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Impacts of plastic debris on biota and implications for human health: A South African perspective

Entanglement and ingestion of plastics are the main ecological impacts of marine plastic debris on marine biota, but indirect effects such as the transport of alien species and benthic smothering are also important to note. Entanglement of invertebrates, sharks, turtles, birds and marine mammals is mainly caused by macroplastics (>5 mm), and leads to reduced mobility, ineffective foraging and subsequent mortality. The main plastic types associated with entanglement are improperly discarded fishing nets, lines, ropes and straps. In South Africa and surrounding waters, plastic ingestion has been reported in a number of marine species: sharks ($n=10$), fish ($n=7$), turtles ($n=1$) and birds ($n=36$). Lethal (macroplastic) and sub-lethal effects (microplastic ≤ 5 mm) of marine debris on biota have been noted, but at the time of this review there were no published reports on impacts at the population level. Consumed shellfish are possible vectors for the introduction of microplastics into humans. The specific impacts of microplastic ingestion on human health are largely unknown, but additives associated with plastics represent a threat. The research infrastructure in South Africa is insufficient to monitor and characterise marine plastic debris and, in many cases, not in line with global standards. More research effort is needed to understand the impacts of marine plastic debris on humans and marine biota in South Africa, particularly at the population level.

Significance

- Macroplastics affect marine biota mainly via entanglement and microplastics largely through ingestion.
- Macro- and microplastic interactions with biota can result in sub-lethal effects and mortality but no population effects have been reported for South Africa.
- Consumed shellfish are a potential source of microplastics for humans but their potential effects in humans remain unknown.
- Better infrastructure is needed for improved monitoring and research on the effects of marine debris in South Africa.

Status of the ecological impact of plastics in South Africa

Global records of the number of organisms that interact with plastic debris indicate an increase from 265 species in 1997¹ to 557 in 2015². Records were initially detailed in higher order organisms such as mammals, birds and reptiles; however, more recently fish and invertebrates have become research interests, especially in terms of their interaction with microplastics.² 'Microplastics' is now a globally relevant theme that has received increased attention in South Africa over the last decade. Ryan and Moloney³ provided the first account of these smaller plastics around the South African coastline in 1984 and 1989 and offshore in the 1970s,⁴ but there are still many gaps in our understanding of the prevalence and typology of marine plastic debris in general in South Africa. The widespread bioavailability of microplastics to marine organisms, their potential to act as vectors for both chemicals and microflora, and the resultant impacts on humans and other biota that consume them also represent many unknowns, both in South Africa and globally. This lack of data has hindered the design and implementation of appropriate mitigation strategies.

The marine environment around South Africa supports over 13 000 species, many of which (up to 33%) are endemic⁵, necessitating focused research on the impact of plastic debris on marine biota in the country's waters. The South African coastline has unique currents, bioregions and coastal geomorphological features.⁵ Early research on marine debris in South African coastal environments focused on the impacts on seabirds and began in the mid-1980s^{6,7}, although incidental reports of plastic ingestion in turtles were made in the 1970s⁸. Since then, a number of fish, sea turtle, bird and mammal species in South African oceans have been found to be affected by plastics (Table 1 and [Supplementary table 1](#))^{9,10}; the effects on these species are expanded on below. However, a comprehensive assessment of the variety and degree to which South African biota are affected is lacking. While the World Health Organization rates the risk of plastics to humans as low, there is still a need to evaluate the potential effects of microplastics on the South African human population given the country's reliance on many edible marine species. This need provided the motivation for this review, which assesses the impact of marine plastic debris on biota and the potential implications on human health in South Africa, by drawing on data available for organisms sampled from waters extending from South Africa to more southerly regions, up to the Prince Edward Islands. Where South African data on these aspects were lacking, examples from international studies were used to draw parallels. The objectives of this review were to: (1) review South African literature on marine biota impacted by plastic debris, through entanglement, ingestion, benthic smothering and alien transport; (2) determine the potential for, pathways of and potential impacts of microplastic ingestion on human health, particularly in relation to species of commercial value; and (3) identify the gaps in our understanding of the impacts of marine plastic debris on South African marine biota and human health. This review also comments on how South African literature on marine plastic debris (and its impacts) contributes to the global understanding of the phenomenon.

The impacts of plastic debris on marine biota

Entanglement

A major impact of discarded macroplastics is the potential to physically trap marine organisms.¹⁰ Kühn et al.² provided the most comprehensive global assessment on entanglement in 2015, which lists 344 species including invertebrates, sharks, fish, sea turtles, birds and mammals. This assessment expands on the previous effort by Laist in 1997 of 136 species, which focused on higher order organisms.¹ In general, most entanglement occurs with improperly discarded or accidentally lost fishing gear such as nets, lines, ropes and straps from bait boxes.^{11,12} This impact has received the most public attention, partly driven by social media, especially when organisms are physically injured for long periods before mortality. South African entanglement records prior to 1990 include 6 shark, 2 turtle, 13 seabird and 5 marine mammal species.⁹ A brief overview of the prevalence of entanglement in South African marine species is presented herein, together with recommendations for future research. It must be noted that in many cases of entanglement by fishing gear, it is often challenging to discriminate between active and ghost gear.¹⁰

Invertebrates

Published entanglement records for South African invertebrate species were not available at the time of this review. Globally, an assessment in 2015 lists 25 mollusc, 21 echinoderm and 46 crustacean species affected by entanglement.² These numbers are higher than those of the assessment in 1997 which lists 8 species, most of which were crustaceans, and probably reflects an increase in research effort.¹ Based on the global literature, pelagic invertebrates are usually smaller and therefore possibly more susceptible to plastic ingestion than entanglement. However, sessile taxa are also at risk; for example, Lamb et al.¹³ estimated that 11.1 billion plastic items are currently entangled on corals in the Asia-Pacific. This entanglement will likely affect feeding and gaseous exchange in these coral systems.¹⁴

Sharks and other fish

South African literature identified plastic straps, from bait boxes and land-based packaging, to be the main plastic types associated with sharks caught in gill nets (or shark nets).¹¹ Shark nets are put in place by government agencies to protect bathers.¹¹ Between 1978 and 2000, 53 of the 28 000 sharks (0.18%) caught were found to be entangled by marine debris, and although a wide variety of species was observed, only the dusky shark, *Carcharhinus obscurus*, showed an increase in entanglement over time.¹¹ Shark fins are not retractable, increasing their vulnerability to entanglement.¹¹ Discarded fishing nets can also entangle and capture fish and other marine biota, a phenomenon known as ghost fishing.¹⁴ There were no South African studies that provided quantitative data on this phenomenon, possibly because it is difficult to distinguish between active and ghost gear. However, discarded fishing gill nets are removed daily from estuaries around South Africa, some of which appear to have been abandoned. For example, on the Mlalazi Estuary, conservation officers recovered 51 monofilament gill nets, holding 195 fish of 12 species, from 21 April 2018 to 28 March 2019 (Buthelezi T, Ezemvelo KZN Wildlife, 2020, personal communication, February 27). Globally, lost or discarded fishing gear continue to capture fish, which could affect fish populations.¹⁴ The United Nations Environment Programme estimated that 640 000 tons of discarded fishing gear is added to the oceans annually, which captures a wide variety of both commercial and non-target species.¹⁵ As marine organisms trapped in these nets decompose, they attract and entangle scavengers in a cyclic manner, making it difficult to acquire a reliable global estimate of mortalities, but localised international monitoring has seen high mortality rates in some places. For example, Good et al.¹⁶ reported that from 2002 to 2010, 32 000 marine organisms, mainly fish and invertebrates, were recovered from abandoned fishing gear in inland waters of Washington (USA).

Sea turtles

Most reports on entanglement of turtles in South Africa have been made by aquariums along the coastline (Prof. Nel R, Nelson Mandela University, 2019, personal communication, October 17). In addition to this, Ryan⁹

has reported two South African turtle species that have been entangled by rope. Drawing from global literature, the impact of turtle entanglement involves the restriction of movement, which compromises their ability to surface for air.¹² Tightly wound lines can also restrict blood flow, causing decreased mobility and the potential loss of limbs.¹² Plastic rings around turtles' necks can also asphyxiate them as they grow, eventually leading to mortality.¹⁴ The impact on sea turtles is therefore partially dependent on the plastic types they encounter. As turtles are particularly vulnerable to many other anthropogenic perturbations¹⁷, plastics represent an additional factor that can lead to population declines. Although plastics left on beaches may not necessarily contribute to entanglement, they can result in a decrease in the number of turtles nesting on beaches. Fujisaki and Lamont¹⁸ found a 200% increase in nests when beaches in Florida were cleared of natural and anthropogenic debris. As the sex of turtle hatchlings is dependent on nest temperature, any temperature anomalies caused by plastic debris in the sediment could also affect the sex distribution of turtle populations.¹⁹

Birds

An extensive review of entanglement of birds by plastic and other marine debris is provided in Ryan¹⁰. As many as 265 bird species, many of which are found in South Africa, were found entangled in plastic or similar types of debris. Fishing line seems to be the major plastic type affecting seabirds and virtually all bird species associated with the marine environment appear to be at risk.¹⁰ However, there are some differences in the risk posed to seabirds by different plastic types. For example, plunge diving birds get entangled more often by plastic bags as they dive for juvenile fish, that shelter under the bags, than do other birds.¹⁰ Birds that frequent mangroves may be more at risk to fishing line entanglement as these plastics get caught up in aerial mangrove roots.¹⁰ Self-removal of plastics is difficult in species that have backward serrations on their beaks.¹⁰ Entangled birds often get injured, have reduced feeding efficiency and become startled, which can sometimes attract unaffected birds that then also get trapped.¹⁰ Birds that use plastic debris to build their nest can also be at risk of entanglement.¹⁰

Mammals

Research in South Africa on entanglement of marine mammals has largely focused on Cape fur seals (*Arctocephalus pusillus*) and whales.^{20,21} In the case of seals, a study that dates back to 1979 indicated that marine debris was encountered in generally less than 1% per colony of seals that were harvested from locations in the Western Cape; harvesters recorded removing rope, string, fishing line and plastic straps from seals.²⁰ Of the 72 000 seals observed, 84 were found to be entangled by plastics, suggesting that this was not a major impact on their population numbers at the time. Debris was mostly observed around the neck and was seen to cut into flesh as individuals grew. However, on Marion Island, a territory of South Africa, entanglement was recorded in 101 sub-Antarctic (*Arctocephalus tropicalis*) and Antarctic (*A. gazella*) fur seals and 5 elephant seals (*Mirounga leonina*) over a 10-year period (1991–2001).²² These numbers imply that only 0.24% of the seal population on this island were observed to be affected over this period, but both entanglement and increase in debris types closely coincided with a longline fishery that was implemented around Marion in 1996. This fishery has since ceased; however, it should be noted that seals are generally inquisitive, and the prevalence of marine debris has escalated globally, which may increase their risk of entanglement.¹⁴ In the case of whales along the South African coastline, most cases of entanglement have been attributed to fishing gear (associated with a lobster fishery) or shark nets.²¹ Humpback whales (*Megaptera novaeangliae*) and southern right whales (*Eubalaena australis*) are the species that are commonly entangled, but it was concluded that the entanglement rates of 9.5–21.6% were not affecting populations.²¹

Although the possibility of population-level effects by entanglement of organisms appears to be low, in general, reducing the disposal of items such as packing rings associated with canned and bottled drinks, monofilament line and bait box straps will decrease the risk of entanglement.¹⁰ This was the reasoning behind banning packaging rings and ring pulls on drink cans in South Africa, in the 1980s. Measures

such as introducing discard bins near popular fishing spots with accompanying sign posts may also reduce the line and plastic straps from bait boxes entering the marine environment.¹⁰

Smothering

Benthic invertebrates can be smothered by macroplastics that have settled out of the water column, on the seabed, reefs or on beaches.¹⁴ While the diversity of South African coral reefs and that of sediments have been well characterised⁵, it is unclear how susceptible these systems are to disruption of species assemblages by debris. Smothering could affect filter feeding in sessile species or food location in mobile organisms. For example, beached plastic debris decreased the foraging efficiency of the gastropod *Nassarius pullus*²³, and in the same way may affect benthic species in South Africa. Alteration of physical characteristics of these benthic habitats by debris (e.g. porosity of the sediment and its heat transfer capacity⁹) has also not been assessed in South Africa. The global literature indicates that plastic accumulation may alter temperature, water permeability and gaseous exchange in marine sediments, which could cause physiological stress to meiofaunal communities.^{14,19} Plastic debris on beaches may lead to anoxic conditions, altering infaunal communities.²⁴

Transport

Plastics have the potential to transport alien species.¹⁴ Bacteria, cyanobacteria, dinoflagellates, coccolithophores, corals, bryozoans, hydroids, and others have all been found on plastics in marine environments globally.²⁵ While marine debris can assist invasions of alien species²⁶, the prevalence of this phenomenon in South African systems has not been well characterised, with the exception of a record from gooseneck barnacles²⁷. Nevertheless, the epipelagic community, now termed the 'plastisphere'^{25,28}, can potentially impact marine biota through transfer by ingestion if pathogenic bacteria are transferred from the environment to biota via plastics. This possibility is concerning for South African marine species, as high levels of pathogenic bacteria, like *Escherichia coli*, can be present in urban estuaries.²⁹ Coral reefs can also suffer from diseases vectored by plastics, as Lamb et al.¹³ found that plastics on corals increased the likelihood of disease from 4% to 89% in the Asia-Pacific.

Ingestion

To date, ingestion of plastics has been recorded for more species than has entanglement.^{2,30} Globally, plastic ingestion has been recorded in many taxa, ranging from annelids to mammals, but South African research has focused on fewer groups (Table 1). Factors influencing plastic ingestion by organisms that actively ingest plastic, include the abundance, type, size and colour of plastics, as well as feeding strategy.³¹ Plastic shape and chemical factors such as chemical additives, and external pollutants that are associated with plastics, determine the risk(s) posed to specific organisms.³² In addition, exposure and gut retention time also determine the impacts of different plastics on specific species.³⁰ Organisms can be classed as those that (1) regurgitate plastics after ingestion, (2) excrete most plastics or (3) retain much of the ingested plastics for long periods.³⁰ These differences need to be considered when investigating plastic ingestion in organisms, especially when investigating the effects of persistent organic pollutant (POP) transfer via plastics. For instance, organisms that regurgitate plastics after ingestion may have limited digestive transfer of POPs compared with organisms that retain plastics.³⁰ Mortalities have been noted mainly from macro/mesoplastic ingestion and can be caused by gut blockage and subsequent starvation, as shown for some South African bird and turtle species.^{9,33} However, it must be noted that mortality is a rare phenomenon for most taxa.

Smaller particles usually have sub-lethal effects, primarily caused by the chemicals associated with plastics.³² An investigation of 55 different plastic polymers found that polyurethanes, polyacrylonitriles, polyvinyl chloride, epoxy resins and styrenes were likely to be the most hazardous, due to the mutagenic and carcinogenic monomers they contain.³⁴ Fortunately these are not the dominant plastic types recorded in South African systems.^{4,35,36} Plastic additives such as phthalates, bisphenol A, polybrominated diphenyl ethers and tetrabromobisphenol A can leach out from plastics and may affect reproduction as well as increase the risk of genetic aberrations and hormonal imbalances.^{37,38}

Coupled with this, metals and POPs such as polychlorinated biphenyls, dichloro-diphenyl-trichloroethanes, polycyclic aromatic hydrocarbons, aliphatic hydrocarbons and hexachlorocyclohexanes have been found to adhere to the surface of plastics.³⁸⁻⁴⁰ POPs are of particular concern as they can act as endocrine disruptors or carcinogens in organisms⁴¹; however, assessments of pellets show that POPs have decreased over the last few decades in South Africa⁴².

Plastics ingested by marine organisms can also release associated pollutants, as some simulated desorption experiments have shown.⁴³ This can depend on stomach conditions, such as the type of oil present in the stomach and also the retention time of particles.⁴⁴ If this is the case, organisms around urban centres in South Africa may be at a higher risk of exposure to pollutants associated with plastics, as urban harbours and other estuaries in South Africa have been shown to exhibit elevated levels of metals⁴⁵ and organic pollutants^{46,47}. These areas are therefore ideal sites for ecotoxicological investigations on plastics. However, it must be noted that coal and wood can also transport equally high, if not higher, amounts of external pollutants to biota than microplastics⁴⁸, and if these sites exhibit both plastic and non-plastic debris, this should be factored into the sampling framework.

Invertebrates

Microplastics are generally the bioavailable size class to marine invertebrates such as filter-feeding mussels and barnacles.^{49,50} The South African brown mussel (*Perna perna*) for example, has been shown to ingest fibres⁵¹, although the polymer identity was not confirmed. Ingestion in brown mussels ranged from 4 fibres/g tissue (wet weight, ww) (collected near an estuarine mouth) to 1 fibre/g tissue (ww) (collected 2 km away).⁵¹ However, this trend was not consistent across estuaries⁵¹, suggesting that catchment activities and possibly biogeomorphology, play a role in determining microplastic ingestion levels in rocky shore invertebrates within estuarine systems.

Fibrous microplastics have the potential to form bundles, which can increase their gut residence time, as found in Norwegian lobsters, *Nephrops norvegicus*.⁵² Active feeding invertebrates such as fiddler crabs, *Uca rapax*, were also shown to consume microplastics in experiments by Brennecke et al.⁵³ These authors showed that fragments of polystyrene pellets (180–250 µm) can transfer to the stomach, hepatopancreas and gills of crabs; however, no harmful effects were observed, at least for a period of up to 2 months.

Fish

Global observations of plastic ingestion by fish were made soon after mainstream plastic production commenced in the 1950s.^{54,55} The limited South African literature on the phenomenon focuses almost exclusively on plastic ingestion in estuarine environments.^{56,57} These environments are the pathways for plastics to the ocean, as storm-water drains, canals and treated waste-water effluent often flow into these estuaries in South Africa. Estuaries are also nursery areas for fish fry, and up to 160 South African fish species are dependent on estuaries at some stage of their life cycle.⁵⁸ Chronic exposure of the estuarine glassfish (*Ambassis dussumieri*) to virgin and harbour-collected microplastics compromised their growth and survival in experimental tanks, possibly due to energy normally used for growth being redirected to ridding the body of plastics and their associated pollutants.⁵⁹ Juvenile fish fed virgin and harbour-collected microplastics grew shorter on average, in standard length, than control fish, after a 3-month exposure period.⁵⁹ Kaplan–Meier curves showed significant reductions in survival probability in fish fed plastic relative to the control, mainly after 50 days of exposure.⁵⁹ Importantly, four species of juvenile fish (*Oreochromis mossambicus*, *Terapon jarbua*, *Ambassis dussumieri* and *Mugil* sp.), collected from four mangrove forests in KwaZulu-Natal, were shown to have ingested fibres and fragments of rayon, polyester, nylon and polyvinylchloride in proportions of 70.4%, 10.4%, 5.2% and 3.0% of the total particles consumed, respectively.⁶⁰ Generalist feeding fish such as mullet may consume larger numbers of particles than fish that feed on specific prey⁶¹; however, particles seem to pass through the gastrointestinal tract without physical influence⁵⁶. In this regard, it is important to consider

the residence time of particles in fish, as some fish, such as herbivores, tend to have longer guts and therefore particles may remain in the gut for longer periods. Mullet that were force-fed plastic fibres showed gut residence times of up to five-fold longer than those of control fish that were fed food only.⁶² Increased residence time allows for surface contaminants (e.g. POPs) and inherent additives to dissociate from particles and enter the organism. However, the global literature reveals no clear trend of net influx of pollutants adhering to plastics transferring to organisms by dissociation in the gut, compared with natural routes, such as ingesting wood.⁴⁸ Currently there are also no published estimates of microplastic concentrations in the commercially important South African species.

Sea turtles

Kühn et al.² observed plastic ingestion in all seven sea turtle species; this observation is concerning as, in addition to plastic ingestion often being fatal to turtles, their conservation status is either threatened or data deficient. A global review on this phenomenon is provided by Schuyler et al.¹⁷, who found that green turtles (*Chelonia mydas*) and leatherback turtles (*Dermochelys coriacea*) were the most prone to consuming plastic debris, with an increase in ingestion probability from 1985. Turtles are particularly prone to plastic ingestion and the effects of ingesting mesoplastics can be fatal.³³ Possibly the earliest report of plastic ingestion in turtles from South Africa was made by Hughes in 1974⁴⁸, who reported plastic pellets in the digestive system of stranded loggerhead (*Caretta caretta*) hatchlings. In the South African context, Ryan et al.³³ noted that mesoplastics could block and rupture the digestive tract of turtles, and subsequently break into the bladder with peristaltic movement, which may lead to death. Post-hatchlings are at risk because they drift on the surface along drift lines that accumulate marine debris.³³ A variety of plastic types are ingested with a high incidence of ingestion (Supplementary table 1). Those authors noted that post-hatchling loggerhead turtles off South Africa mainly consumed white and blue mesoplastics.

Birds

As with entanglement, records of plastic ingestion by South African seabirds has been well documented.^{6,30,63} Ryan⁶ recorded plastic ingestion in 36 of 60 seabird species in South Africa and the African sector of the Southern Ocean, noting that birds consume mesoplastics based on colour and foraging strategy. Birds with a mixed or omnivorous diet had a higher incidence of ingested plastic and consumed darker-coloured plastics. Ingestion by members of the Procellariiformes, such as petrels, albatrosses and shearwaters (Supplementary table 1), is of concern, as they forage at the sea surface, consume a wide range of prey items and many members do not usually regurgitate indigestible material. Bird size and plastic size also influence ingestion, with smaller birds having a higher incidence of ingestion, ingesting smaller plastics and being less colour selective than larger birds. These birds could possibly also be consuming microplastic fibres, as observed in freshwater duck species from South Africa.⁶⁴ Reynolds and Ryan⁶⁴ found that duck faecal samples from areas near a sewage facility had higher (1–17%) numbers of microplastic fibres than faecal pellets collected from a site without this

facility (1–3%). This supports the suggestion that these facilities are a potential source of plastic fibres to marine environments.⁶⁵

Pellets, fragments, fibres and foams are the major plastic types consumed by seabirds.⁶ Consumption of these particles can potentially have negative impacts on birds, as experiments on chickens fed polyethylene pellets resulted in decreased appetite and growth.⁷ However, it must be noted that this did not hold true during short exposure times in similar experiments on white-chinned petrels.⁶⁶ Ogata et al.⁶⁷ showed that pre-production pellets collected from South Africa also contained high concentrations of hexachlorocyclohexanes, and this is a concern near the main industrial hubs where plastics can accumulate and concentrate chemical pollutants.⁴² However, the incidence of pellets being ingested by seabirds in South Africa has decreased relative to other plastic types.⁶³ This suggests that the concentration of pellets in the environment may have decreased over time, which may be attributed to increased education and awareness, resulting in less spillage from industry.⁶³

Mammals

Published literature on the ingestion of plastics in South African mammals is scarce compared with that for the rest of the world. However, seals and whales are a common feature of the South African coastline, and plastics can be unintentionally ingested by filter-feeding whales, or enter via primary and secondary ingestion in toothed species.³⁰ These larger organisms are thought to ingest larger fragments of plastic and possibly, in the case of baleen whales, a higher abundance of microplastics than other groups of organisms, although this supposition has yet to be confirmed.⁶⁸ An analysis of the scat from fur seals on Macquarie Island suggests that they mainly consume plastic fragments through their diet of small pelagic fish⁶⁹, yet this is not common in South African species³⁰. In a similar way, dolphins and other species feeding on filter-feeding pelagic fish may ingest plastics. No population responses that were directly linked to plastic ingestion had been published at the time of this review.

Potential impacts on human health

Fish consumption in South Africa grew by more than 26% between 1994 and 2009. This figure poses a potential threat to human health, as the consumption of some marine species (such as invertebrates and fish) can result in the transfer of microplastics and associated chemicals and microbes to humans.⁷⁰ It must be noted, however, that the World Health Organization regards the threat of microplastics to humans as minor.⁷¹ While current literature focuses on the fate and movement of microplastics, nanoplastics (<1 µm) also pose a threat to human health.⁵⁰ Countries in Europe, the Persian Gulf and China have quantified the amount of plastics humans consumed from specific food groups (mussels, shrimp)⁷⁰; these amounts vary across different regions and are subject to the dependence of the population on seafood. Additionally, these organisms are consumed whole, unlike fish which in most cases are usually gutted first, which removes microplastics in the gastrointestinal tract. As mentioned earlier, edible marine organisms in South Africa that have been investigated for microplastics are brown mussels⁵¹ and four species of estuarine fish⁶⁰. At the time of this review, data on levels of transferral of microplastics from edible aquatic species

Table 1: Summary of records of South African vertebrates found to be entangled or to have ingested plastics

Organisms*	Entanglement		Ingestion	
	Number of species	Main plastic type	Number of species	Main plastic type
Sharks	8	Plastic bands/straps	10	Plastic bags and sheets
Bony fish	Not distinguished from active gear		7	Fragments and fibres
Turtles	2	Rope	1	Fragments, films and pellets
Birds	265	Plastic bags and line	36	Fragments, pellets and foams
Mammals	5	Nets, rope, line and straps	0	–

*Species names and metadata for ingestion are given in Supplementary table 1.
Note: These figures would be higher if unpublished reports were considered.

to humans were unavailable for South Africa. Nevertheless, there is a possible route of microplastic uptake for people who consume a number of marine species that include filter feeders (e.g. mussels and oysters).⁷²

Dried fish may pose a higher threat to consumers than fish that are gutted, because even though the former may have the viscera and gills removed, microplastics may still be present in the gut.^{70,73} This is relevant in the South African context, as the production or processing of dried fish or 'bokkoms' traces back to the 17th century, with mullet (*Chelon richardsonii*) being dried and salted in the Western Cape.⁷⁴ Unlike dried fish from other parts of the world, these are generally gutted before drying and the microplastics in the gut may therefore be removed, but the danger still exists for the bioaccumulation of other chemicals in fish tissue. Salt is also a source of microplastics that may be directly added to our diets. Salt from more than eight countries, including South Africa, tested positive for microplastics, with 1–3 microplastic particles per kilogram found for the size range of 160–980 μm .⁷⁵

The fate of consumed microplastics may depend on the size of the particle. Some studies have identified microplastics in the faeces of humans, showing that most particles (90%) are excreted.^{75,76} Particles that are $<150 \mu\text{m}$ may move from the gut to the lymph and circulatory systems, with particles $<20 \mu\text{m}$ likely to penetrate the organs and those within the smallest fraction likely to move through cell membranes, the blood-brain barrier and the placenta.^{70,75} The body responds to the presence of these particles by triggering a number of responses such as immunosuppression, immune activation and abnormal inflammatory responses.^{70,77} Unfortunately, at the time of this review no published studies had been conducted in South Africa but given the high dietary seafood content of a considerable proportion of the country's population, future research in this area should be prioritised. However, drinking water and inhalation seem to be the dominant uptake routes for microplastics in humans, with ingestion a secondary route.⁷¹ Microplastics are classified as toxic vectors and may facilitate transfer of chemicals in organisms consumed by humans; associated chemical ingestion may be a more important issue than the consumption of the plastics themselves.

Key uncertainties, existing knowledge gaps and research challenges

Much of our uncertainties around the impacts of marine plastic debris on South African biota stem from the lack of monitoring marine debris in the country's water bodies, more especially microplastics. Additionally, reports of plastic ingestion in a wide range of biota (sharks, fish, turtles, birds and mammals) in South African waters⁹ point to the need to monitor trends in the amount and composition of debris ingested by indicator species, as well as those species that are regularly consumed⁷⁸. Indicator species should be studied from different trophic levels and feeding guilds, to determine whether the transfer of plastics and their associated pollutants are an issue. The need for continuous monitoring in the South African context is emphasised by the fact that, while the number of biota recorded with plastics in their guts has increased over time, with a wider diversity of plastic types³³, some types of ingested plastics seem to be decreasing (e.g. pellets in seabirds)⁶³. These fluctuations in plastic prevalence are important considerations, as some plastic types are considered to be more toxic than others. The transfer of microplastics into organs of biota has been shown, but the level of toxicity has not been established.⁵⁰ Fibres are the most common microplastics in marine organisms (Supplementary table 1), and may be overlooked in some of the larger biota, but many probably are not actually synthetic. Assessing the impacts of fibres is also important, because the width of fibres is usually small and they may therefore be transferred to organs. The impacts of fibres on biota with regard to ingestion, inhalation, assimilation and their ability or inability to carry associated pollutants, remain largely unknown globally.

As alluded to above, data on the transfer of plastics along the food chain is limited in South Africa (and globally). These data are needed to ensure the quality and market acceptance of commercial species, which have the potential to transfer microplastics to humans. Research on plastics in South African biota exists for relatively few focal groups.

However, even within a group of organisms there are differences in feeding strategies, gut biology and residence times that can affect their interaction with plastics. A suite of indicator species should therefore be selected to account for this potential variability. South African fisheries are regionally important (fish and invertebrates in particular).⁷² While there have been reports of microplastic ingestion in fish and invertebrate species associated with the country's coastline, data for commercially important species are virtually non-existent (Supplementary table 1). Plastic ingestion in commercially important invertebrates in other parts of the world, e.g. Norway lobster in Scotland⁵² and brown shrimp in the North Sea⁷⁹, suggests the need for South Africa to consider the effects of marine debris on the country's wide variety of commercially important species (e.g. prawns, lobster, mussels and abalone)^{80,81}. There is a need to determine if there are harmful effects of consuming these species and if this can be linked to the secondary ingestion of plastics by humans. Pilchards and anchovies are also processed for fish meal and exported to other countries which could make secondary ingestion also important in cultured species.⁸²

At the time of this review, an evident knowledge gap was the lack of understanding around the amounts of pollutants that are transferred, dissociated or bioaccumulated in biota as a consequence of plastic ingestion. This gap must be filled in order to make predictive decisions in regard to safety for consumption. Given the short gut retention times of some fish and invertebrates, plastic particles may pass without much interference, but chronic exposure does show changes in organisms⁵⁹, and research into these key interactions will help us understand the risk of plastic ingestion to both biota and humans.

Some of South Africa's research challenges with regard to the impacts of marine plastics are, however, similar to those faced globally. This challenge is largely due to the lack of standardised protocols for investigating the uptake and biological effects of plastics on biota. A primary step for efficient monitoring is the development of consolidated protocols for the isolation of plastics from different organisms. Challenges associated with the development of these protocols include directly observing for plastics under the microscope in organisms, while gut contents hamper visualisation. Furthermore, in some instances, chemicals are used to digest organic materials in the hope of leaving microplastics behind⁸³, but certain polymers can be degraded depending on the chemical(s) used, for example, nitric acid disintegrates polyamides⁵⁷. The lack of access to instrumentation such as micro-Fourier transform infrared spectroscopy, which is used for the characterisation of plastic polymers⁸⁴, is a further challenge in developing countries such as South Africa. Given that many studies conducted in South Africa to date have not used these analytical methods^{56,85}, comparison with global trends is difficult. Contamination also represents a major research challenge in many laboratories in South Africa; plastic microfibres are often airborne and can thus contaminate samples, especially when working with small organisms and small plastics. The lack of sufficient contamination control measures in many of the laboratories involved in plastic research in South Africa must be urgently addressed. Ways to minimise the risk of contamination include the route taken by researchers at the University of Plymouth (United Kingdom) who have designed laboratories dedicated to microplastic work, in which ventilation systems are isolated from the rest of the building and air that enters the working area is filtered.

Implications if the gaps are not addressed

Despite the research gaps and challenges described above, South Africa has been at the forefront of research on marine plastics. For example, studies by Ryan⁴ and Ryan and Moloney³, both of which quantified microplastics in South African marine systems, are regarded as seminal research in this field of research. However, microplastic pollution is fast becoming a 'hot topic' globally, and South African research is falling behind in terms of its coverage, depth and methodological approach. This is largely because some of South Africa's health (HIV/Aids) and developmental challenges (large-scale unemployment and lack of adequate water and sanitation) are considered research priorities⁸⁶ by the government and funders alike. Greater investment in human capacity and infrastructure for marine plastic research needs to be made by all



stakeholders within governmental, research and environmental sectors. The lack of evidence-based research on marine plastic pollution will also hamper the development of policies and practices to mitigate its effects in the country. For instance, no published data on declining biota populations due to interaction with plastics were found for South Africa. Also, the potential effects of plastic ingestion on humans as a consequence of consuming marine biota have yet to be confirmed. Many of the impacts, particularly in relation to microplastic ingestion, are sub-lethal, but the consequence of not continuously monitoring these products is that the sub-lethal impacts may go unnoticed, which could directly impact consumers both locally and abroad. Major efforts also need to be made to encourage and upskill researchers presently working in the area to transition from empirical to more interpretative, predictive and systems-based science. However, given the paucity of data on many research topics related to marine plastic pollution in South Africa, it is essential (at least in the short to medium term) to draw on the international literature to predict possible impacts of this type of pollution on organisms (including humans), to design policy to mitigate its effects, and to drive the research agenda on the topic.

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Authors' contributions

T.N. undertook the literature review and the write-up of the draft manuscript. S. helped develop ideas and was involved in the write-up and editing of the manuscript. A.R. helped develop ideas and was involved in the write-up and editing of the manuscript.

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