be in the ocean in 2011; and based on the value of marine ecosystem services in 2011, and the assumed percentage reduction in ecosystem service delivery due to marine plastic, **each tonne of plastic in the ocean gives rise to an estimated annual reduction in the value of marine ecosystem services of between $3300 and $33 000** (Beaumont et al., 2019).

2.1.4.2 Extending the Beaumont et al. (2019) approach to include lifetime costs: WWF (2021).

The impact per tonne of plastic ($3300 to $33 000 per tonne) calculated as above by Beaumont et al. (2019) is based on the *annual* reduction in marine ecosystem service delivery due to each tonne of plastic in the ocean; that is, the damage caused by each tonne of plastic *in one year*.

However, ocean plastic takes hundreds to thousands of years to fully degrade, during which time it breaks down into smaller particles (WWF, 2021). It will therefore remain in the ocean and continue to accumulate as more waste enters the marine environment each year. During this time, it will continue to affect ecological functions and processes. Marine plastic can therefore impact on ecosystem services not only in one year, but every year over the course of its lifetime (WWF, 2021).

WWF (2021) therefore extend on Beaumont et al.'s (2019) analysis of the *annual* cost per tonne of plastic, by calculating the **lifetime cost of each tonne of plastic in the ocean**. This is done by applying a **Net Present Value (NPV)** formula to the annual cost per tonne. An NPV formula is typically used to calculate the overall value of an investment by 'discounting' the future stream of positive and negative cash flows to present value terms, and aggregating these flows over the lifetime of the project. Future cash flows are discounted using an appropriate discount rate to reflect the 'time value of money', that is, the higher value placed on money in the present as compared to an equivalent amount of money in the future.

In the context of economic valuations of inter-generational environmental issues (such as climate change, or plastic pollution), a similar NPV formula can be used to quantify the environmental impacts imposed by current economic activities on future generations. In this context, discounting the future impacts essentially gives more weight to impacts occurring in the present as opposed to impacts on future generations. As such, given the need to ensure inter-generational equity, it is often argued that a relatively low (or even zero) discount rate should be applied. In this case, WWF (2021) apply a relatively low social discount rate (SDR) of 2%, based on Drupp et al. (2018), who found through a survey of 200 experts that the majority supported a median SDR of 2% (WWF, 2021). This ensures that costs imposed on future generations are still given a reasonably high weighting within the calculation, relative to the case of a higher discount rate being applied.

First, WWF (2021) note that Beaumont et al.'s (2019) estimates are based on a fairly outdated (2007 USD) figure for the total annual value of marine ecosystem services ($49.7 trillion; see Section 2.1.4.1). WWF (2021) adjusted this to $61.3 trillion in 2019 USD, based on inflation (changes in the U.S. Consumer Price Index). Applying the 1-5% range from Beaumont et al. (2019) in terms of the percentage loss in ecosystem service delivery due to marine plastic (see Section 2.1.4.1), results in an increase in the range of values for the annual cost per tonne of plastic; which now ranges between $4087 and $40 867[2] per tonne.

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[2] This range is an update on the values calculated by Beaumont et al. (2019) ($3300 to $33 000 per tonne; see Section 2.1.4.1), based on the updated figure for the value of marine ecosystem services ($61.3 trillion as per WWF (2021), as compared to the $49.7 trillion applied by Beaumont et al. (2019)). Based on the updated value of marine ecosystem services of $61.3 trillion, a 1–5% decline in marine ecosystem service delivery equates to an annual loss of approximately $613 billion – $3.1 trillion in the value of benefits derived from

Secondly, for the sake of being conservative; WWF (2021) apply only the **low end** of Beaumont et al.'s (2019) range for the reduction in marine ecosystem service delivery due to plastic (i.e. **1%**, rather than the full 1 - 5% range). This results in a more conservative range of **$4087 to $8173[3] for the annual cost per tonne of plastic.**

Finally, applying the NPV formula as described above to these annual costs per tonne, results in a lifetime cost of approximately $204 270 – $408 541 per tonne of plastic. In other words, **the total impact on ecosystem services caused by each tonne of marine plastic over its lifetime is between $204 270 and $408 541 per tonne** (WWF, 2021). Therefore, the total lifetime cost of the plastic produced globally in 2019 that becomes marine plastic debris (estimated at around 11 million tonnes) ranges from $2.1 trillion to $4.2 trillion (median estimate = $3.1 trillion), in terms of impacts on marine ecosystem services over its lifetime (WWF, 2021).

2.2 Direct damage to affected industries

2.2.1 Industries affected by marine plastic

In terms of the impacts of marine plastic on industry, most of the literature (e.g. McIlgorm et al., 2009; Ten Brink et al., 2009; Mouat et al., 2010; Trucost, 2016; Deloitte, 2019; Arabi and Nahman, 2020; McIlgorm et al., 2020) focuses on three industries that are potentially affected by marine plastic debris, namely:

- **Fisheries and aquaculture,** e.g. losses in earnings due to reduced catch size and/or contaminated catch due to the presence of marine plastic; as well as increased costs associated with repairing damage to fishing vessels and equipment (Mouat et al. 2010).
- **Shipping (marine transport)**, e.g. through "fouling of propellers, damage to drive shafts, fouled anchors, clogging of intake pipes, and increasing maintenance and repair costs" (Arabi and Nahman, 2020).
- **Tourism** (specifically **marine and coastal tourism**). For example, research has shown that the presence of debris on beaches has a negative impact on beach-goers and can lead to a reduction in visitors to polluted beaches, which could in turn negatively affect the tourism industry (Arabi and Nahman, 2020).

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marine ecosystem services. Dividing the lower end estimate of the annual loss ($613 billion loss per year) by the higher end estimate of the amount of plastic in the ocean (150 million tonnes; see Section 2.1.4.1), gives rise to a low-end cost of $4087 per tonne (note that this differs slightly from the figure of $4085 per tonne presented in WWF (2021), due to rounding differences). Dividing the higher estimate of the annual loss ($3.1 trillion per year), by the lower estimate of the amount of plastic in the ocean (75 million tonnes), gives rise to $40 867 per tonne, as a higher-end estimate.

[3] Calculated as above, except that since WWF (2021) apply only the 1% reduction in the value of ecosystem services (rather than the full 1-5% range from Beaumont et al. (2019)); only the low-end figure for the annual loss ($613 billion) is applied. Dividing the $613 billion loss per year by the higher end estimate of the amount of plastic in the ocean (150 million tonnes), gives rise to a low-end cost of $4087 per tonne, as above. Dividing the $613 billion loss per year by the lower estimate of the amount of plastic in the ocean (75 million tonnes), gives rise to $8173 per tonne, as the higher-end estimate applied by WWF (2021). Note that the figures calculated here differ slightly from those presented in WWF (2021) due to rounding differences.

Some literature also highlights impacts on other industries, such as real estate (Ofiara and Seneca, 2006; Wang and Sen, 2019). However, the three industries listed above (fisheries and aquaculture, shipping and tourism) are the ones most often identified in the literature as being impacted by marine plastic; and will therefore form the focus of this report in terms of impacts on industry.

Importantly, these industries can be affected by marine plastic in three different ways:

- Impacts that arise *indirectly, through a reduction in ecosystem service delivery* (see Section 2.1). For example, the fisheries industry relies on the supporting and provisioning services provided by marine ecosystems (e.g. habitat provision for fish populations). Impacts on ecosystem services as a result of marine plastic (e.g. impacts on fish habitats, or impacts arising through ingestion of microplastics), can therefore lead to a reduction in the quantity or quality of fish stocks, thereby negatively affecting the fisheries industry through a reduction in revenues (or, an increase in the effort (and therefore cost) required to maintain the same level of harvest).
- Impacts that arise through *direct encounters with plastic debris*, rather than through impacts on ecosystem services. For example, macroplastic debris can cause damage to fishing vessels, leading to downtime (and in turn a reduction in revenues), as well as increased costs associated with repair; thereby impacting on the fishing industry directly. Similar impacts are also relevant to the marine transport (shipping) industry; while impacts on tourism are likely to arise through an unwillingness among tourists to visit beaches with a high concentration of plastic debris; which may in turn lead to a reduction in tourism revenues in coastal areas that are heavily impacted by plastic.
- Costs associated with clean-up operations (clearing and removal of plastic debris; see Section 2.3), which are aimed at *avoiding* the direct and indirect damages referred to above.

In order to avoid double-counting with the other impact categories discussed in this report (see Sections 2.1 and 2.3); we attempt as far as possible to separate out the costs to industry that arise through impacts on ecosystem services (see Section 2.1) or through clean-up operations (Section 2.3); from those that arise as a result of direct damage caused by plastic debris (the current section). In other words, Section 2.2 focuses only on *direct damage* to industry; and excludes costs arising through impacts on ecosystem services or from clearing of plastic debris. In terms of the results, we assume that impacts on industry which arise through impacts on ecosystem services will already be included in the estimate of ecosystem service impacts (Section 4.1); and therefore exclude them from the analysis of direct damages in Section 4.2, to avoid potential double-counting (WWF, 2021). As such, when discussing impacts on industry, we attempt rather to focus only on those impacts arising as a result of direct encounters with plastic debris (i.e., direct damage).

2.2.2 South African data on direct damage to industry from marine plastic

As was the case for impacts on ecosystem services, Arabi and Nahman (2020) identified significant knowledge gaps regarding the impacts of marine plastic on industry in South Africa, particularly in terms of direct damage. For the **fisheries and aquaculture** industries, the authors noted that no information could be found regarding direct damages resulting from marine plastic. In the case of **shipping**, Arabi and Nahman (2020) note that "debris (including plastic) in and around the Port of Durban can become a shipping hazard, particularly after periods of heavy rainfall. However, there has been little assessment of the associated economic impacts." They do provide anecdotal evidence on costs incurred by the Port in clearing debris; but as explained above, in the current report these costs are discussed in relation to clean-up costs (see Section 2.3), rather than under direct damage to industry (current section).

For **tourism** on the other hand, Arabi and Nahman (2020) referred to a study by Ballance et al. (2000), which found that:

> *"cleanliness was the primary factor influencing visitors to the Cape Peninsula when choosing a beach, particularly for international tourists. Almost 50% of residents would be prepared to spend more to visit clean beaches further away; while litter densities of more than 10 large items per metre of beach would deter 40% of foreign tourists, and 60% of domestic tourists, from returning to Cape Town, with a significant potential impact on the local economy. If beaches had more than 10 large debris items per metre, 97% of visitors would not visit them, leading to a decline in total recreational value of approximately R300 000 ($19 600) per year, and a loss of R8 million ($520 000) for the regional economy (based on 1996 values)"* (Arabi and Nahman, 2020).

More recently, Benn et al. (2022) estimated the 'foregone economic value' associated with the 'linear plastic packaging model' in terms of loss of revenue (GDP reductions) in specific sectors; namely tourism, real estate, and fisheries and aquaculture; for three African countries, by adapting data from international studies. The loss of revenue for these sectors in South Africa was estimated at $2.9 million per annum. In addition, they estimate "increased operational and maintenance costs of seaports, marinas, waterways and stormwater networks" of $1.1 million per annum. Taken together, these can be seen as providing an estimate for direct damages to industry totalling $4 million per annum (in 2018 USD), equivalent to R63.6 million in 2022 Rands.

2.2.3 International literature on direct damage to industry

Tables 2, 3 and 4 summarise evidence on the direct damage imposed by marine plastic on the three industries (fisheries and aquaculture, shipping, and tourism) in other countries. The impacts are typically reported on a cost per annum basis (Table 2); or in terms of the damage associated with a specific incident (Table 3), such as a container spill or shipping accident.

Table 2: Estimates of direct damage caused by marine plastic on three industries, in terms of costs per annum

Industry	Type of debris	Type of impact	Area	Costs (USD per year)	Source
Fisheries and aquaculture	Ghost fishing gear (nets)	Loss of fisheries production (lobsters)	USA	$250 000 000	Raaymakers (2007), cited in McIlgorm et al. (2020)
	Floating objects	Damage to fishing boats	Japan	$45 000 000	Takehama (1990); McIlgorm et al. (2020)
	Ghost fishing gear (crab pots)	Loss in production	USA	$11 000 000 (based on increase in production of $66m in 6 years due to ghost gear removal)	Bilkovic et al. (2016); McIlgorm et al. (2020)
Shipping (marine transport & related services)	General debris	Cost of repairs, lost sales & downtime due to damage to commercial leisure boats (entanglement of propellers)	USA	$792 000 000	Ofiara and Seneca (2006); McIlgorm et al. (2020)
Marine & coastal tourism	Plastics, fishing gear and general debris	Loss of amenity to beaches and reefs	USA	$1 000 000 – $28 000 000	Ofiara & Seneca (2006); McIlgorm et al. (2020)

Table 3: Estimates of direct damage following specific incidents related to marine plastic debris

Industry	Type of debris	Type of impact	Area	Damage caused	Source
Fisheries and aquaculture	Plastic pellets (ship container spill - Sinopec accident)	Loss of fishing product value for fish farmers	Hong Kong / China / Chinese Taipei	30-40% price reduction to fish farmers	SCMP (2012); McIlgorm et al. (2020)
Shipping (marine transport & related services)	Nylon rope	Loss of life due to sinking of passenger ferry after entanglement	Korea	292 lives lost	WWF (2021)
Marine & coastal tourism	Litter and other waste	Reduction in visitors and tourism revenue due to debris washing down rivers onto beaches after flooding	Geoje Island, Korea (2011)	63% reduction in visitors; $29-37 million loss in tourism revenue	Jang et al. (2014); McIlgorm et al. (2020)
	Plastic and marine debris	Reduction in tourism revenue due to mass marine litter wash up	New Jersey, USA (1988)	$379m to $3.6 billion loss in tourism expenditure	NRC (2009); Ofiara & Brown (1989); McIlgorm et al. (2020)

Some studies have summarised the available evidence on direct damages in terms of a percentage reduction in the value of output (i.e. revenues or contribution to GDP) in each industry. Table 4 summarises the ranges reported in the literature for the percentage reduction in revenues or GDP across the three industries.

Table 4: Estimates of direct damage caused by marine plastic on three industries, in terms of percentage reduction in revenues or GDP

Industry	% reduction in revenues or GDP due to marine plastic (range)	Source
Fisheries and aquaculture	0.3% - 5%	Takehama (1990), Ten Brink et al. (2009), Deloitte (2019), McIlgorm et al. (2020).
Shipping (marine transport & related services)	1%	McIlgorm et al. (2020)
Marine & coastal tourism	0.3% - 5%	Ten Brink et al. (2009), Mouat et al. (2010), Trucost (2016), Deloitte (2019), McIlgorm et al. (2020).

For **fisheries and aquaculture**, the literature suggests that marine plastic leads to a reduction in annual revenues or GDP ranging between 0.3% and 5% (see Table 4). Takehama (1990) estimates damages of 0.3% of the value of the annual output of the fisheries industry in Japan, “based on the amounts of damages covered by insurance and resulting from collision, entanglement, engine trouble, and other accidents associated with objects floating in the sea”. This estimate is still applied as recently as 2019, in a report by Deloitte (2019).

McIlgorm et al. (2020) likewise cite the Takehama (1990) estimate; however, they argue that because plastic production is now 3.2 times higher than in 1990, the 0.3% estimate should be increased to 1% to account for the higher associated damages. Finally, according to Deloitte (2019), the percentage loss for the fisheries industry can reach as high as 5%, which could perhaps be seen as an upper-bound estimate.

For the **shipping** industry, which includes marine transport and ship-building, only one estimate of the percentage reduction in the value of output could be found in the literature, namely a 1% reduction in annual GDP for this industry (McIlgorm et al., 2020) (see Table 4).

Finally, for **marine and coastal tourism**, a wider range of estimates of the percentage reduction in revenues or GDP due to marine plastic can be found in the literature, ranging between 0.3% and as high as 5% (see Table 4). Citing Takehama (1990) and Ten Brink et al. (2009); Deloitte (2019) apply a range between 0.3% and 3%. However, aside from being outdated, the 0.3% estimate from Takehama (1990) is not strictly relevant, as it was derived based on damages to fishing vessels (see above), rather than based on losses to the tourism industry.

According to McGilorm et al. (2020), more recent studies (such as Mouat et al., 2010 and Trucost, 2016) apply a damage estimate for the marine tourism sector ranging between 2 – 5%. In their own modelling, McGilorm et al. (2020) apply a 1.5% reduction.

Finally, Deloitte (2019) provides a summary (per region) of the average loss in economic value due to marine plastic for the marine tourism and fisheries & aquaculture sectors combined, in USD per capita (see Table 5). For Africa, the average loss in revenues is $0.06 per capita, with a global average of $0.36 per capita.

Table 5: Average loss in economic value in the marine tourism and fisheries & aquaculture sectors due to marine plastic, per region (Source: Deloitte 2019).

Region	Loss in economic value (per capita)
Asia	0.32
Europe	0.94
North America	0.65
Latin America	0.27
Oceania	0.32
Middle East	0.12
Africa	0.06
Global Average	**0.36**

2.3 Clean-up costs

2.3.1 South African data on clean-up costs

In contrast to the case of impacts on marine ecosystem services, and direct damage to affected industries; there is some South African data available in the literature on the costs associated with beach clean-ups aimed at removing beach debris (including plastics, among other materials). However, this data is mostly only available for clean-up operations by municipalities, particularly by the City of Cape Town; or by the Port of Durban following specific storm events. Information on costs associated with clean-ups organised by the private sector or civil society is not readily available (see Section 3.3). In addition, for the most part the data is fairly outdated; and its relevance to the current situation, where the tonnages of plastic reaching the marine environment have increased significantly in recent years (Chitaka and Von Blottnitz, 2018; McGilorm et al., 2020), and where clean-up efforts have presumably ramped up in response, can be questioned.

Table 6 provides an overview of South African data on clean-up costs available from the literature, as reported in Arabi and Nahman (2020).

Table 6: Available data on the costs of clearing and removal of marine debris in South Africa, as per Arabi and Nahman (2020)

Authority	Data on costs	Year	Source
City of Cape Town	R2.7 million spent on beach clean-ups during the 1992-93 financial year (approximately R14.3 million in 2022 Rands); amounting to R3 000 per tonne (R15 949 per tonne in 2022 Rands) for beach debris removal (including plastics as well as other materials).	1992 - 1993	Swanepoel (1995); cited in Arabi and Nahman (2020)
City of Cape Town	R3 million spent on beach cleaning during 1994-95 (R13.5 million in 2022 Rands).	1994 - 1995	Ballance et al. (2000); cited in Arabi and Nahman (2020)
63 coastal authorities across SA	R5.5 million spent by 34 coastal authorities on cleaning beaches (R3.5 million alone for City of Cape Town); extrapolated to R8 million for all 63 coastal municipalities (approximately R35.9 million in 2022 Rands).	1994 - 1995	Ryan and Swanepoel (1996); cited in Arabi and Nahman (2020)
Port of Durban	Clean-up costs due to storm events in April/May 2019 ranged between R52 800 and R1 046 000 per event; amounting to R4 350 000 over that two-month period.	2019	Personal communication cited in Arabi and Nahman (2020)

More recently, however, Benn et al. (2022) estimate a cost to run clean-up activities in South Africa of $1.3 million annually (2019 USD; equivalent to R21.7 million in 2022 Rands). This was based on an adaptation from international studies.

In addition to coastal clean-ups, South Africa's coastal municipalities also spend significant amounts on clearing of illegal dumping to avoid unnecessary leakage of plastic and other debris into the marine environment. The amount spent on clearing of illegal dumping by nine of the 14 coastal municipalities in the Western Cape alone exceeds R217 million per annum (Western Cape Department of Environmental Affairs and Development Planning, 2017).

2.3.2 International data on clean-up costs

In the international literature, the costs associated with clean-up operations are reported in various ways; e.g. in costs per annum, costs per tonne of plastic removed, costs per recovery operation; or, in the case of fishing gear removal, in terms of costs per net or trap removed. In some cases, rather than reporting on costs, studies provide an estimate of the benefits of clean-up operations (e.g. in terms of increased fishing harvest, increased number of beach visits or increased tourism revenue associated with a certain percentage reduction in marine debris).

Table 7 provides a summary of clean-up costs (and benefits) for the Asia-Pacific Economic Cooperation (APEC) Region (McGilorm et al., 2020).

Table 7: Estimates of clean-up costs and benefits in the APEC region (Source: McGilorm et al. 2020).

Type of action / Type of impact avoided	Area	Year	Costs	Benefits
Removal of ghost crab pots (to avoid reduction in catch)	USA			14% increase in blue crab harvest from removal of 10% of derelict pots
Retrieval of ghost fishing nets (to avoid loss of fishing gear and downtime due to entanglement)	Australia / New Zealand		$10 000 000 per year	
Removal of ghost fishing nets and traps	USA		$1.22 per m^2 of net; $193 per trap	
Removal of ghost fishing nets	Australia		$25 000 per recovery operation	
Recovery and clean-up of plastic pellets from container spill (to avoid impacts on value of fish farmers' product following Sinopec accident)	Hong Kong / China / Chinese Taipei		$8 600 per tonne of pellets*	
Clearing of marine debris (to avoid impacts on tourism due to marine debris on beaches)	31 California beaches, USA	2013		$29.5m benefit from 25% per capita reduction in marine debris; $148m benefit from 100% per capita reduction
Cleaning municipal beaches and waterways	New York City		$2 719 500 per year or $0.33 per capita	
Beach and waterway clean ups to combat litter & curtail marine debris	West Coast, USA		$520m spent by cities across 3 states	
Reducing debris in six beaches near the mouth of Los Angeles River (to avoid impacts on tourism due to marine plastic on beaches from urban sources)	California, USA			43% increase in beach visits / $53 million increase in revenues from 75% reduction in debris
Clearing of marine debris (to avoid loss of recreational expenditure and regional economic effects)	California, USA			A benefit of $137m would arise from a 100% reduction in marine debris
Contract for collection & disposal of marine floating refuse & refuse from vessels	Hong Kong / China	2018	$11 500 000 per year, $716 per tonne	
Local government clean-up of 214 711 tonnes of marine litter and shoreline debris over 8 years	Japan	2009 - 2016	$451m total cost over 8 years; $848 to $8 188 per tonne	
Clean up of 348 000 tonnes of marine debris (shoreline, floating & from natural disasters)	Korea	2014 - 2018	$282m across 21 programs over 5 years; $733 to $1 149 per tonne	
Clean up of shoreline and waterways, involving local government and volunteers	Australia		$26 000 000	
Recovery of plastic pellets from container spill (MV Rena)	New Zealand		$600m spent on recovery	

** The high cost per tonne associated with retrieval of plastic pellets can be expected given the greater difficulty in retrieving pellets as compared to macro-debris.*

On the other hand, Deloitte (2019) summarises available information on clean-up costs from various international studies, and provide an average estimate of clean-up costs per capita, for each region (see Table 8). Unfortunately, Deloitte (2019) does not specify if the 'per capita' refers to coastal populations only, national populations, or the population of the region as a whole; however our assumption is that it refers to national populations.

Table 8: Average clean-up costs per capita in each region (Source: Deloitte 2019).

Region	Clean-up cost (USD per capita)
Asia	2.51
Europe	0.29
North America	0.24
Latin America	0.54
Oceania	0.06
Middle East	0.01
Africa	0.06
Global Average	**1.61**

3 Methods

Recall from Section 2 and Figure 1 (repeated as Figure 4 below) that, in this report, we focus on quantifying three main components of the total economic impact of marine plastic, namely:

1. Impacts on marine ecosystem services
2. Direct damage to affected industries
3. Clean-up costs

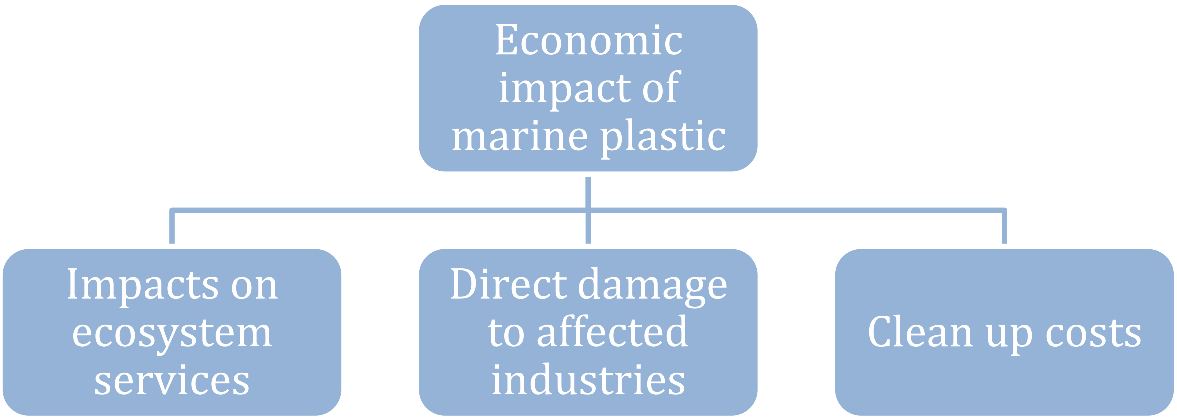

Figure 4: Components of the total economic impact of marine plastic

The overall approach to the study involved quantifying the economic impact associated with each of the three components, through extensive reviews of relevant local and international literature, as well as engagements with local experts and stakeholders; followed by aggregation to derive an estimate of the total economic impact of marine plastic in South Africa (per annum, and per tonne of plastic).

Initially, the literature review focused on assessing the current state of knowledge regarding the economic impacts of marine plastic debris. Specifically, the focus was on understanding the extent of relevant local knowledge that could potentially be used to derive locally relevant estimates of the impacts of marine plastic; as well as on understanding the approaches that have been used internationally for quantifying the impacts of marine plastic in other contexts.

In general, the initial review of the local literature suggested that very little information was available locally to enable quantification of the economic impacts of marine plastic in South Africa (see Section 2). This was confirmed through subsequent engagements with experts and stakeholders, including experts relating to each of the three components of the total economic impact (i.e. experts relating to marine ecosystem services; representatives from the main affected industries; as well as experts from government, industry and civil society involved in coordinating clean-up events conducted across South Africa).

As such, for each of the three components, it became necessary to apply a version of the '**benefits transfer' method** in order to quantify the economic impacts. Benefits transfer is an economic valuation technique based on transferring existing estimates of economic impacts (benefits or costs) from other study site(s) to the site in question; and making appropriate adjustments to accommodate for contextual differences between the original study site(s) and the new study site (e.g. socioeconomic, demographic, geographic and climatic differences) (Georgiou et al., 1997; Barbier et al., 1997, Eshet et al., 2005). Benefits transfer is often applied in situations where there is a lack of relevant local data for undertaking economic valuation based on primary valuation methods.

In this case, the approach involved adapting the best available estimates of the impacts of marine plastic (in relevant units) from international studies to the South African context, based on relevant local information. Specifically, it involved the identification of relevant 'unit impact values' (Wen et al., 2021) from global studies; i.e. estimates that are framed in units (e.g. impacts per tonne, or in percentage terms) allowing them to be adapted to the South African context based on relevant local variables.

It also involved consultation with relevant local experts and stakeholders to help adapt and refine the unit impact values from the international studies to the SA context as best as possible. Specifically, an online expert/stakeholder consultation workshop was conducted on 7 December 2022, with the aim of achieving consensus among the participants on how best to adapt the unit impact values from international studies to the South African context, and to help refine the preliminary estimates. Approximately 90 relevant experts and stakeholders from government, industry, civil society organisations and academia were invited; while 40 participants joined the meeting.

In general, the approach applied for quantifying each component of the total economic impact of marine plastic (Figure 4) was as follows:

1. Extensive review of international literature to identify the best available estimates of the impacts of marine plastic in relevant units; i.e. in terms that can be adapted to the SA context based on available local data. For each component of the total economic impact of marine plastic, a range of estimates of the unit impact value was obtained.
2. Make preliminary estimates of the impacts of marine plastic in South Africa (within a range), by applying the range of unit impact values to the South African context.
3. Consult with relevant local experts and stakeholders to achieve consensus on how best to adapt the international estimates to the South African context; i.e. to discuss where South Africa lies within the range of unit impact values for each component, based on our specific context; and to refine the preliminary estimates.
4. Based on the refined unit impact values, and relevant local variables, calculate the cost (per tonne of plastic, and per annum) for South Africa, for each component of the total economic impact.
5. Ground-truth the resulting estimates by comparing them with any existing relevant local information, where available.

As mentioned above, the costs associated with each component were then aggregated, in order to derive an estimate of the total economic impact of marine plastic in South Africa, per annum and per tonne of plastic.

The following sub-sections describe the specific approach applied for each component in more detail.

3.1 Impacts on marine ecosystem services

The original approach proposed for the evaluation of the impacts of marine plastic on ecosystem services in SA was to develop an impact framework structured around the impacts of marine plastic debris on the biophysical structure of marine ecosystems, and a conceptual understanding of the links between marine plastic debris and ecosystem service provision, based on the ecosystem services cascade model (see Figure 3). The intention was then to consult with relevant local experts on the impact pathways of marine plastic debris on ecosystem services, and the expected decrease in ecosystem service delivery as a result of marine plastic debris.

As such, a detailed conceptual framework was developed, drawing on Jones et al. (2012) and Beaumont et al. (2019), as described in a separate report (Blanchard and Smith-Adao, 2023). Based on the approach of Beaumont et al. (2019), the framework aimed to develop impact pathways for several ecosystem services based on exposure of marine habitats or biota to plastic, and the resulting impacts; as well as an understanding of how these species-level impacts translate into impacts on ecosystem structure and functioning. However, it soon emerged from initial piloting of the framework with relevant experts that there is currently an insufficient level of knowledge in South Africa regarding the impacts of plastic debris on specific species, or regarding the mechanisms by which this results in impacts on ecosystem structure and functioning (and therefore on ecosystem services) in South Africa. In addition, the lack of baseline studies quantifying marine ecosystem services in South Africa, means that little information is available on the indicators or the spatial units that underpin ecosystem services, which could be used to assess the impact of pressures such as plastic.

It therefore became clear that, while this framework could provide a South African perspective on the ecosystem services impacted by marine plastic (see the separate report by Blanchard and Smith-Adao (2023) for more details); it would not be possible at present to apply this framework to quantify the impacts of marine plastic debris in the South African context; and that an alternative approach would need to be applied.

Recall from Section 2.1.4.1 that Beaumont et al. (2019) applied a similar framework in estimating the impacts of marine plastic on ecosystem services at a global level. At that scale, the authors were able to apply the framework by drawing on a large number of data points from international studies; which was not possible at the national scale in South Africa due to a lack of SA-specific data. Recall also that based on applying this framework at the global scale, Beaumont et al. (2019) estimated a 1–5% reduction in marine ecosystem service delivery (annually) as a result of the stock of marine plastic in the oceans in a particular year (in their case, they used 2011); and a resulting cost imposed on marine ecosystem service delivery per tonne of plastic in the ocean (see Section 2.1.4.1). As discussed in Section 2.1.4.2, Beaumont et al.'s (2019) approach has since been adapted by WWF (2021), who extend on the approach by looking at the impacts generated by each tonne of plastic not only in a single year, but over the lifetime of the plastic (since plastic will remain in the ocean for a long period of time, and will continue to impact on ecosystem services).

Following an extensive review of other international literature to try and identify alternative approaches, it became evident that **adapting and applying the Beaumont et al. (2019) and WWF (2021) approaches to the South African context would be best suited to deriving a preliminary estimate of the economic impacts of marine plastic on ecosystem services in South Africa**, given the existing lack of local data. The methods applied in adapting the Beaumont et al. (2019) and WWF (2021) approaches to the South African context are described in the following sub-sections.

3.1.1 Determining the (annual) cost per tonne of plastic

Section 2.1.4.1 presented the Beaumont et al. (2019) approach in detail. To summarise, Beaumont et al. (2019) calculate a global estimate of the cost per tonne of marine plastic (per annum), as follows (Equation 1):

$$Cost\_per\_tonne\_ES_{pa} = \frac{Global\_value\_marine\_ES_{pa} \times \%\_reduction\_global\_ES_{pa}}{Global\_accumulated\_plastic_{tonnes}} \quad (1)$$

Where the input variables are as follows:

- Input variable 1: $Global\_value\_marine\_ES_{pa}$ = the economic value of global marine ecosystem services (in USD), per annum
- Input variable 2: $\%\_reduction\_global\_ES_{pa}$ = the percentage decline in ecosystem service delivery (per annum) due to the total stock of accumulated plastic in the world's oceans
- Input variable 3: $Global\_accumulated\_plastic_{tonnes}$ = the total stock of plastic that has accumulated in the world's oceans (in tonnes)

And where the resulting $Cost\_per\_tonne\_ES_{pa}$ = the cost (in USD) per tonne of plastic in terms of impacts on marine ecosystem services, per annum.

The input data applied by Beaumont et al. (2019), inflated to 2019 values[4] as per WWF (2021), are summarised in Table 9.

Table 9: Input variables applied by Beaumont et al. (2019) in calculating the low- and high-end estimate of the annual cost per tonne of marine plastic in terms of impacts on marine ecosystem services (inflated to 2019 USD as per WWF, 2021).

Input variable		Unit	Low estimate	High estimate
1	$Global\_value\_marine\_ES_{pa}$	2019 USD	61.3 trillion*	
2	$\%\_reduction\_global\_ES_{pa}$	%	1	5
3	$Global\_accumulated\_plastic_{tonnes}$ **	Tonnes	150 000 000	75 000 000

** $49.7 trillion in 2007 US dollars, based on Costanza et al. (2014). As explained in Section 2.1.4.2, WWF (2021) inflate this to $61.3 trillion in 2019 US dollars, based on changes in the U.S Consumer Price Index.*
** Note that for the input variable $Global\_accumulated\_plastic_{tonnes}$, which appears in the denominator as per Equation 1, the higher value (150 million tonnes) is used to calculate the lower-end estimate of costs per tonne; while the lower value (75 million tonnes) is used to calculate the higher-end estimate of costs per tonne.*

The resulting low-end and high-end estimates of the annual cost per tonne of marine plastic (calculated as per Equation 1 above), in terms of impacts on marine ecosystem services, are as follows:

$$Cost\_per\_tonne\_ES_{pa}\_low = \frac{\$61.3\ trillion \times 1\%}{150\ 000\ 000\ t} = \$4087\ per\ tonne \quad (2)$$

[4] As seen in Section 2.1.4.2, Beaumont et al. (2019) applied a 2007 estimate of the value of marine ecosystem services ($49.7 trillion); which was inflated to $61.3 trillion in 2019 USD by WWF (2021).

$$Cost\_per\_tonne\_ES_{pa}\_high = \frac{\$61.3\ trillion \times 5\%}{75\ 000\ 000\ t} = \$40\ 867\ per\ tonne \quad (3)$$

Recall from Section 2.1.4.1 that the range for the annual cost per tonne presented in Beaumont et al. (2019) is $3300 to $33 000. The higher range ($4087 to $40 867 per tonne) reported here results from the application of a higher value for Input variable 1 (the global value of marine ecosystem services, for which Beaumont et al. (2019) apply a 2007 value), to account for inflation, as per WWF (2021) – see Section 2.1.4.2, as well as Table 9 and the accompanying note.

Ideally, in applying the Beaumont et al. (2019) approach to the South African context, one should seek to calculate a South African specific estimate of the cost per tonne of marine plastic (based on Equation 1), by replacing the global input variables (Input variables 1 – 3 in Table 9) with South African specific data. In other words, the Beaumont et al. approach to estimating the cost per tonne of marine plastic should essentially be replicated, in order to derive a South African specific estimate of the cost per tonne of marine plastic. This would in turn require South African specific data on each of the key input variables, namely:

- Input variable 1: $SA\_value\_marine\_ES_{pa}$; i.e. the economic value of South Africa's marine ecosystem services, per annum
- Input variable 2: $\%\_reduction\_SA\_ES_{pa}$ = the percentage decline in ecosystem service delivery (per annum) due to the total stock of accumulated plastic in South Africa's marine environment
- Input variable 3: $SA\_accumulated\_plastic_{tonnes}$ = the total stock of plastic that has accumulated in South Africa's marine environment (in tonnes).

Unfortunately, extensive reviews of the literature and engagement with local experts and stakeholders suggests that there is currently insufficient data regarding either Input variable 1 (the economic value of South Africa's marine ecosystem services)[5], or Input variable 3 (the total stock of plastic that has accumulated in South Africa's marine environment)[6].

Therefore, as a second-best approach, the Beaumont et al. (2019) estimate of the annual cost per tonne of plastic (as subsequently updated based on WWF, 2021) was adapted to the South African context; by refining Input variable 2 (the percentage decline in ecosystem service delivery) as best

[5] Insufficient research has been conducted to quantify marine ecosystem services in South Africa; with terrestrial landscapes receiving much of the attention. Only a subset of marine ecosystem services in South Africa have been valued in economic terms. For example, Turpie et al. (2017) estimate that South Africa's terrestrial, freshwater and estuarine habitats are worth at least R275 billion per annum to South Africans, of which <R1 billion was ascribed to habitat benefits provided by estuaries to the fishery sector. Turpie et al. (2003) estimated a value of R1.3 billion per year from the harvesting of marine resources, such as linefish, rock lobster, abalone and bait species. However, a comprehensive assessment of the value of all marine ecosystem services in South Africa is lacking.

[6] While a number of studies have estimated annual leakage of plastics to the ocean from land-based sources in South Africa (Jambeck et al., 2015; Verster and Bouwman, 2020); or to the aquatic environment more broadly (including both freshwater and marine environments) (IUCN-EA-QUANTIS, 2020 and 2021; Stafford et al., 2022); there is far less understanding of the ultimate fate of this plastic, and of how much remains and accumulates within South Africa's marine environment.

as possible to the SA context. In other words, in the absence of SA-specific data on Input variables 1 or 3, the next best approach was to at least refine Input variable 2 (percentage decline in ecosystem service delivery due to marine plastic) as best as possible for our context.

Unfortunately, there isn't a clear indication in Beaumont et al. (2019) regarding how the 1-5% range in terms of the decline in ecosystem service delivery relates to specific ecosystem types; making it difficult to link the overall estimate to the specific ecosystem types in the SA marine environment. As such, the approach to refining Input variable 2 involved consultation with relevant local experts and stakeholders, to adapt the 1-5% range to the SA context as best as possible based on their local expert knowledge. Specifically, an online workshop was conducted on 7 December 2022 (see above), with the aim of achieving consensus among relevant local experts and stakeholders on the percentage decline in ecosystem service delivery due to marine plastic in SA.

Specifically, participants were presented with the approach and the resulting 1-5% range estimated by Beaumont et al. (2019) in terms of the percentage decline in ecosystem service delivery due to marine plastic; and were asked to consider where they felt South Africa may lie within (or outside of) this range, and why. Specifically, the following questions were posed:

- Does this 1-5% range make sense for SA?
- Do we sit somewhere within this range; and if so, at the higher or lower end?
- Or, do we sit somewhere outside of this range (higher or lower?)
- What is the rationale?

During the workshop, the majority of participants noted that **South Africa is likely to lie at the higher end of the 1-5% range**. Some of the reasons suggested for this were as follows:

- South Africa has the highest consumption of plastics on the continent; our plastics per capita consumption is comparable to developed countries.
- In terms of land-based sources, our collection systems are poor, and we have large amounts of plastic coming through aquatic systems via stormwater and getting deposited on beaches even after relatively small flood events, which are extremely regular occurrences. As such, a lot more plastic waste ends up in aquatic systems (and ultimately makes it to estuaries and beaches), as compared to the case in developed countries.
- In terms of marine sources, there is a large amount of shipping traffic along our coastline.
- Unlike other pollutants such as nutrients and organic waste; plastic is not easily assimilated by the system. It tends to enter via rivers and estuaries to the near-shore environment, where much of it tends to remain, or washes up on beaches.
- Current assessments of the impacts of marine plastic on ecosystem services are likely to focus mainly on the visible impacts, particularly those relating to macroplastics, such as entanglement and ingestion, as well as impacts on provisioning services (e.g. fisheries). Other types of impacts, particularly those relating to microplastics, e.g. impacts on reproduction and on regulating services (such as climate regulation), are much more difficult to assess, and are likely to be under-represented in current estimates.

It was also noted that plastics are highly durable and remain in the ocean for long periods of time, and will have prolonged impacts on ecosystem services far beyond just one year. However, this aspect is dealt with separately in Section 3.1.3; where the analysis is extended to include the lifetime costs of plastic in the ocean; the current section deals only with the impacts in a single year, in order to establish a baseline.

Other participants suggested that the lower-end estimate may be more relevant, e.g. because of South Africa's coastline being very active, with strong currents moving plastic away from our coast; and because of our distance to other land masses, suggesting that there is a lower accumulative effect of plastics around our coasts than would be the case in Europe, for example. However, others pointed out that the high-energy nature of South Africa's coastline leads to significant breakdown of macroplastics to microplastics; which is less visible, but still impacts on ecosystem services.

Finally, it was agreed during the workshop that, **given the number of uncertainties involved, it would be of value to present the results based on the full 1-5% range; including a conservative, lower bound estimate; a mid-range estimate; and a higher bound estimate. This is therefore the approach adopted in the report**. Although most participants noted that the higher end of the 1-5% range in terms of the percentage reduction was likely to be more realistic for the South African context, others pointed out that a conservative approach is warranted given the uncertainties in the data. As such, a lower-end estimate is provided as a conservative estimate of the minimum impact of marine plastic on ecosystem services in South Africa; while the mid-range estimate is calculated using an average between the lower and upper end of the range (i.e. 3%), and can perhaps be seen as the "best" estimate.

The following equation is applied to obtain the cost per tonne of marine plastic in South Africa:

$$Cost\_per\_tonne\_ES_{pa} = \frac{Global\_value\_marine\_ES_{pa} \times \%\_reduction\_SA\_ES_{pa}}{Global\_accumulated\_plastic_{tonnes}} \quad (4)$$

Where $\%\_reduction\_SA\_ES_{pa}$ is the percentage decline in ecosystem service delivery (per annum) due to plastic in South Africa's marine environment, and where all other terms are defined as per Equation 1.

The input variables used in calculating the low, mid-range and high-end estimates of the impact of marine plastic on ecosystem services in South Africa are presented in Table 10. The mid-range estimate is calculated using an average value for those input variables where a range of values is applied by Beaumont et al. (2019).

Table 10 also presents the resulting estimate of costs per tonne of marine plastic, in both 2019 USD (2nd last row), as well as 2022 Rands (bottom row). In terms of its impacts on marine ecosystem services (per annum), the cost per tonne of plastic ranges between $4087 and $40 867 per tonne (in 2019 USD), with a mid-range or "best" estimate of $16 347 per tonne.

Table 10: Variables applied in this study to calculate the low, mid-range and high estimate of annual costs per tonne of marine plastic in terms of impacts on marine ecosystem services; and the resulting estimated costs per tonne.

	Variable	Unit	Low estimate	Mid-range	High estimate
1	$Global\_value\_marine\_ES_{pa}$	2019 USD	61.3 trillion		
2	$\%\_reduction\_SA\_ES_{pa}$	%	1	3	5
3	$Global\_accumulated\_plastic_{tonnes}$*	Tonnes	150 000 000	112 500 000	75 000 000
	$Cost\_per\_tonne\_ES_{pa}$	2019 USD	4 087	16 347	40 867
	$Cost\_per\_tonne\_ES_{pa}$	2022 Rands	68 142	272 569	681 423

** Note that for the input variable $Global\_accumulated\_plastic_{tonnes}$, which appears in the denominator as per Equation 1, the higher value (150 million tonnes) is used to calculate the lower-end estimate of costs per tonne; while the lower value (75 million tonnes) is used to calculate the higher-end estimate of costs per tonne.*

In this report, the results (Section 4) are presented in 2022 South African Rands. As such, historical values from the literature reported in other currencies are first converted to Rands (using the average exchange rate for the year in question, e.g. 2019 in this case), and then inflated to 2022 values based on changes in the South African Consumer Price Index (CPI) over that time period. In the case of the costs in Table 10, the values are first converted from 2019 USD to 2019 ZAR, based on the average exchange rate of 14.45 ZAR/USD in 2019 (https://www.exchangerates.org.uk/USD-ZAR-spot-exchange-rates-history-2019.html). Then, the 2019 ZAR values are inflated to 2022 values based on changes in the CPI, as per Statistics South Africa (2023).

Following this approach, in 2022 Rands, **the annual cost per tonne of marine plastic, in terms of its impacts on ecosystem services, ranges between R68 142 and R681 423, with a mid-range or "best" estimate of R272 569 per tonne** (see Table 10).

3.1.2 Aggregation from cost per tonne to total cost per annum

While Section 3.1.1 suggested that there is no reliable data on the total stock of plastic that has accumulated in South Africa's marine environment; a number of studies have estimated the flows of plastic entering South Africa's marine environment each year, primarily from land-based sources.

This allows us to estimate the total cost (per annum) associated with the plastic entering the marine environment each year, in terms of its impact on marine ecosystems; by multiplying the cost per tonne (estimated as per Section 3.1.1) by the tonnages of plastic entering the marine environment each year:

$$Annual\_cost\_ES_{year\_x} = Cost\_per\_tonne\_ES_{pa} \times Tonnes\_entering_{year\_x} \quad (5)$$

Where $Cost\_per\_tonne\_ES_{pa}$ is the cost per tonne of plastic in terms of impacts on marine ecosystem services, per annum (calculated as per Section 3.1.1); $Tonnages\_marine\_plastic_{year\_x}$ is the amount of plastic entering the marine environment in year *x*, and $Annual\_cost\_ES_{year\_x}$ is the resulting total cost (per annum) of plastic entering the marine environment in year *x*, in terms of its impacts on marine ecosystem services.

In terms of data sources for the amount of plastic entering the South African marine environment each year, four relevant studies are those of Jambeck et al. (2015), Verster and Bouwman (2020), IUCN-EA-QUANTIS (2020 and 2021), and Stafford et al. (2022). Of these, only the IUCN-EA-QUANTIS reports consider marine-based sources in addition to land-based sources; the other three studies focus on land-based sources.

In terms of land-based sources, Jambeck et al. (2015) estimated that between 90 000 – 250 000 tonnes per annum reaches the oceans from land-based sources in SA; based on an assumption of 56% mismanaged plastic waste, and that 15-40% of mismanaged waste from coastal populations (within 50km of the coast) will enter the ocean. However, Jambeck et al.'s (2015) estimate for South Africa has since been criticised as being too high (Ryan, 2020; Verster and Bouwman, 2020). In particular, the assumption of 56% mismanaged waste in SA has been criticised as not being based on supporting evidence (Verster and Bouwman, 2020).

Verster & Bouwman (2020) apply a more realistic 29% of mismanaged waste, based on local published data (Rodseth et al., 2020). They then apply similar assumptions as Jambeck et al. (2015) regarding the proportion of mismanaged waste that is presumed to enter the ocean. Specifically, like Jambeck et al. (2015), they only include waste generated by populations within 50km of the coast; and they assume that only 15-40% of the mismanaged waste from these areas will enter the ocean. Their resulting estimate of 15 000 to 40 000 tonnes of plastic entering the ocean per annum from land-based sources in South Africa is significantly lower than that of Jambeck et al. (2015).

The IUCN-EA-QUANTIS (2020 and 2021) reports take a somewhat different approach, in that they also include waste generated by inland populations; and provide an estimate of land-based plastic leaking to both rivers and oceans; rather than specifically apportioning the amount of plastic ending up in the ocean. The original report (IUCN-EA-QUANTIS, 2020) therefore derives a higher estimate of 79 000 tonnes of land-based plastic leaking to rivers and oceans per annum; of which 72 000 tonnes is macro-leakage and 6500 tonnes micro-leakage. The updated report (IUCN-EA-QUANTIS, 2021) provides an even higher estimate of 107 000 tonnes per annum.

However, the IUCN-EA-QUANTIS reports, which have been criticised for not making sufficient use of South African-relevant data, do not provide a clear indication of what proportion of this plastic will specifically enter the marine environment; aside from the contention that "except for Gauteng, populated areas are usually located close to a waterway or the coast. This will increase the possibility of transfer to the marine environment" (IUCN-EA-QUANTIS, 2020).

Similarly, Stafford et al. (2022) estimate that 68 000 tonnes of aquatic plastic pollution (both freshwater and marine) will be generated annually; based on mismanaged plastic waste arising from populations within 1km of a waterway. However, as with the IUCN reports, they don't apportion how much of this will remain in the freshwater environment vs. how much will eventually reach the marine environment.

On the other hand, unlike the other studies, the IUCN-EA-QUANTIS reports do provide an indication of plastic from some marine sources (specifically mismanaged/lost at sea fishing gear and overboard litter), of 379 tonnes per annum; although this is negligible relative to the land-based sources.

Table 11 summarises the range of estimates of plastic entering the marine environment annually from land-based sources in South Africa; as well as the assumptions underlying each study.

Table 11: Estimates of plastic entering SA's marine (or aquatic) environment from land-based sources per year

Source	Jambeck et al. (2015)	Verster & Bouwman (2020)	IUCN-EA-QUANTIS (2020; 2021)	Stafford et al. (2022)
Assumption regarding the % of mismanaged plastic waste	56%	29%	40%	29%
Assumptions regarding the proportion of mismanaged waste entering the ocean	15-40% of mismanaged waste from coastal populations (within 50km of coast) will enter the ocean	15-40% of mismanaged waste from coastal populations (within 50km of coast) will enter the ocean	Mismanaged waste from inland populations is also included. Estimates 79 000 tonnes of plastic leakage to waterways and oceans annually (107 000 in the updated report); but doesn't apportion freshwater vs. marine	Estimates 68 000 tonnes of aquatic plastic pollution (freshwater and marine) per annum; based on mismanaged plastic waste from all populations within 1km of a waterway; but doesn't apportion freshwater vs. marine
Plastic entering marine environment from land-based sources (tonnes per annum)	90 000 – 250 000	15 000 – 40 000		

Ignoring for now the issue of marine-based sources (still to be added, see below); in order to determine which estimate of plastic entering the marine environment from land-based sources would be most relevant for applying in our calculations, the range of estimates in Table 11 (as well as the underlying assumptions) were presented to experts and stakeholders at the workshop session conducted on 7 December 2022 (see above). Participants were then asked to discuss the merits of each estimate (and the associated assumptions), so that consensus could be achieved in terms of the most relevant estimate to be applied in the calculations.

In general, participants were in favour of applying the higher-end estimate from the Verster and Bouwman (2020) range, i.e. 40 000 tonnes of land-based plastic reaching the marine environment annually, for the following reasons:

- The Verster and Bouwman study is based on local data.
- The range estimated by Verster and Bouwman (15 000 to 40 000 tonnes per annum) is conservative relative to other estimates. In particular, the assumption that only plastic arising from populations within 50km of the coast will reach the marine environment, is seen as conservative[7]. As such, it makes sense to apply the upper end of this range; which is still relatively conservative compared to other estimates.

[7] Participants mentioned that in some countries (e.g. in the Ganges River in China); geo-tagged plastic has been found to travel along rivers up to 2000km. In South Africa, however, there tends to be far more retention of plastics (particularly macroplastics) in the upper reaches of our large inland river systems (e.g. due to the number of dams and water transfer schemes altering the natural hydrology of the rivers); with plastic therefore less likely to travel large distances as compared to other countries.

However, it should be borne in mind that the Verster and Bouwman (2020) estimates are for land-based sources of plastic only (i.e. marine-based sources are excluded); while the estimates are also based on average conditions, and ignore episodic events such as flooding, which lead to additional plastic entering the marine environment. As such, participants at the workshop suggested adding a certain proportion to the 40 000 tonnes per annum, in order to account for both the additional plastic reaching the sea due to episodic flooding, as well as marine-based sources of plastic (e.g. from fisheries and shipping).

In terms of episodic flooding, there isn't a clear indication of the tonnages of plastic associated with these events; although anecdotal evidence suggests that these events lead to a significant amount of additional plastic reaching the sea.

In terms of marine-based sources; IUCN-EA-QUANTIS (2020 and 2021) report that 379 tonnes of plastic arise annually in South Africa's marine environment from mismanaged/lost at sea fishing gear and overboard litter; which, as noted above, is negligible relative to the land-based sources.

Evidence from other countries suggests a much a higher contribution from marine-based litter; with a number of sources referring to a ratio of 80% of ocean plastics coming from land-based sources and 20% from marine sources (Ocean Conservancy and McKinsey, 2015; Li et al., 2016; Ritchie and Roser, 2022). According to IUCN-EA-QUANTIS (2020), the estimate for mismanaged/lost at sea fishing gear for South Africa is low because "the number of fishing vessels reported is low compared to other countries, although they are larger in size as fisheries in South Africa is mainly commercial. Gear loss and leakage is minor in the country and does not represent a critical sector hotspot" (IUCN-EA-QUANTIS, 2020). However, other marine-based sources (e.g. from shipping) should also be taken into account. Participants at the workshop conducted as part of this project noted that there is a large amount of shipping traffic along the South African coastline.

All in all, assuming that 40 000 tonnes per annum represents a conservative estimate of land-based sources of marine plastic, excluding episodic events; and taking into account the 80:20 ratio of land-based to marine-based sources reported for other countries, but that marine-based sources in South Africa may be less significant relative to other countries; it seems reasonable to add 10 000 tonnes per annum to account for both episodic events *and* marine sources; for a total of **50 000 tonnes per annum of plastic entering South Africa's marine environment**. This would maintain the 80:20 ratio found in the literature for other countries; albeit with the 20% in this case comprising of both marine sources *and* episodic flooding related to land-based sources; to account for the fact that marine sources alone may represent a lower proportion of total marine plastic in South Africa, as compared to other countries.

The resulting total of 50 000 tonnes per annum also seems reasonable when taking into account that the 40 000 tonnes from Verster and Bouwman (2020) is based on the conservative assumption that only plastic from populations within 50km of the coast will reach the marine environment. It is also consistent with the fact that IUCN-EA-QUANTIS (2020a and 2021a) and Stafford et al. (2022) estimate that between 68 000 and 107 000 tonnes of plastic pollution ends up in the aquatic environment (including both freshwater and marine aquatic environments) from land-based sources per annum.

3.1.3 Extending the analysis to include lifetime costs

To account for the fact that plastic take hundreds to thousands of years to break down, and will continue to impose negative impacts on ecosystem services throughout its lifetime (see Section 2.1.4.2); we apply the WWF (2021) approach in extending the cost per tonne of plastic *per annum*, to estimate the cost per tonne of plastic *over its lifetime*. As seen in Section 2.1.4.2, this is done by applying a Net Present Value (NPV) formula to the annual cost per tonne of plastic (estimated as per Section 3.1.1), to derive the lifetime cost per tonne of plastic.

Whereas WWF (2021) only apply the NPV formula to the low-end estimate of annual costs per tonne (i.e. based on a 1% reduction in marine ecosystem service delivery, see Section 2.1.4.2); we apply it to each of the low-end, mid-range and high-end estimates of the annual cost per tonne (see Table 10), i.e. based on a 1%, 3% and 5% reduction in ecosystem service delivery (Beaumont et al., 2019), to similarly derive a range of estimates for the lifetime cost per tonne. This is done to ensure consistency with the approach described in Section 3.1.1 for annual costs; where a low-end, mid-range and high-end estimate is provided. In particular, recall from Section 3.1.1 that participants at the December 2022 workshop suggested that South Africa lies at the higher end of the 1-5% range for reduction in ecosystem service delivery due to marine plastic; suggesting that results based on the full range (rather than only the low-end of the range) should be presented.

Consistent with WWF (2021), we apply a social discount rate of 2%. While WWF (2021) assume that the time horizon for plastic pollution in the ocean is infinity, we use a time period of 250 years (as the NPV formula used in Microsoft Excel imposes a limit of 254 time periods). This is considered sufficient; since, according to WWF (2021); because of the discounting of future periods, 95% of the overall lifetime costs are borne in the first 150 years, and costs incurred beyond 200 years do not contribute significantly to the total lifetime cost.

Applying the NPV formula to the range of annual costs per tonne of plastic presented in Section 3.1.1 (ranging from R68 142 to R681 423, with a mid-range estimate of R272 569 per tonne; see Table 10), the resulting **lifetime cost per tonne of plastic,** in terms of impacts on ecosystem services over its lifetime, **ranges between R3.4 million and R33.8 million; with a mid-range or "best" estimate of R13.5 million per tonne of plastic.**

Then, as was the case for the annual costs per tonne (Section 3.1.1), the lifetime costs per tonne can be multiplied by the estimated tonnages of plastic entering the marine environment each year (50 000 tonnes per annum, see Section 3.1.2), to derive an estimate of the lifetime cost of the plastic entering the marine environment each year.

3.2 Direct damage to affected industries

Obtaining relevant primary data on the impacts of marine plastic on affected industries (such as fisheries, shipping and tourism) in South Africa proved to be challenging, for a number of reasons. For example, our initial discussions with representatives from the fishing industry suggested that it was difficult to differentiate impacts on fish stocks that were specifically attributable to marine plastic, as compared to impacts arising from other pressures. Since fish populations globally are under pressure from a number of other drivers (such as over-fishing and climate change), it becomes difficult to quantify the specific impact arising from marine plastic. Similarly, initial discussions with the tourism sector suggest that, at present, the damages caused specifically by marine plastic are not currently being tracked.

However, there are a number of alternative sources that can be drawn on in order to work towards an estimate of direct damages for these industries in South Africa.

Specifically, recall from Section 2.2.3 that a number of international reports provide an indication of the typical percentage reduction in revenues or GDP for each industry resulting from marine plastic (see Table 4, repeated below in Table 12). Table 12 summarises the range of estimates of the % reduction in revenues or GDP per industry, derived from the literature.

Table 12: Estimates of direct damage caused by marine plastic on three industries, in terms of % reduction in revenues or GDP

Industry	% reduction in revenues or GDP due to marine plastic (range)	Source
Fisheries and aquaculture	0.3% - 5%	Takehama (1990), Ten Brink et al. (2009), Deloitte (2019), McIlgorm et al. (2020).
Shipping (marine transport & related services)	1%	McIlgorm et al. (2020)
Marine & coastal tourism	0.3% - 5%	Ten Brink et al. (2009), Mouat et al. (2010), Trucost (2016), Deloitte (2019), McIlgorm et al. (2020).

These estimates of the percentage reduction in revenues or GDP can potentially be applied to South Africa, taking into account annual revenues or GDP for each of these industries in South Africa, in order to calculate the annual loss in revenues (or in contribution to GDP) for each industry affected by marine plastic in South Africa.

Firstly, however, as was the case for impacts on marine ecosystem services (see Section 3.1), we workshopped the range of estimates from the literature regarding the percentage reduction in revenues / GDP for each industry with South African experts and stakeholders, in order to derive more refined estimates for the South African context. As such, at the expert/stakeholder consultation workshop conducted on 7 December 2022 (see above), the range of estimates from the literature (for each industry, as per Table 12) was presented to the participants; who were asked to discuss where South Africa might lie within (or outside of) each of these ranges, based on their knowledge of the impacts of marine plastic on each industry in the South African context.

At the workshop, some participants mentioned the need to be conservative and to present results based on the lower-end estimates. As such, similarly to the case for impacts on ecosystem services (see Section 3.1), we apply a low-end, conservative estimate; a middle-road “best” estimate, and a high-end “worst case” estimate of the % reduction in revenues (for each industry).

Another point raised at the workshop in relation to the ranges presented in Table 12, is that a number of the estimates (particularly the lower-end estimates within each range) are fairly outdated (some from as far back as 1990), and are therefore no longer relevant, given that plastic leakage and accumulation (and the resulting impacts) have increased significantly in subsequent years.

Indeed, recall from Section 2.2.3 that according to McIlgorm et al. (2020), plastic production is now 3.2 times higher than in 1990, and as such the lower-bound estimate for fisheries (0.3%, based on Takehama, 1990) should be increased to 1% to account for the higher associated damages. Recall also that for marine and coastal tourism, the 0.3% lower-bound estimate applied by Deloitte (2019) is not strictly relevant, as this figure was also based on the Takehama (1990) study on damages to fishing vessels (see above), rather than specifically based on losses to the tourism industry. According to McGilorm et al. (2020), more recent studies (such as Mouat et al., 2010 and Trucost, 2016) apply a damage estimate for the marine tourism sector ranging between 2 – 5%. In their own modelling, McGilorm et al. (2020) apply a 1.5% reduction, which could perhaps be seen as a more realistic lower-bound estimate for this sector.

As such, refined low-end and high-end estimates for the percentage reduction in revenues/GDP for each industry are presented in Table 13. In addition, a mid-range estimate of the percentage reduction is calculated as a simple average between the low-end and high-end estimate in each case.

Table 13: Refined low-end, mid-range and high-end estimates of the % reduction in revenues or GDP due to marine plastic

Industry	Low estimate	Mid-range estimate	High estimate
Fisheries and aquaculture	1%	3%	5%
Shipping (marine transport & related services)	1%	1%	1%
Marine & coastal tourism	1.5%	3.3%	5%

To determine the annual loss in revenues/GDP for each industry due to marine plastic, the percentages presented in Table 13 were applied to the current annual values of revenues or GDP for each industry.

Table 14 presents the annual value of revenues/GDP for each of the industries in question; as well as notes regarding the year to which the data applies, and the source of information. Note that since the revenue or GDP data for the three industries in question were derived from previous years (varying between 2015 and 2020), these were inflated to 2022 values (see last column), based on changes in the CPI as per Statistics South Africa (2023).

Table 14: Annual value of output (expressed as revenues or contribution to GDP) for the tourism, shipping and marine & coastal tourism industries in South Africa

Industry	Reported revenues/GDP contribution, in R billions (year in parenthesis)	Source	Notes regarding reported revenues / GDP contribution	Revenues/GDP contribution, inflated to 2022 R billions based on CPI
Fisheries	15.95 (2020)	Statistics South Africa (2020)	Total income in the "ocean (marine) fisheries and related services" industry in 2020. This includes enterprises mainly engaged in the ocean (marine) fisheries and related services industry (Ocean and coastal fishing (SIC 131)). Note that it *excludes* "Fish hatcheries and fish farms" (SIC 132); i.e. aquaculture). As such, in the report we will provide results based on (marine) fisheries only, excluding aquaculture (mariculture).	17.82
Shipping (marine transport & related services)	4.00 (2019)	Statistics South Africa (2019)	Total income for the "water transport" (R1.1 billion) and "supporting services to water transport" (R2.9 billion) sub-sectors of the "transport and storage" industry in 2019. Since there are no navigable rivers in SA (Britannica, 2023), and therefore no inland water transport (SIC 7220); income for water transport can all be allocated to "sea and coastal water transport" (SIC 7211). Supporting services to water transport are also included, since this includes "the operation of terminal facilities such... harbours, piers... etc, waterway locks, ... navigation, pilotage and berthing activities... [and] salvage activities" (Statistics South Africa, 2019); which may also be affected by marine plastic.	4.62
Marine & coastal tourism	11.90 (2015)	Depart-ment of Tourism (2017)	Direct contribution to GDP of the coastal and marine tourism sub-sector in 2015, according to the Department of Tourism (data on income for marine and coastal tourism was not available from Statistics South Africa).	16.73

The resulting preliminary estimates of the annual impact of marine plastic on each industry are provided in Table 15.

Table 15: Preliminary estimates of direct damage to South African industry as a result of marine plastic

Industry	Annual value of output (2022 R billions)	Reduction in value of output	Low estimate	Mid-range estimate	High estimate
Fisheries*	17.82	% loss / year	1%	3%	5%
		Cost per year (R millions)	178.2	534.5	890.9
Shipping	4.62	% loss / year	1%	1%	1%
		Cost per year (R millions)	46.2	46.2	46.2
Marine & coastal tourism	16.73	% loss / year	1.5%	3.3%	5%
		Cost per year (R millions)	251.0	543.9	836.7
Total		**Cost per year (R millions)**	**475.3**	**1 124.5**	**1 773.7**

** Marine fisheries only, excluding mariculture*

However, comparing these estimates with those based on other sources suggests that the estimates in Table 15 are too high.

Firstly, recall from Section 2.2.2. that Benn et al. (2022) estimated the loss in revenue in specific sectors (tourism, real estate, and fisheries & aquaculture), as well as "increased operational and maintenance costs of seaports, marinas, waterways and stormwater networks", totaling $4 million per annum (2018 USD), equivalent to approximately R63.6 million in 2022 Rands; based on an adaptation from international studies. This an order of magnitude lower than the low-end estimate in Table 15 of R475.3 million per annum.

Secondly, Deloitte (2019) provided a summary (per region) of the average loss in economic value due to marine plastic for two sectors (marine tourism and fisheries & aquaculture); in USD per capita (see Table 5 in Section 2.2.3). For Africa, the average loss in revenues is $0.06 per capita. Inflating this estimate to 2022 Rands (approximately R1 per capita), and multiplying by the South African population (currently estimated at approximately 61 million, as per https://www.worldometers.info/world-population/south-africa-population/), results in an annual cost of R61 million per year; which is very similar to the Benn et al. (2022) estimate; and again significantly lower than the low-range estimate in Table 15.

In order to explain this discrepancy, it is worth noting that the estimates in Table 15 are derived based on the range of percentage reduction in revenues from international studies (see Section 2.2.3 and Table 12), primarily from European and Asian countries, where the impacts on industry due to marine plastic are likely higher than in South Africa. Therefore, given that the low-end estimates in Table 15 are an order of magnitude higher than those based on Benn et al. (2022) and Deloitte (2019); it is likely that those 'low-end' estimates are in fact high-end estimates in the South African context. In addition, some of the impacts on industry reflected in Table 15 may in fact already be captured under impacts associated with ecosystem services, rather than purely being associated with direct damage to industry, as explained in Section 2.2.1.

As such, for the sake of being conservative, avoiding potential double-counting, and ensuring alignment with estimates based on other sources; it is proposed that the *low-end* of the ranges for the percentage reduction in revenues reported in Table 13 in fact be used to derive *high-end* estimates of the annual damages to industry in South Africa (see Table 16). This approach also seems warranted given that participants at the expert/stakeholder consultation workshop suggested adopting a conservative approach in the case of the estimates of direct damages to industry (see above).

For the low-end estimates of annual damages; we propose using the total estimate based on Benn et al. (2022) (R63.6 million in 2022 Rands); which represents the only available estimate that has been made specifically for the South African context. A mid-range estimate is then calculated as an average between the low-end and high-end estimates. The resulting refined estimates are presented in Table 16. These estimates, which have been triangulated as best as possible based on the available information, will be used to inform the results presented in Section 4.2.

Table 16: Refined estimates of direct damage to South African industry (per annum) as a result of marine plastic

<table>
<tr><th rowspan="2">Low estimate (total)</th><th rowspan="2">Mid-range estimate (total)</th><th colspan="4">High estimate (per sector)</th></tr>
<tr><th>Industry</th><th>Annual value of output (2022 R billions)</th><th>Reduction in value of output</th><th>High estimate</th></tr>
<tr><td rowspan="7">R63.6 million; based on Benn et al. (2022) estimate of $4 million in 2018 USD</td><td rowspan="7">R269.5 million, calculated as an average between the low-end and high-end estimates</td><td rowspan="2">Fisheries*</td><td rowspan="2">17.82</td><td>% loss / year</td><td>1%</td></tr>
<tr><td>Cost per year (R millions)</td><td>178.2</td></tr>
<tr><td rowspan="2">Shipping</td><td rowspan="2">4.62</td><td>% loss / year</td><td>1%</td></tr>
<tr><td>Cost per year (R millions)</td><td>46.2</td></tr>
<tr><td rowspan="2">Marine & coastal tourism</td><td rowspan="2">16.73</td><td>% loss / year</td><td>1.5%</td></tr>
<tr><td>Cost per year (R millions)</td><td>251.0</td></tr>
<tr><td colspan="3">Total cost per year (R millions)</td><td>475.3</td></tr>
</table>

** Marine fisheries only, excluding mariculture*

3.3 Clean-up costs

Section 2.3.1 presented available South African data on the costs associated with marine debris clearing and removal, as per published literature. Most of this information, particularly the data presented in Table 6, cannot easily be extrapolated to provide an overall estimate of the costs of clearing marine plastic across South Africa; for a number of reasons:

- The available data is mostly outdated (e.g. from the early to mid-1990s). Although it would be possible to inflate these to current values based on changes in the Consumer Price Index (CPI); this still doesn't take into account the increase in tonnages of marine plastic over the last 30 years; and the resulting increase in clean-up efforts.
- The studies mainly focus on beach clean-ups (they exclude for example river clean-ups that are aimed at reducing the amount of land-based plastic reaching the marine environment in the first place; as well as other types of clearing activities within the marine environment).
- They generally include all types of beach debris; rather than specifically plastics; making it difficult to apportion the costs specifically to plastic as compared to other materials.
- They mainly consider expenditure by municipal authorities on beach clean-ups; they exclude clean-up efforts by the private sector and civil society (including voluntary clean-up efforts, the 'hidden' costs of which are typically very difficult to quantify).

In terms of the costs associated with private sector or civil society clean-up efforts, some information was obtained from participants at the expert/stakeholder consultation workshop held in December 2022. For example:

- The costs for Hennops Revival (non-profit organisation), working in a 30km stretch of river, are at least R1 million per year. This is just the cost of bags and paying people to clean up on a daily basis; it excludes volunteers, organising volunteer days, etc.
- For the clean-up week coordinated by Plastics SA in September, as part of the International Coastal Clean-Up event, the direct cost for bags only is over R900 000.

Again, however, this information is not sufficiently comprehensive to enable extrapolation towards a national total. For example, in most cases information is available for certain items (e.g. the costs of providing bags), but not for others (e.g. the value of the time given up by volunteers, and the costs of waste removal and disposal following clean-ups); while in some cases the information is related to specific clean-up events, and therefore doesn't necessarily represent a generalisable average.

An alternative approach could be to obtain data on the total tonnages of plastic cleared from the marine environment on an annual basis, and to multiply this by available data regarding the associated cost per tonne; e.g. Swanepoel's (1995) estimate for the City of Cape Town (see Table 6 in Section 2.3.1).

Again, however, looking at the available data on tonnages of plastic cleared, and through discussions with Plastics SA, it became evident that it is extremely difficult to extrapolate an estimate of the national tonnages of plastic cleared annually through various types of clean-ups.

For example, according to a report by Plastics SA (2022a), "2500 tonnes of waste was diverted away from the ocean and the natural environment" through clean-up campaigns between September 2021 and June 2022, i.e. over a ten month period. This could potentially be extrapolated to 3000 tonnes over the course of a year, assuming 250 tonnes collected per month. However, this is only for clean-up campaigns sponsored by Plastics SA; it excludes other types of clean-up operations, e.g. by municipalities, as well as clean-ups coordinated by other organisations without Plastics SA's involvement.

Another report by Plastics SA (2022b) mentions that more than 7450 tonnes of debris was collected purely from audited clean-ups on land, and another 680kg from underwater clean-ups, over a two-week period (Kieser, pers comm) coinciding with the International Coastal Clean-Up event. Again, however, this is difficult to extrapolate to an annual total, as the International Coastal Clean-Up is a specific, particularly large event. In addition, the figures are only based on the audited clean-ups over this two-week period; a large number of non-audited clean-ups were also conducted (Kieser, pers comm).

In addition, in both cases mentioned above, the debris collected includes materials other than plastic. While plastic makes up the bulk of the items collected in the International Coastal Clean-Up (Kieser, pers comm; Plastics SA, 2022b); there is no clear indication of the proportion by weight made up of plastic, taking into account that plastic is lightweight relative to other materials collected.

Furthermore, even if it was possible to derive a national total of the tonnages of plastic cleared annually, very little information is available on the costs per tonne of plastic collected through these types of clean-ups. The only published information we could find on clean-up costs per tonne for South Africa is a study by Swanepoel (1995) in the City of Cape Town, where R3 000 per tonne was spent on beach debris removal (including plastics as well as other materials) in the 1992-93 financial year (see Table 6 in Section 2.3.1); equivalent to R15 949 per tonne in 2022 Rands.

However, this is unlikely to be generalisable to other types of clean-ups. According to Plastics SA (Kieser, pers comm), no two clean-up events are the same; each requires different types and levels of support (e.g. just providing bags vs also providing gloves, catering, transport for volunteers, removal of waste etc.; while every clean-up also gets support from local sponsors); making it very difficult to estimate a typical cost per tonne.

Given the various difficulties with attempting to estimate total annual clean-up costs in South Africa based on available local data; an alternative approach is to look at available international data that could potentially be adapted to the SA context. For example, Table 7 (see Section 2.3.2) provided an indication of clean-up costs from the APEC region, including some estimates of clean-up costs per tonne. However, since we don't have a reliable estimate of the total tonnages cleared annually in SA (see above), it would be difficult to apply these costs per tonne to SA to derive an annual cost.

As an alternative approach, recall from Section 2.3.2 that Deloitte (2019) provides an estimate of average clean-up costs per capita in each region (see Table 8, repeated below as Table 17).

Table 17: Average clean-up costs per capita in each region (Source: Deloitte 2019).

Region	**Clean-up cost (USD per capita)**
Asia	2.51
Europe	0.29
North America	0.24
Latin America	0.54
Oceania	0.06
Middle East	0.01
Africa	0.06
Global Average	**1.61**

Looking at the average for Africa ($0.06 per capita in 2019 USD; equivalent to approximately R1 per capita in 2022 Rands), and multiplying this by the South African population size of approximately 61 million (see Section 3.2), gives rise to a cost of R61 million in current (2022) South African Rands.

This estimate of R61 million was then workshopped with experts and stakeholders at the workshop conducted in December 2022. Specifically, participants were asked to discuss whether this was seen as being in the correct order of magnitude as an estimate of the total costs expended on cleaning up marine plastic debris in South Africa per annum.

The overwhelming consensus from the discussion was that R61 million represents a significant underestimate of the total costs being spent across South Africa on efforts for clearing and removal of marine plastic. For example, it was mentioned that:

- City of Cape Town alone spends about R200 million a year on cleaning up of illegal dumping
- For Plastics SA's clean-up week in September alone, the direct cost for bags only is over R900 000.
- The costs just for Hennops Revival (NPO), working in a 30km stretch of river, are at least R1 million a year, just for the bags and paying people to clean up on a daily basis. It excludes volunteers, organising volunteer days, etc. So the R61 million is very low, considering that it takes R1 million a year just to get 10 people to clean up a river on a daily basis.
- A lot of other costs don't seem to be factored into the estimate. E.g. in addition to the costs associated with paying people and providing bags; there are also costs associated with transporting people and the material collected, providing food or vouchers, raising awareness (e.g. community meetings, marketing, branded clothing e.g. T-shirts), etc. In the case of under-water clean-ups, there are additional costs associated with chartering vessels.
- Many of the costs are hidden; e.g. the costs associated with the time put in by volunteers. In addition, coastal municipalities spend money on clean-ups; but they also have permanently employed staff at beaches and tidal pools whose specific job is to clean up; so there are hidden salary costs. Also, a number of Expanded Public Works Programme workers are directed to beach clean-ups; while SANPARKS also deploys some of their staff to clean up beaches located within national parks.

The fact that the R61 million estimate derived from international literature was seen as being too low also puts into perspective the difficulty in applying the existing South African data on clean-up costs referred to in Section 2.3.1. The most comprehensive estimates available of the total costs of cleaning marine plastic in South Africa are those of Ryan and Swanepoel (1996), and Benn et al. (2020). As seen in Section 2.3.1, Ryan and Swanepoel (1996) extrapolate a cost of R8 million for cleaning beaches across 63 coastal authorities; equivalent to approximately R35.9 million in 2022 Rands. Benn et al. (2022) estimate a cost to run clean-up activities in South Africa of $1.3 million annually (2019 USD); or R21.7 million in 2022 Rands; based on an adaptation from international studies.

These estimates are both significantly lower than the R61 million estimated in the current study based on the international literature; which was in turn viewed by the experts and stakeholders as being far too low.

Taking into account that the R35.9 million estimate based on Ryan and Swanepoel (1996) is for municipal beach cleaning only, and excludes private sector and civil society / volunteer efforts, as well as clean-ups in rivers and other areas; and that the R61 million as estimated above was seen by the workshop participants as being too low; suggests that the R61 million could be seen as a very conservative lower-bound estimate of the total costs associated with clearing and removal of marine plastic in South Africa.

In order to derive a mid-range and higher-end estimate; it may be worth looking at some of the other figures in Table 17; namely estimates of the clean-up costs per capita for other regions. The R61 million was estimated based on the average clean-up cost for Africa of 0.06 USD per capita. However, it could be expected that expenditure on clean-ups is likely to be far higher in South Africa than for other African countries; given that our plastic consumption rates are far higher (more on par with European countries); and that more public and private sector funding is likely to be directed towards clean-up efforts. For example, the costs in South Africa may be more aligned with those of Europe (0.29 USD per capita) given our high levels of plastic consumption; while we also share similar socio-economic characteristics with Latin America (0.54 USD per capita) and Asia (2.51 USD per capita). However, looking at the figures in Table 17, Asia is clearly an outlier, which also disproportionately increases the global average. It therefore seems reasonable to use the global average (1.61 USD per capita) as a high-end estimate; and to use the average across all the regions *excluding* Asia (0.2 USD per capita) as a mid-range estimate (see Table 18).

Based on this approach, the low-end, mid-range and high-end estimate in terms of clean-up costs per capita (converted from 2019 USD to 2022 Rands) are presented in Table 18, as well as the resulting preliminary costs per annum, based on a population size of 61 million.

Table 18: Preliminary low-end, mid-range and high-end estimate of clean-up costs per capita and per year

	Low estimate	**Mid-range estimate**	**High estimate**
Cost per capita (2019 USD)	0.06	0.20	1.61
Cost per capita (2022 Rands)	1.00	3.33	26.85
Cost per year* (R millions)	61.0	203.4	1 637.6

** Based on an estimated population of 61 million in 2023.*

Recall from above that the available South African data was not sufficient to allow a confident estimate to be made of annual clean-up costs based on local data. Nevertheless, some of the South African data described above may provide a useful means of cross-checking the estimates provided in Table 18. For example, based on the information presented above regarding the tonnages collected through Plastics SA sponsored clean-up events, and bearing in mind the various difficulties noted, we could assume, as a very rough (but likely conservative) estimate, that somewhere in the ballpark of 10 000 tonnes of plastic per annum is collected annually through clean-ups in South Africa (based on the 2500 tonnes of debris collected through Plastics SA sponsored events over a ten month period, and the approximately 7500 tonnes collected during the International Coastal Clean-Up). It should be borne in mind that, on the one hand, these figures are only based on Plastics SA sponsored events, excluding non-audited clean-ups as well as municipal and other cleaning operations; while on the other hand, they also include other materials in addition to plastics. Nevertheless, multiplying this crude estimate of 10 000 tonnes per annum by the R15 949 cost per tonne estimated based on Swanepoel (1995), results in a cost of R159 million per year. This is in the same order of magnitude as the mid-range estimate of the annual cost in Table 18 (R203 million); albeit somewhat lower, which is understandable given that it is likely based on a conservative estimate of tonnages cleared per annum.

Another way of cross-checking the estimates of annual costs in Table 18 is to divide the estimated annual costs by the assumed 10 000 tonnes cleared per annum (as above), to derive an estimated cost per tonne cleared; and to compare this with the existing South African data on costs per tonne for clean-ups (from Swanepoel 1995). In this way, the cost per tonne of plastic cleared (based on the annual costs presented in Table 18, and an assumed 10 000 tonnes cleared per annum) ranges from R6103 to R163 758 per tonne, with a mid-range estimate of R20 343 per tonne. While the low-end and mid-range estimates of costs per tonne seem reasonable relative to the R15 949 per tonne (in 2022 Rands) estimated for City of Cape Town based on Swanepoel (1995); the high-end estimate of R163 758 per tonne seems unrealistic. It is also higher than the estimates from the international literature of clean-up costs per tonne[8], presented in Table 7 (see Section 2.3.2). This in turn implies that the high-end estimate of annual costs in Table 18 (R1.6 billion per year) is too high.

Recall that the high-end estimates in Table 18 are based on the global average for clean-up costs per capita, including for Asia, which from Table 17 is clearly an outlier. As an alternative for the high-end estimate, we therefore propose using the average across Europe, North America and Latin America only; i.e. the global average excluding all outliers (i.e. excluding both Asia, which is likely too high; as well as Oceania, the Middle East and Africa, which are likely all too low). This gives rise to an average of 0.36 USD per capita, or R5.95 per capita in 2022 Rands, as a high-end estimate of the cost per capita. This would in turn give rise to a high-end estimate for the annual total of R362.8 million (see Table 19), or R36 277 per tonne cleared (assuming 10 000 tonnes cleared per annum), which seems more realistic as compared to R163 758 per tonne.

As such, the revised estimates of clean-up costs per capita and per annum (based on a population size of 61 million) are provided in Table 19. The estimates of clean-up costs per year in Table 19 have been triangulated as best as possible based on the information available, and are therefore the estimates that will be applied in this report.

Table 19: Low-end, mid-range and high-end estimates of clean-up costs per capita and per year

	Low estimate	Mid-range estimate	High estimate
Cost per capita (2019 USD)	0.06	0.20	0.36
Cost per capita (2022 Rands)	1.00	3.33	5.95
Cost per year* (R millions)	61.0	203.4	362.8

** Based on an estimated population of 61 million in 2023.*

[8] When converted to 2022 Rands, the estimates in Table 7 range from approximately R13 000 to R150 000 per tonne. However; the higher-end costs in this range relate to the costs of plastic pellet removal, which are likely to be higher than the costs associated with clearing of macro-debris.

4 Results and discussion

4.1 Impacts on marine ecosystem services

Based on the approach described in Section 3.1; the costs associated with marine plastic debris in South Africa, in terms of its impacts on annual ecosystem service delivery, are presented in Table 20. Recall from Section 3.1.1 that **the cost per tonne of marine plastic, in terms of its impacts on ecosystem service delivery (per annum), ranges between R68 142 and R681 423 per tonne, with a mid-range or "best" estimate of R272 569 per tonne.** Multiplying this by the estimated 50 000 tonnes of plastic entering South Africa's marine environment each year (see Section 3.1.2) results in a **total cost ranging from R3.4 billion to R34.1 billion per year, with a mid-range or "best" estimate of R13.6 billion per year, in terms of impacts on marine ecosystem services each year.**

Table 20: Costs imposed by marine plastic each year in terms of impacts on annual ecosystem service delivery (assuming 50 000 tonnes of plastic entering South Africa's marine environment annually)

	Low estimate	Mid-range estimate	High estimate
% reduction in annual marine ecosystem service delivery	1%	3%	5%
Cost per tonne of plastic, per year (Rands)	68 142	272 569	681 423
Annual cost for plastic entering marine environment each year* (R millions)	3 407	13 628	34 071

** The total cost per year refers to the total damage imposed on ecosystem services annually, by all plastic entering the marine environment each year (estimated at 50 000 tonnes per year)*

Note that the total cost per year in Table 20 refers to the reduction in marine ecosystem service delivery *each year*, as a result of the plastic debris that reaches the marine environment *in a single year* (estimated at 50 000 tonnes per year). In other words, this excludes the damage caused by the existing stock of marine plastic that entered the marine environment in *previous years*. It also excludes the damages arising in *future years* due to plastic entering the marine environment *this* year.

Likewise, the cost per tonne presented in Table 20 refers to the damage caused by each tonne of plastic, *in a single year*. It excludes damage caused by each tonne of plastic *over its lifetime*.

Recall from Sections 2.1.4.2 and 3.1.3 that plastic entering the marine environment takes hundreds to thousands of years to break down, and will continue to impose negative impacts on ecosystem services throughout its lifetime.

Table 21 presents the *lifetime cost* per tonne of plastic, as well as the lifetime cost of the 50 000 tonnes of plastic entering South Africa's marine environment in a single year, in terms of its impacts on ecosystem services, over the lifetime of the plastic; based on the approach described in Section 3.1.3. As seen in Section 3.1.3, **the lifetime cost per tonne of marine plastic, in terms of its impacts on ecosystem services over its lifetime, ranges between R3.4 million and R33.8 million per tonne; with a mid-range estimate of R13.5 million per tonne.**

Multiplying this by the estimated 50 000 tonnes of plastic entering South Africa's marine environment each year (see Section 3.1.2), results in a **total cost of between R169 billion and R1691 billion (R1.69 trillion), with a mid-range estimate of R677 billion,** in terms of **impacts on ecosystem services over the lifetime of the plastic entering the marine environment each year**. Note that this refers to the total impact on ecosystem services over the lifetime of the plastic that enters the marine environment *in one year* – it therefore excludes the impacts associated with the *existing stock* of marine plastic, as well as cumulative impacts associated with the additional plastic that enters the marine environment in *subsequent years*.

Table 21: Lifetime costs imposed by marine plastic in terms of impacts on ecosystem services over its lifetime (assuming 50 000 tonnes of plastic entering South Africa's marine environment annually)

	Low estimate	Mid-range estimate	High estimate
% reduction in marine ecosystem service delivery	1%	3%	5%
Lifetime cost per tonne of plastic (R millions)	3.4	13.5	33.8
Lifetime cost imposed by plastic entering marine environment each year (R billions)	169	677	1 691

Note that these results are consistent with initial estimates that have been made for South Africa in global studies. Specifically, WWF (2021) estimated that "the minimum lifetime cost of the plastic produced in 2019 imposed on South Africa is approximately $60.72 billion"; equivalent to approximately R1 trillion in 2022 Rands; which is mid-way between the mid-range and high estimate in Table 21. It should be noted however, that the WWF estimate:

- Is "not a holistic and bottom-up estimate of the costs incurred by South Africa, rather it is a pro-rata of the global cost estimate based on South Africa's share of global waste generation" (WWF, 2021).
- Is based on the impacts associated with total annual plastic waste generation, rather than specifically plastic entering the marine environment.
- Includes "damage to livelihoods and key economic industries, imposition of clean-up costs on governments and threats to the population's health" (WWF, 2021) associated with the full plastic life cycle; rather than only impacts on ecosystem services associated with plastic at end of life.

It should also be noted, however, that in their calculations, WWF (2021) apply "the most conservative end of the 1-5% range from the Beaumont et al. paper", i.e. 1% (aligned with our low-end estimate), rather than the full 1-5% range (see Section 3.1.3). The fact that the WWF (2021) estimate for South Africa (approximately R1 trillion) is an order of magnitude higher than our low-end estimate (R169 billion) arises because their estimate relates to a broader range of impacts associated with all plastic waste generation; rather than only impacts on ecosystem services associated with marine plastic debris.

4.2 Direct damage to affected industries

Based on the approach described in Section 3.2, the costs associated with marine plastic in terms of direct damage to each of the three industries (fisheries, shipping, and marine and coastal tourism) are presented in Table 22. Across the three industries, **direct damages** resulting from plastic entering the marine environment on an annual basis **range from R63.6 million to R475.3 million per annum, with a mid-range or "best" estimate of R269.5 million per annum**. This is equivalent to **R1272 to R9507 per tonne of plastic (mid-range or "best" estimate of R5390 per tonne of plastic**).

Table 22: Direct damage to South African industry as a result of marine plastic

<table>
<tr><th rowspan="2"></th><th rowspan="2">Low estimate (total)</th><th rowspan="2">Mid-range estimate (total)</th><th colspan="4">High estimate (per sector)</th></tr>
<tr><th>Industry</th><th>Annual value of output (2022 R billions)</th><th>Reduction in value of output</th><th>High estimate</th></tr>
<tr><td rowspan="7">Cost per year (R millions)</td><td rowspan="7">R63.6 million; based on Benn et al. (2022) estimate of $4 million in 2018 USD</td><td rowspan="7">R269.5 million, calculated as an average between the low-end and high-end estimates</td><td rowspan="2">Fisheries*</td><td rowspan="2">17.82</td><td>% loss / year</td><td>1%</td></tr>
<tr><td>Cost per year (R millions)</td><td>178.2</td></tr>
<tr><td rowspan="2">Shipping</td><td rowspan="2">4.62</td><td>% loss / year</td><td>1%</td></tr>
<tr><td>Cost per year (R millions)</td><td>46.2</td></tr>
<tr><td rowspan="2">Marine & coastal tourism</td><td rowspan="2">16.73</td><td>% loss / year</td><td>1.5%</td></tr>
<tr><td>Cost per year (R millions)</td><td>251.0</td></tr>
<tr><td colspan="3">Total cost per year (R millions)</td><td>475.3</td></tr>
<tr><td>Cost per tonne of plastic** (Rands)</td><td>1 272</td><td>5 390</td><td colspan="4">9 507</td></tr>
</table>

** Marine fisheries only, excluding mariculture*
*** Cost per tonne of plastic is estimated by dividing the total cost per year by the tonnages of plastic entering the marine environment each year (estimated at 50 000 tonnes per year)*

The estimates in Table 22 are in the same order of magnitude as estimates that can be derived using an alternative approach based on international literature. Specifically, recall from Table 5 (see Section 2.2.3) that Deloitte (2019) note a global average in terms of losses to economic value across the fisheries & aquaculture and marine tourism sectors of 0.36 USD per capita. Multiplying this by the South African population of approximately R61 million, and translating to 2022 Rands, results in an estimated total loss of approximately R366 million, which is between the mid-range (R269 million) and high-end (R475 million) estimates of the annual cost provided in Table 22.

4.3 Clean-up costs

Based on the approach described in Section 3.3, **clean-up costs for marine plastic are estimated at between R61.0 million and R362.8 million per annum (mid-range or "best" estimate of R203.4 million per annum)** (see Table 23).

Table 23 also provides an indication of clean-up costs per tonne of plastic. However, note that here the clean-up cost per tonne of plastic refers to the costs *per tonne of plastic entering the marine environment annually* (estimated at 50 000 tonnes per year); and *not* the costs per tonne of plastic *cleared*. Recall that in Section 3.3, we made some very rough estimates of the costs per tonne of plastic cleared (based on crude assumptions regarding the tonnages of plastic cleared annually); as a means of cross-checking the estimates of costs per annum. In this section, to be consistent with how the results are presented for the other components of the total economic impact (see Sections 4.1 and 4.2), and to enable aggregation towards a total cost per tonne in Section 4.4, we present clean-up costs per tonne of plastic *entering the marine environment* each year, *not* per tonne of plastic cleared. These costs per tonne are calculated by dividing the total clean-up costs per year by the estimated 50 000 tonnes of plastic entering the marine environment each year. Since tonnages of plastic cleared annually are likely to be lower than the tonnages entering the marine environment each year, the actual clean-up cost per tonne of plastic cleared is likely to be *higher* than the costs per tonne indicated in Table 23.

Table 23: Clean-up costs for marine plastic debris in South Africa

	Low estimate	Mid-range estimate	High estimate
Cost per capita (Rands)	1.00	3.33	5.95
Cost per year* (R millions)	61.0	203.4	362.8
Cost per tonne of plastic entering the marine environment annually**	1 221	4 069	7 256

** Based on an estimated population of 61 million in 2023.*
*** Costs per tonne refer to the costs per tonne of plastic entering the marine environment each year, not per tonne of plastic cleared. Estimated by dividing the total cost per year by the tonnages of plastic entering the marine environment each year (estimated at 50 000 tonnes per year)*

Box 2: A note on aggregation and double-counting

Recall from Section 2 (Figure 1) that the total economic impact of marine plastic is composed of three components, namely **impacts on ecosystem services, direct damage to industry, and clean-up costs.** Sections 4.1, 4.2 and 4.3 presented the results for each of these components.

In working towards an estimate of the total economic impact of marine plastic (Section 4.4), the literature is divided in terms of whether the three components discussed in Sections 4.1 to 4.3 can be aggregated, or whether doing so would result in double-counting.

For example, according to Beaumont et al. (2019); estimates of the economic impacts of marine plastic on ecosystem services based on their approach (i.e. as per Section 4.1) should be seen as an underestimate of the total economic impact of marine plastic; as there are also "broader social and economic costs that need to be quantified and included, for example, direct and indirect impacts on the tourism, transport and fisheries sectors" (Beaumont et al. 2019). This suggests that the costs estimated in Sections 4.1 (impacts on ecosystem services) and 4.2 (direct damage to industry) should be aggregated.

On the other hand, according to WWF (2021); impacts on fisheries, tourism etc. should *not* be added to the estimates of impacts on ecosystem services, "to avoid double-counting; as the impact on fisheries and tourism is already accounted for in the figure that estimates the cost of marine ecosystem service reduction" (WWF, 2021). This suggests that the costs presented in Sections 4.1 and 4.2 should *not* be aggregated.

To overcome this issue, recall from Sections 2.2.1 and 3.2 that in this report we have attempted to ensure that our estimate of impacts on industry (see Section 4.2) is conservative; specifically, that it refers only to *direct damage* caused by plastic; rather than impacts arising through a reduction in ecosystem service delivery. In this regard, it should be possible to aggregate the impacts on ecosystem services (Section 4.1) with direct damage to industry (Section 4.2), with no concerns around double-counting.

In terms of clean-up costs (see Section 4.3), it could be argued that, in order to avoid double-counting, these should *not* be added to the other two components; since clean-up activities are typically conducted to *avoid* damages to ecosystem services and/or industry. However, our interpretation of the data on which the estimates of impacts on ecosystem services and industry (Sections 4.1 and 4.2) are based, is that these refer to impacts that are actually being incurred, *in spite of* clean-up efforts. In other words, the real costs to society associated with marine plastic include both actual damages to ecosystems and industries, as well as clean-up costs to avoid *potentially even higher* damages. From this perspective, it could be argued that clean-up costs *can* be aggregated with the other two components (since in the absence of such clean-up efforts, the damage to ecosystem services and industries may have been even higher).

4.4 Total economic impact of marine plastic in South Africa

Sections 4.1, 4.2 and 4.3 presented the results in terms of each of the three components of the total economic impact of marine plastic (**impacts on ecosystem services, direct damage to industry, and clean-up costs**). Table 24 summarises the costs per annum and per tonne of plastic (per year) associated with each of the three components (from Sections 4.1 to 4.3); as well as the total cost, assuming that the three components can indeed be aggregated (see Box 2).

Table 24: Summary of the total economic impact of marine plastic in SA per annum (based on 50 000 tonnes of plastic entering the marine environment each year); and costs per tonne of plastic

	Annual costs arising from plastic entering South Africa's marine environment each year (R millions)			Annual costs per tonne of plastic (Rands per tonne)		
	Low estimate	Mid-range estimate	High estimate	Low estimate	Mid-range estimate	High estimate
Impacts on ecosystem services (per annum)	3 407	13 628	34 071	68 142	272 569	681 423
Direct damage to industry	64	269	475	1 272	5 390	9 507
Clean-up costs	61	203	363	1 221	4 069	7 256
Total	**3 532**	**14 101**	**34 909**	**70 635**	**282 028**	**698 186**

Based on impacts on ecosystem services (per year), direct damage to industry, and clean-up costs; **the total economic impact associated with the plastic reaching South Africa's marine environment each year** ranges between **R3.5 billion and R34.9 billion per year.** This is equivalent to between **0.05% and 0.5% of South Africa's annual GDP[9]; or 4.7% to 46% of the value of the SA plastics industry's direct contribution to annual GDP[10].**

The **mid-range or "best" estimate is R14.1 billion per year, equivalent to approximately 0.2% of South Africa's annual GDP, or 18.6% of the plastics industry's direct contribution to GDP.**

The cost associated with **each tonne of plastic ranges between R70 635 and R698 186; with a mid-range or "best" estimate of R282 028 per tonne.** Note that the estimates presented in Table 24 are based on an assumed 50 000 tonnes of plastic reaching the marine environment each year.

It can be seen that **impacts on ecosystem services make up the bulk of the costs associated with marine plastic**. For example, based on the mid-range estimate of annual impacts (i.e. a cost of R14.1 billion per annum), **impacts on ecosystem services account for 97% of the total, with direct damage to industry (2%) and clean-up costs (1%)** making up a much smaller proportion (Figure 5).

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[9] South Africa's nominal Gross Domestic Product at market prices in 2022 was R6.64 trillion (Statistics South Africa, 2022).
[10] South Africa's plastics industry contributed R68 billion directly to GDP in 2020 (Plastics SA, 2022c). To be consistent with other values applied in this study, this was inflated to 2022 values (R75.9 billion) based on CPI.

This implies that the question of whether the three components should be aggregated (see Box 2) becomes somewhat of a moot point, as the overall impact is in any case dominated by impacts on ecosystem services.

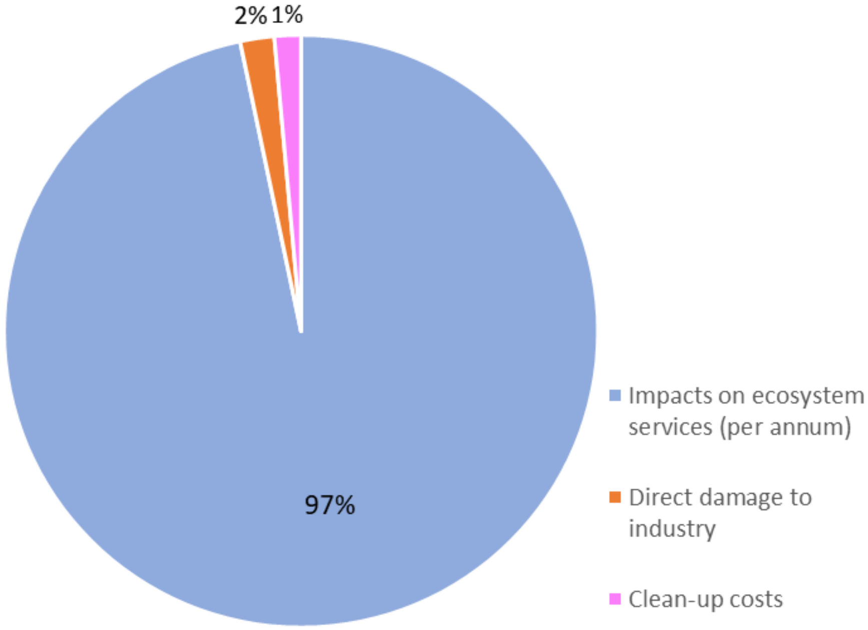

Figure 5: Percentage contribution of impacts on ecosystem services, direct damage to industry and clean-up costs to total economic impact (based on mid-range estimate of annual impacts of R14.1 billion)

Sections 3.2 and 4.2 provided an indication of the direct damage component as a proportion of the revenues or GDP contribution of each of the affected industries (fisheries, shipping and tourism). In addition, it may be of interest to compare the estimated *total* annual economic impact across all three components (including impacts on ecosystem services, direct damage, and clean-up costs, as per Table 24), as a percentage of revenues/GDP in each industry. These results are provided in Table 25. It can be seen that even the low-end estimate of the total annual economic cost represents a substantial proportion of revenues in each industry. In the case of the mid-range and particularly the high-end estimates, the total economic impact starts to *exceed* annual earnings for these industries. This could be explained by the fact that the total economic impact is dominated by impacts on ecosystem services (including provisioning, regulating, cultural and supporting services), the value of which goes beyond the revenues earned by specific sectors of the economy.

Table 25: Total annual economic impact as a proportion of revenues / GDP for each of the affected industries

Industry	**Revenues / GDP contribution, inflated to 2022 R billions based on CPI***	**Total economic cost (including impacts on ecosystem services, direct damage, and clean-up costs) as a % of revenues / GDP contribution of each industry**		
		Low estimate (R3.5 billion)	**Mid-range estimate (R14.1 billion)**	**High estimate (R34.9 billion)**
Fisheries**	17.82	19.8%	79.1%	195.9%
Shipping	4.62	76.5%	305.5%	756.3%
Marine & coastal tourism	16.73	21.1%	84.3%	208.6%

** See Section 3.2*
*** Marine fisheries only, excluding mariculture*

It is important to note that the results presented in Table 24 only consider the impacts arising *annually*, due to the plastic entering the marine environment in one year (or, the impacts generated *annually* by each tonne of plastic in the marine environment). However, **plastic entering the marine environment takes hundreds to thousands of years to break down, and will continue to impose negative impacts on ecosystem services throughout its lifetime**. The results in Table 24 ignore the impacts on ecosystem services that will arise in the future due to the plastic that reaches the marine environment in the current year.

As seen in Section 4.1, **the lifetime cost per tonne of marine plastic, in terms of its impacts on ecosystem services over its lifetime, ranges between R3.4 million and R33.8 million; with a mid-range estimate of R13.5 million per tonne of plastic** (see Table 21). Multiplying this by the estimated 50 000 tonnes of plastic entering South Africa's marine environment each year, results in a **total cost of between R169 billion and R1.69 trillion (2.5% to 25.5% of South Africa's annual GDP), with a mid-range estimate of R677 billion (10.2% of annual GDP),** in terms of **impacts on ecosystem services over the lifetime of the plastic entering the marine environment each year**. Note that even this refers only to impacts resulting from plastic entering the marine environment *in one year* – it therefore excludes the impacts associated with the existing stock of marine plastic, as well as cumulative impacts associated with the additional plastic that enters the marine environment in subsequent years.

5 Conclusions and recommendations

The results provided in Section 4 of this report should be seen as a *preliminary* estimate of the economic impact of marine plastic debris in South Africa. The intention was to develop an understanding of the order of magnitude of these impacts; so as to move the discussion forward. Owing to the various uncertainties involved, and the lack of relevant South African information; a range of estimates has been provided, based primarily on adapting and adjusting unit impact values from international studies to the South African context as best as possible; while a number of assumptions have had to be made. The estimates provided in this report should therefore be seen in this context, and used with caution. All assumptions have been made clear, so that these can be tested and the resulting estimates refined as necessary.

To summarise:

- **The total economic impact associated with the plastic reaching SA's marine environment each year** ranges between **R3.5 billion and R34.9 billion per year** (**0.05% to 0.5% of South Africa's annual GDP, or 4.7% to 46% of the SA plastics industry's direct contribution to annual GDP**). The mid-range or "best" estimate is **R14.1 billion per year (0.2% of GDP, or 18.6% of the plastics industry's direct contribution to GDP).**
- The **cost per tonne of plastic (per year)** ranges between **R70 635 and R698 186 (mid-range estimate of R282 028 per tonne).**

- The **lifetime cost per tonne of marine plastic**, in terms of its impacts on ecosystem services over its lifetime, ranges between **R3.4 million and R33.8 million** per tonne (**mid-range estimate = R13.5 million per tonne**).
- The **plastic entering the marine environment each year** imposes a total cost of between **R169 billion and R1.69 trillion (2.5% to 25.5% of annual GDP), with a mid-range estimate of R677 billion (10.2% of annual GDP),** in terms of **impacts on ecosystem services over its lifetime.**

However, the estimates in this report should be seen as an underestimate of the total environmental impact associated with plastic, for a number of reasons.

First, the report only focuses on the impacts of plastic at end of life. Plastic gives rise to various other negative impacts across its life cycle, including greenhouse gas emissions and human health impacts associated with plastic production (WWF, 2021).

Secondly, the report focused only on the impacts of *marine* plastic. According to Verster and Bouwman (2020), an estimated 440 000 tonnes of mismanaged plastic waste is generated annually in South Africa; of which only a relatively small proportion reaches the marine environment; with the vast majority remaining in the terrestrial or freshwater environment; or being subject to open burning, thereby giving rise to air pollution (Stafford et al., 2022). The environmental and human health impacts associated with these forms of plastic pollution still need to be quantified.

Thirdly, the report only attempts to quantify the impacts of marine plastic in terms of a reduction in ecosystem service delivery, direct damage to industry, and clean-up costs. Recall from Section 2 that a number of other types of impacts associated with marine plastic (e.g. impacts on human health, and on 'non-use' values such as existence and bequest values) are excluded, primarily because they are less easily quantifiable. To the extent that these are not captured within impacts on ecosystem services or on industry, the estimates presented in this report are an underestimate of the total economic impact of marine plastic in SA.

Finally, the estimates of total economic impact are based on current rates of plastic waste generation, i.e. an assumed 50 000 tonnes of plastic reaching the marine environment each year. In the absence of significant intervention measures, plastic leakage is projected to increase in future (Jambeck et al., 2015; Stafford et al., 2022). For example, application of the Pathways tool[11] to South Africa suggests that, in the absence of intervention, plastic pollution in South Africa is set to almost double between 2020 and 2040 (Stafford et al., 2022). This projected rise in plastic pollution will in turn lead to an increase in the associated impacts on ecosystem services and the economy.

The Pathways report (Stafford et al., 2022) also highlights that, given the projected rise in plastic production and consumption in South Africa, no single intervention strategy implemented in

[11] The 'Pathways Tool' (https://www.pewtrusts.org/en/research-and-analysis/fact-sheets/2022/09/a-new-tool-can-help-address-ocean-plastic-pollution) was first applied in the global Breaking the Plastic Wave study (The Pew Charitable Trust and SYSTEMIQ, 2020); and has since been applied by the CSIR at a national level in South Africa (https://wasteroadmap.co.za/research/grant-046/ ; Stafford et al. 2022).

isolation will effectively reduce plastic pollution. Even with the Extended Producer Responsibility (EPR) Regulations in place, under the current targets for collection and recycling of plastic packaging at end of life, 2040 levels of plastic pollution will be similar to current levels, given the projected growth in plastic production and consumption. Only a scenario of “optimal system change”; encompassing a reduction in plastic production and consumption, as well as an increase in plastic waste collection, recycling, and safe disposal to sanitary landfill to ensure effective containment; will ensure a reduction in plastic pollution (Stafford et al., 2022).

At the same time, the costs estimated in this study should be compared alongside the many benefits of plastic. Plastic is an extremely lightweight, durable and versatile material, which brings significant value to society, and provides a number of socio-economic and environmental benefits as compared to alternative types of materials (World Bank and CSIR, 2022). Life cycle assessment studies show that transitioning away from plastics toward alternatives is not necessarily the solution, particularly if the requisite infrastructure for dealing with alternative materials at end of life is not in place.

A number of **recommendations** can therefore be drawn from this study.

Firstly, there is a need to **address key data gaps**. In terms of assessing the **impacts of marine plastic**, the following gaps need to be addressed to enable the preliminary estimates provided in this report to be further refined:

- While a number of studies have estimated flows of plastic to the marine environment from land-based sources in South Africa; the assumptions underlying some of these studies can be questioned; and an improved understanding of these flows is required. In particular, an improved understanding is required of freshwater aquatic systems as possible sinks for plastics, the retention times of plastic in freshwater sediment and its role as a possible secondary source of plastic debris (Verster and Bouwman, 2020), how far plastic travels along South Africa’s river systems, and how much of this plastic eventually reaches the marine environment. In addition, there is a need for better information on marine sources of plastic in the South African context, for which very little information is currently available.
- There is a need for improved data on exposure of coastal and marine biota and ecosystems in SA to plastic, an improved understanding of the causal relationships between exposure and the resulting impacts on ecological functions and processes underpinning the provision of marine ecosystem services, and location-specific case studies to enable an improved understanding of impacts across SA’s diverse coastal environments. This will enable a more detailed bottom-up assessment of the impacts of marine plastic on ecosystem services in the SA context; using the framework developed by Blanchard and Smith-Adao (2023).
- Alternatively, in order to improve on the estimate derived in this study based on a “top-down” application of the Beaumont et al. (2019) approach, there is a need for data on:
    - The economic value derived by society from the various ecosystem services provided by South Africa’s marine ecosystems; and
    - The total stock of plastic (both macroplastic and microplastic) that has accumulated in South Africa’s marine environment.
- Although direct impacts on industry and clean-up costs were found to be significantly lower than impacts on ecosystem services, the estimates for these costs also need to be refined; based on:

  - An improved understanding of the impacts of marine plastic on the fisheries, aquaculture, shipping, tourism, and other industries affected by marine plastic in SA; relative to other drivers that may be impacting negatively on these industries.
  - Improved, updated data on the total amount of plastic removed from the marine environment through the various types of clean-up efforts in South Africa, and the costs incurred in such efforts at a national level (or the costs per tonne).
- There is also a need for research related to the other impacts associated with marine plastic not assessed in this report; such as impacts on human health, and on non-use values such as existence and bequest values.

Furthermore, taking into account that only a relatively small proportion of waste plastic generated in South Africa ends up in the marine environment; there is a need to quantify the **negative impacts associated with plastic pollution in terrestrial and freshwater environments** (including impacts on ecosystem services), as well as the environmental and human health impacts associated with air emissions from **open burning of plastic.**

More broadly, however, there is a **need for research** not only on the negative impacts associated with plastic at end of life; but **on the positive and negative social, economic and environmental impacts (benefits and costs) of plastic (and of alternatives to plastic) across its full life cycle; and of alternative intervention strategies; to inform decision making**. In particular:

- There is a need to quantify the positive and negative economic, social and environmental impacts (benefits and costs) associated with both plastic *and* alternative materials, across their full life cycle, and in different applications; enabling a comparative assessment of plastic and of alternative materials for each application; so as to inform a suitable material choice in each application.
- Building on Stafford et al. (2022); there is a need to assess the cost-effectiveness of alternative intervention strategies (reducing, redesigning, reusing and recycling, as well as improved waste collection and disposal) in reducing plastic leakage; as well as their broader economic and social impacts; to inform an appropriate combination of strategies for reducing plastic pollution (World Bank and CSIR, 2022). The cost estimates provided in the current report, which can be used to inform the benefits associated with intervention strategies aimed at reducing marine plastic pollution, are one part of this picture.

At the same time, given the urgency of the problem, **it is important to ensure that the current lack of data is not used as an excuse to delay action**.

There is a clear need for system-wide change, incorporating a broad range of upstream and downstream interventions; in line with the principles of a circular economy. In particular, more emphasis is needed on upstream solutions, such as rethinking, reducing and redesigning plastic products for circularity, so as to avoid the generation of plastic waste in the first place; as compared to the current focus on end-of-pipe solutions aimed at removing plastic that has already entered the environment. A recent report by the World Bank and CSIR (2022) sets out a vision for a thriving, equitable and inclusive circular plastics economy in South Africa; and recommendations for achieving this vision. Making this transition will require a concerted, collaborative effort among all role players, all working towards a shared vision.

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ANNEXURE 1: Impacts of marine plastic on the main ecosystem types found in South Africa's marine environment

Table A1: Examples of exposure of marine organisms to plastic within the main ecosystem types (or habitat types) found in South Africa's marine environment, and potential impacts on ecosystem services

Marine Ecosystem	Marine species	Type of plastic	How plastic materialises in this ecosystem	How marine species are affected by plastic	Potential impacts on ecosystem services
Rocky shore ecosystems Found where the sea meets the land; characterised by the life that lives in the intertidal zone – the area between the high- and low tide levels. Provides habitats and critical feeding places for a large number of marine species.	Birds, mollusca (mussels, clams, barnacles), shellfish, anemones, urchins, small fish, star fish, see cucumbers, bryozoans, sea anemones, Spirorbis worms, other polychaete worms, limpets, chitons, etc.	Macroplastic	Plastic gets trapped amongst the rocks, between crevices and even amongst the rock dwellers. This trapped plastic leads to the formation of plasticrusts (plastic debris encrusting the rocky surface) (Gestoso et al., 2019).	Plastics can form 'plasticrusts' over volcanic rocks. Gastropods and other grazers in the intertidal zone feed by scraping diatoms and algae off rocks. By grazing on these plasticrusts, species may ingest microplastics and thus act as a vector for microplastics and their associated chemicals into higher trophic levels (Teuten et al., 2009; Gestoso et al., 2019). Some rocky shore organisms are displaced by macroplastics, resulting in a change in diversity of species; while others are suffocated, especially by plastic bags, causing death (Teuten et al., 2009). Sessile marine organisms such as larvae attach to floating plastic, which in turn facilitates the spread of invasive species.	Plastic in this ecosystem disrupts cultural services. Negative impacts on marine and coastal tourism (i.e., significantly reduced tourist numbers) and numerous marine-related industries (e.g., shipping, fishing, energy production, aquaculture). Potential loss in economic value / revenue (Krelling et al., 2017; Arabi and Nahman, 2020).
		Microplastic	The higher the urbanisation surrounding beaches, the higher the concentration of microplastics in the organs of bivalves (Costa et al., 2022).	Bivalves are filter feeders, some of which attach themselves to rocks and other hard surfaces. Species start consuming microplastic due to fragments of plastics being broken off from macroplastic items (Zhang et al., 2022). This leads to transfer of microplastics along the food chain. Bioaccumulation of microplastic leads to inhibition of growth and development (Zhang et al., 2022)	Through provisioning services, microplastics enter other organisms and accumulate; disrupting body functions (Kumar et al., 2019).

Marine Ecosystem	Marine species	Type of plastic	How plastic materialises in this ecosystem	How marine species are affected by plastic	Potential impacts on ecosystem services
Sandy beach ecosystem Refers to the foredunes, beach, and surf zone. Found along the entire 3000km coastline of South Africa. Beaches are known to be depositional sites where marine litter from adjacent ocean and land compartments accumulate and are exchanged, with still unclear dynamics (Costa et al,. 2022).	Crustaceans such as ghost crabs and mole crabs, shore birds, pinnipeds, sandhoppers, bivalves such as clams, polychaetes, nematodes, certain insects, reptiles such as turtles that come ashore to lay their eggs.	Macroplastic	Washed up and stranded plastic smothers plants and animals, leading to plastic entanglement, entrapment, and ingestion (Costa et al., 2022). Studies show that plastic on the beach effects sediment temperatures by altering thermal inputs and outputs (e.g., infrared radiation absorption) (Lavers et al., 2021).	Vertebrates and invertebrates that use sandy beaches for resting, nesting, staging, and foraging are exposed to being entangled in macroplastic. For example, turtle hatchlings emerging from nests have been entangled in fishing nets and entrapped in plastic containers, invertebrates are becoming stuck inside plastics, and discarded containers on beaches act as pitfall traps for sand-dwelling beetles (Costa et al., 2022). Large debris deposited on the sand also imposes adverse effects on female sea turtle nesting and hatchlings. Disorientated turtle hatchlings may be easier prey, with litter playing a role in reducing seaward orientation (Costa et al., 2022). It was also found that organisms using this ecosystem have prolonged searching time for food and decreasing accuracy of orientation as the level of plastic increases on beaches (Costa et al., 2022). Temperature fluctuations in sediments have potentially significant implications for faunal species, many of which have narrow thermal tolerance limits and are functionally important in beach habitats (Lavers et al., 2021).	Plastic in sandy beach ecosystems affects provisioning services e.g., clams for food, aquaculture, wild plants and wild animals for food, mineral and metal substances, energy sources, drinking water etc. (Costa et al., 2022) It also affects regulating services e.g. coastal protection, water filtration, nutrient cycling, regulation of chemical composition of atmosphere and ocean, regulation of temperature, wind protection, control of erosion, etc. (Costa et al., 2022) Finally, it affects cultural services e.g. sites of symbolic and spiritual significance, heritage, education, and training (Costa et al., 2022). Negative impacts on marine and coastal tourism (i.e., significantly reduced tourist numbers) and numerous marine-related industries (e.g., shipping, fishing, energy production, aquaculture). Potential loss in

Marine Ecosystem	Marine species	Type of plastic	How plastic materialises in this ecosystem	How marine species are affected by plastic	Potential impacts on ecosystem services
		Microplastic	On sandy beaches, all resident and transient species are very likely ingesting microplastic from the sand, water, and their prey. Sand is a heterogeneous medium, and sand grains are redistributed under the effects of waves, tides, and ocean currents, dispersing microplastics in the sand layers and at various tidal lines. The spatial distribution of microplastic may be influenced by natural factors, such as wind, coastal landscapes, and structures, as well as by anthropogenic factors, including river input, the local population and tourism (Costa et al., 2022).	Numerous studies have shown that the ingestion of microplastic by sandy beach invertebrates contributes to the reduction in population, synergically with other physical and chemical stressors (Costa et al., 2022)	economic value / revenue (Arabi and Nahman, 2020; Harris and Defeo, 2022).
Kelp forest Found along the west coast of South Africa, covering approximately 1000 km of coastline	There are two dominant kelp species in South Africa: Ecklonia maxima and Laminaria pallida. Kelp forests host several commercially valuable species including the West Coast rock lobster, abalone, and a variety of fish species.	Macroplastic	No research to date	No research to date	Kelp forests provide several important ecosystem services including regulating services (e.g., carbon storage and cleaning of the water), provisioning services (primary production, creating habitats including for commercial species, providing raw material for commercial harvest, farming, and industry), and cultural services (ecotourism and recreational fishing) (Hynes et al., 2021).
		Microplastic	No research to date	No research to date	

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Tidal marshes, mangrove forests and seagrass meadow ecosystems (Blue carbon ecosystems) Blue carbon ecosystems cover a combined total of approximately 18 000 ha across the four coastal provinces of South Africa (Adams, et al., 2019). The ecosystem services provided by mangroves are estimated to be worth at least $33 000 - $57 000 per hectare per year (UNEP, 2014; UN 2017).	Mangrove tree species i.e. the white mangrove (Avicennia marina), black mangrove (Bruguiera gymnorrhiza) and red mangrove (Rizophora mucronata). Salt marsh species include Bassia diffusa (Thunb.) Kuntze, Cotula coronopifolia L., Limonium linifolium (L.f.) Kuntze, Juncus kraussii Hochst., Phragmites australis (Cav.) Steud and Triglochin striata Ruiz & Pav. Fish, otters, crabs, gastropods, a wide range of birds such as flamingos, storks, gulls, and kingfishers, vervet monkeys, bushbabies, and mongooses	Macroplastic	Mangrove roots act as filters, retaining and trapping large floating plastic objects (i.e., acting as plastic sinks) (Tekman et al., 2022) Plastic accumulates in mangrove forests covering their root systems, thereby creating an anoxic environment and inducing tree suffocation (van Bijsterveldt et al., 2021; Adyel and Macreadie, 2021, Beraud et al., 2022; Tekman et al., 2022). Macroplastics provide a suitable habitat for microorganisms in these ecosystems. This leads to biofouling by microorganisms.	Covering of root zones (knee roots and pneumatophores) by plastic leads to suffocation of the mangrove trees. This result in mangrove forests not performing optimally in terms of their ecosystem functions (Tekman et al., 2022). Entanglement can lead to lacerations, reduced ability to swim or move, internal injuries and starvation (Tekman et al., 2022).	The resulting damage to mangrove trees disrupts the regulating services provided by this unique ecosystem, including carbon sequestration, water purification and coastal protection against floods and storms (van Bijsterveldt et al., 2021, Darabi et al., 2021). Disrupts cultural services. Negative impacts on marine and coastal tourism (i.e., significantly reduced tourist numbers) and numerous marine-related industries (e.g., shipping, fishing, energy production, aquaculture). Potential loss in economic value / revenue (Krelling et al., 2017; Arabi and Nahman, 2020).
		Microplastic	Marsh vegetation traps microplastics (Pinheiro et al., 2022). Macroplastic items are broken down into microplastic because of UV exposure, wind, and precipitation while trapped in the tidal marsh and roots of mangroves. Species that visit these ecosystems ingest plastic items and can also get entangled in plastic. Due to mangrove species such as fish, mollusca, crustaceans, and gastropoda ingesting small particles either directly or indirectly, microplastic accumulates in such	Microplastic alters sediment microbial community composition and nitrogen cycling processes. Studies indicate that nitrogen cycling processes in sediments can be significantly affected by different microplastics, which may serve as organic carbon substrates for microbial communities (Seeley et al., 2020). Ingestion of plastic can lead to bioaccumulation within the body, which then may have implications for development, reproduction, neurological disorders, etc.	Disrupts provisioning services due to the bioaccumulation of microplastic, which affects and inhibits growth and development of faunal species due to stomach and gut blockages, decline in fecundity and reproductive success, and an increase in mortality. This ultimately affects food provision due to the disruption of healthy fisheries provided by such ecosystems (Kumar et al., 2021). Considering these ecosystems offer unique habitats to young and

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			mangrove species, which are then passed along the food chain (Maghsodian et al., 2022). Microplastics accumulate in the sediment. Research indicates that the mangrove trees act as plastic carbon sinks. The root system of mangrove trees therefore absorbs microplastic and sinks it into the sediment in the swamps. Mangroves, generally support high sediment accretion rates, efficiently sequester plastics in their sediments (Martin et al., 2020). This is similar within tidal marshes. Biological colonisation of macro and microorganisms including viruses, bacteria, algae, fungi, invertebrates, and even urochordates occur on microplastic floating in the open ocean. Once these communities, collectively known as plastispheres, are deposited in sedimentary marine systems such as tidal marches and mangroves this can lead to the ecosystem being exposed to invasive species that negatively impact the functioning of the ecosystem (Amaral-Zettler et al., 2020; Pinheiro et al., 2022).	Accumulation of microplastics in faunal species causes inhibition of growth and development due to stomach and gut blockages, decline in fecundity and reproductive success, and an increase in mortality (Zhang et al., 2022).	spawning fish, and critical habitat for migratory fish and birds (i.e., breeding, roosting, and feeding); the bioaccumulation of microplastic in species leads to a break down in the provisioning services typical of fish. This also applies to other species that consume or are entangled by plastic (Adyel and Macreadie, 2021). Mangrove forests act as hot spots for microplastic sequestration in their sediments. Hence, blue carbon strategies to conserve and restore mangrove habitats are not only effective to mitigate and adapt to climate change, but are also critically important to prevent the remobilisation of plastic litter accumulated in the sediments (Adyel and Macreadie, 2021, van Bijsterveldt et al., 2021, Darabi et al., 2021).

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Coral reef ecosystems 50 km along the northern KZN coast from north of Cape Vidal to the Mozambique border	Abundance of tropical reef fish, Moray eels, large schools of pelagic fish, Potato bass, turtles (Hawksbill, Loggerhead, Green and Leatherback), sharks, worms, sponges, coral species, anemones, star fish, etc.	Macroplastic	Substantial amounts of plastic items have been found entangled in the reefs (Tekman et al., 2022). The spikier the coral species, the more likely they were to snag plastic.	Disease increases 20-fold once coral is draped in plastic. Plastic debris stresses coral through light deprivation, toxin release, and anoxia, giving pathogens a foothold for invasion (Lamb et al., 2018; Tekman et al., 2022). At the same time, the low-light, low-oxygen conditions created when plastic settles on coral is ideal for microbes that cause black band disease to flourish, resulting in complete tissue degradation. Microhabitats for reef-associated organisms and valuable fisheries will be disproportionately affected (Lamb et al., 2018).	Declines in the structural complexity of reef habitats are often linked to changes in fish communities, with likely impacts on fishery services and thereby the provisioning services of coral reefs (Woodhead et al., 2018). Coral reefs play a significant role in protecting coastlines. Damage to coral reefs impacts upon their regulating services (Woodhead et al., 2018). Disrupts cultural services. Negative impacts on marine and coastal tourism (i.e., significantly reduced tourist numbers in the diving industry) and numerous other marine-related industries (e.g. shipping, fishing, energy production, aquaculture). Potential loss in economic value / revenue.
		Microplastic	Microplastics can host pathogens that are frequently implicated as triggers of disease outbreaks on coral reefs (Tekman et al., 2022). Corals, being non-selective feeders, consume smaller size organisms, such as zooplankton, and ingest microplastic particles present in water due to their size similarities.	Studies have shown that corals can eat, spit out, or keep plastic particles in the individual coral polyps. These microplastics when ingested and accumulated within corals, cause severe tissue damage, affect their immune system, reduce their food intake, affect growth, and cause necrosis and bleaching (Utami et al., 2021). This can lead to the coral having decreased feeding, energy, and/or reproduction. Microplastics can cause physical and chemical harm to the corals and can potentially transmit more pathogens. Additionally, all corals have an ability to clean themselves through ciliary action, mucus production, or tissue expansion to take care of natural or artificial particles that land on them. However, microplastics could block the ability of corals to clean themselves, and cause further declines in coral health such as tissue necropsy or bleaching (Lamb et al., 2018; Lanctot et al., 2020).	

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				Corals also accumulate microplastics in and on their polyps, negatively impacting the corals themselves and their associated symbiotic algae, thereby altering reef community structures (Tang et al., 2021).	
Deep sea ecosystem	Turtles, fish, birds, seals, whales, sharks, phytoplankton, zooplankton	Macroplastic	Larger marine plastic debris threatens marine species by means of entanglement, entrapment, and ingestion. Plastics adsorb organic and inorganic nutrients from water which, along with its physical properties and widespread distribution, provides a unique and stable habitat attracting bacteria, viruses, plankton, and other microorganisms, which adhere to its surface and colonise (Frère et al., 2018). Macroplastic floating in the open ocean breaks down into microplastic because of physical, chemical, and biological processes such as mechanical degradation, biodegradation, thermal actions, UV degradation, photodegradation, mechanical forces (e.g. friction), turbulence, and other processes (Kumar et al., 2021)	According to Gall and Thompson (2015), >13 000 individuals representing 208 species and >30 000 individuals belonging to 243 species have encountered issues related to ingestion and entanglement by macroplastic fragments, respectively. Entanglement cases were mainly recorded between the individual organisms and fishing nets or plastic rope in fishing gear. Ingestion is highly associated with individual organisms and plastic fragments (Gall and Thompson, 2015). Species including turtles, birds, seals, dolphins, whales, etc. are affected by means of direct ingestion, which can cause debilitation and death through internal injury and intestinal blockage; entanglement; and impacts on hatchling survival (Tekman et al., 2022). As a direct result of entanglement or ingestion, coastal and marine biotic organisms suffer injuries or die. Sub-lethal effects cause reduced capturing and swallowing of food particles, impaired reproductive ability, loss of sensitivity, the inability to escape from predators, loss of mobility and decreased growth. Comparatively, sea turtles, marine mammals, and all types of sea	Entanglement, entrapment, and ingestion of plastic by any species found in the ocean has the potential to reduce the efficiency and productivity of the species. This impacts the provisioning services of this ecosystem.

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				birds are at higher risk of entanglement and ingestion by plastic pollution. Green sea turtles, Hawksbill turtles, Fulmars, Seals, Sea Lions, Puffins, Albatrosses, Right whales, and Greater shearwaters are among the species affected (Gall and Thompson, 2015). It is estimated that up to 90% of all seabirds and 52% of all sea turtle individuals ingest plastics (Wilcox et al., 2015; Schuyler et al., 2015; Prokić et al., 2019. Macro and microorganisms including viruses, bacteria, algae, fungi, invertebrates and even urochordates colonise on plastic floating in the open ocean. This ultimately facilitates the transportation of such species to non-native regions where they don't naturally occur. They may become invasive and/or contribute to the introduction of disease to a new ecosystem (Shen et al., 2020; García-Gómez et al 2021).	
		Microplastic	The presence of microplastics on the ocean floor due to it having sunk may affect the ocean's carbon stock. The ocean surface is not the final destination for ocean plastics. The sinking ability of plastics is related to its density and biofouling. Biofilm coatings on microplastics can change the buoyancy and viscosity of microplastics in seawater, thus weakening the floatation kinetics and hydrophobicity of microplastics, and causing the microplastics to settle	When microplastics exist in water, phytoplankton can easily combine with them, affecting their feeding, metabolism, development, and reproduction. Microplastic reduces the chance of phytoplankton coming into contact with light and thereby photosynthesising, ultimately reducing marine primary productivity. This toxicity effect increases with the smaller size of microplastic particles (Shen et al., 2020). Microplastics have toxic effects on zooplankton and affect their development and reproduction. Zooplankton may consume less carbon	Although phytoplankton may be small, these creatures play a significant role in marine ecosystems. Phytoplankton are the primary producers of the ocean, and can utilize CO_2 adsorbed from the atmosphere or ocean to produce organic matters and oxygen by photosynthesis (Shen et al., 2020). Research shows that the photosynthetic rate of phytoplankton (*Dunaliella tertiolecta*) reduced by 45% after exposure to

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			into the depths of the ocean (Shen et al., 2020). The aquaculture industry makes extensive use of plastic. For example; plastics are used to keep the structures floating and are fixed in a place using ropes. For cages, plastics are used from small to high-scale facilities for ropes, nets, and buoys. In ponds, plastics are used in pond linings, ropes, floats, and fish feeders. Furthermore, plastics are generally used in the aquaculture process for packaging, feed, transportation, and in the daily life of farmers including cups, bags, and bottles. The breakdown of this plastic into microplastic contributes to an increase of fish pathogens. Studies have found that fish pathogens attach in higher numbers to plastics than to stainless steel used in aquaculture. Additionally, nylon and copper nets employed in aquaculture contain potential pathogens (Mohsen et al., 2022).	sequestrated by phytoplankton, not only because the consumption capacity of zooplankton declines, but because the carbon sequestration capacity of phytoplankton declines owing to the threat of microplastics (Shen et al., 2020). This may affect the circulation of organic matter and nutrients in deep water, and the ocean's ability to act as a carbon sink (WWF, 2021). Microplastic is also ingested by fish and other species. The plastic gets into their system and is eventually transferred to the broader food chain. The transfer of plastic is dangerous to animals and humans (Kumar et al., 2021). Benthic organisms and suspension feeders also feed on microplastics from bottom sediments and contaminated water.	microplastics (250 mg/L) (Sjollema et al., 2016). Microplastic thereby affects the provisioning and regulating services of phytoplankton. Zooplankton are the first and most important consumers of phytoplankton. They play an important role in the regeneration of marine nutrients, the cycling of biogenic elements, the flow of mass, energy and genetic information through the food chain/web, and the degradation of environmental pollutants (Shen et al 2020). Microplastic thereby affects the provisioning and regulating services of zooplankton.

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