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Plastic Impacts in Argentina: a Critical Research Review Contributing to the Global Knowledge

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Abstract

Purpose of review Plastic pollution research has experienced exponential growth in the last decade; however, Argentina concentrates more than 70% of their research in the last 4 years. This review compiles regional research on plastic pollution in water, soil, sediment, air and organisms in Argentina. It discusses current sampling, quantification, and plastics identification methodologies while analyzing levels, gaps, and opportunities.

Recent findings Research in plastic pollution was mainly focused on the biosphere component (52.9%), followed by the hydrosphere component (29.4%), and finally the lithosphere component (17.7%), with less than 20% addressing multiple components simultaneously. Sixty percent of this research was focused around microplastics, and less than 20% have considered multiple plastic debris sizes. Marine coastal species from Argentina had higher levels of microplastics than organisms from other South American studies, while microfibers were identified in 100% of the freshwater organisms studied. The lowest microplastic concentrations were found in lakes and in the Paraná and La Plata rivers, while the maximum concentrations were found in Pampa´s streams. There was a lack of standardization in methodology and unit expression in studies of sediment microplastics, which hinders comparison between reports.

Summary Argentine scientists have created the national alliance called SciEnce for Plastic Impacts Argentina (SEPIA). SEPIA is a network which aims to systemize plastic pollution research, coordinate methodologies, and enhance relationships with decision-makers, NGOs, and the general public. A time gap was found between the designation of principal international multilateral agreements and the implementation of national regulations for plastic waste treatment, with a tendency to include advanced concepts as Extended Producer Responsibility and Circular Economy.

Keywords Plastic debris · Pollution · Environmental spheres · SEPIA · Microplastics · microplastic identification · Argentina

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Introduction

Over the last few decades, effects of plastic pollution on environmental ecosystems and organisms have been mainly analyzed from marine environments. However, due to the increasing concern of plastic pollution's potential consequences on human health [1], research on this topic has rapidly expanded across the world. Plastic debris can be classified according to their size: mega (> 1 m), macro (2.5 cm–1 m), meso (5 mm–2.5 cm), micro (1 μm–5 mm), and nanoplastics (< 1 μm) [2–4] with microplastics being the most studied [5]. However, to have a global understanding of plastic pollution, all plastic debris sizes should be considered in order to correlate plastic waste, degradation over time, and its subsequent effect on ecosystems. It is necessary to assess the behavior of plastic as a pollutant in each ecosystem to understand their movement between ecospheres on a more global scale. For this, it is essential to understand the distribution and dynamics of plastic particles in each continent and each country. In-force country policies and regulations depend on the cultural relationship between plastic consumption and waste Scientific research and national/regional environmental monitoring programs are a keystone to outline the real and particular problem of each region. In Argentina, 1.7 million tons of plastic material are consumed per year, with disposable packaging comprising the majority of items that end up as waste after use https://ecoplas.org.ar/datos-de-mercado. The current scientific knowledge of plastic pollution, sources, occurrence, transport, fate, and potential impacts for the environment and biota is sparce and has never been reviewed for Argentina before. The main purpose of this review is to provide a critical examination of the existing published literature on plastic debris pollution in Argentina while also discussing international—in force—agreements and future scientific and political goals proposed to mitigate plastic pollution.

Methods

A systematic exploration using Google Scholar as a search web engine was conducted. The keywords "Argentina", "plastic pollution", "microplastic", "plastic debris", and "plastic litter" were used for the literature search. The eligibility criteria was based on the review's scope, focusing only on those peer-reviewed papers. Each study was classified in one or more categories as follows: (1) the studied environmental sphere (biosphere, hydrosphere, lithosphere—sediment samples, and atmosphere); (2) the analyzed size range of plastics (macro-, meso-, and microplastic); and (3) the methodologies used for plastic identification. According to the obtained information, the review was organized in different sections as follows.

Plastic Research Issue in Argentina

At the time of writing this manuscript, there were a total of 29 scientific publications originating from Argentinian institutions in international indexed journals concerning plastic pollution (Table 1). The first record examined seawater debris; however, authors did not discern between plastic size classes so it can be assumed that only macroplastics were observed (102–200 mm mesh) [6]. In the same year, Copello and Quintana identified plastic debris in the stomach content of individual petrels [7] as well as isolated petrel colonies [8]. In 2011, multiple size classes (macro-, meso-, and micro-) of plastic were found in the gastrointestinal tract of Franciscana dolphins [9]. These investigations settled a milestone in the research area and reveal knowledge time gaps in regard to plastic pollution between 2004–2008, 2009–2012, and 2015–2017 in Argentina. Over 70% of the total microplastic research originating from Argentina has been published since 2017 (Fig. 1). Microplastics were first reported in Argentinean rivers by Pazos and Blettler et al. [10, 11] in 2017, and in the Argentinean sea by Arias et al. in 2019 [12]. With regard to the possible biological effects and environmental consequences of plastic pollution, diverse aspects have been analyzed during the last decades, mainly focused in the marine environment. Despite this, the biological effects of plastic pollutants remain a knowledge gap for Argentina. Only Arias et al. have shown a direct relationship between the hepatosomatic index of a fish (*Micropogonias furnieri*) and the number of microplastics in its gastrointestinal tract [12]. This index has been widely used as a biomarker of exposure to pollutants and its increase may be indicative of hypertrophy (increase in size) and/or hyperplasia (increase in the number of hepatocytes) as a consequence of liver detoxification [13, 14]. It has been also shown that microplastics can also have severe

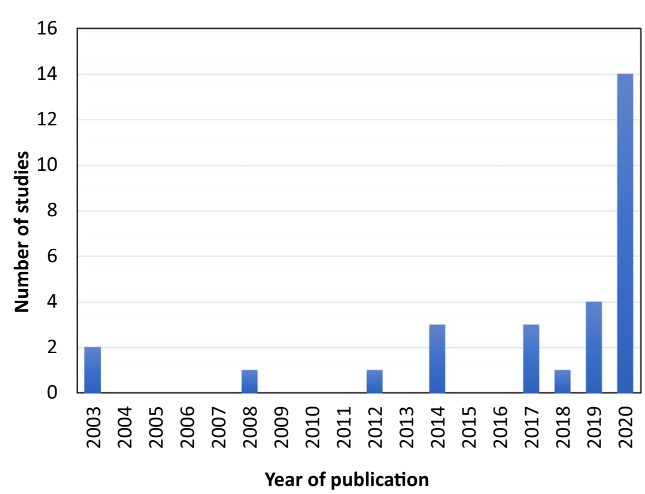

Fig. 1 Number of publications dealing with plastic pollution in Argentina per year

consequences on human health [1]. There is an urgent need to address this issue without exception to assess risks and mitigate consequences.

Sampling and Identification Methods Used in Argentina

Although there was a recent increase in scientific interest addressing plastic pollution impacts in Argentina, a huge variation of sampling, processing, and characterization methodologies was found as there is no standardized procedure for plastic debris sampling and identification [15]. While the different matrix digestion processes do not seem to interfere, the application of diverse sampling and recovery methodologies are important points to be unified. In particular, the standardization of concentration expression for sediments, pore size in mesh nets for water sampling, and type and pore size in filters are key necessities. Finally, the application of characterization techniques is a highly important point to be addressed in future researches.

Sediments/Soils

On sandy-tourist beaches, debris was hand-collected using 10 m width transects [16] or via waste bins set on a pedestal (800 × 160 mm, $n = 24$) distributed along the coastal walkway [17]. Results were expressed as mass debris. Deep sea sediments (6.3 to 14.5 m depth) were sampled using a "shipek" dredger and microplastics were separated by flotation (in saturated NaCl) and sonication, filtration of the supernatant through 8-μm pore size filter paper, and results were expressed as items/kg of dry sediment [18]. Freshwater sediment sampling was conducted using quadrants: 50 m × 5 m for macroplastics; 1 m × 1 m × 3 cm for mesoplastics using a 5-mm mesh sieve, and 25 cm × 25 cm × 3 cm for microplastics using a 350-μm mesh sieve. Oxidative digestion of the samples (30% H_2O_2, 60 °C) was carried out followed by density separation (saturated NaCl) and results were expressed as items/m^2 [11, 19, 20].

Fresh and Marine Water

The first study concerning anthropic litter in Argentina used a 200-mm mesh bottom trawl net only collecting macroscopic items, and results were expressed as items/km^2 [6]. More recent studies have focused on the microplastic fraction and reported methodologies which generally involve treatment with an oxidizing agent to degrade possible biogenic interferences followed by a separation and/or filtration process. These results were expressed as items/m^3 or items/L [18, 21–28].

A Sedgwick-Rafter chamber was used for the visual inspection of an aliquot of direct marine water samplings under an optical microscope [21]. Direct filtration to recover mesoplastics (0.45-μm nitrocellulose filter) was also carried out [22].

Continental shelf water samples were collected using a floating Manta trawl with a 350-μm mesh size, then digested (30% H_2O_2, 40°C, 72h), and finally filtered (8-μm pore filter paper) [18]. Following the same digestion/filtration procedure, freshwater samples (lakes) using a 47-μm or a 38-μm mesh net [24, 25, respectively] were carried out. Rios et al. [25] directly filtered samples from 1 m depth (using a Niskin bottle) through a 0.7-μm pore glass microfiber filter, followed by the digestion of the retained material (30% H_2O_2, 60 °C, 24 h).

The use of the Fenton reaction (concentrated H_2O_2 and iron (II) solutions) and density separation (saturated NaCl) followed by supernatant filtration was also reported for two different water sampling methods: by using a 36-μm plankton net (1 m depth subsurface waters and finally using a 0.45-μm cellulose nitrate filter) [29], or a 60-μm Nansen net (finally filtering in a 0.22-μm cellulose nitrate filter) [27]. Concentration to 10 ml of freshwater (5 L) by heating (50 °C), with or without digestion (30% H_2O_2, 50 °C, 4 h), and then, observation under microscope was reported by Montecinos et al. [28].

Organisms

Throughout the studies discussed in this review, two main methodologies were presented: dissection and visual recognition, and tissue digestion followed by filtration and visual recognition. The analysis of items from dissected organisms were performed for large litter pieces, using a loupe or directly by the naked eye. Following this procedure, macroscopic plastic debris was found in Franciscana dolphins (*Pontoporia blainvillei*) with an average plastic debris size of 7.45 cm [9] and in green turtles' gut contents (*Chelonia mydas*) with a plastic debris size range from 0.5 to 13 cm [30]. Both studies expressed results as items/ind. In a separate study, a 128-cm-length nylon filament line and other eroded plastic packaging items of 2.7 and 8.1 cm^2 were found in the intestinal content of a stranded whale (*Eubalaena australis*) found in Nuevo Gulf [31]. Visual inspection of stomach content and regurgitated pellets was also used for the giant petrel *Macronectes giganteus* [7, 8], and the kelp gull *Larus dominicanus* [32].

Extraction of microplastics from organisms includes a digestion step and an effective, safe, and ecofriendly redox procedure avoiding unwanted effects [33]. In the studies reviewed, different tissues (gastrointestinal tracts, muscle, and soft tissue) were digested using 30% peroxide at temperatures between 45 and 65 °C [10, 12, 19, 21, 25–27, 34], 10% KOH at 40 °C [35], or 22.5 M HNO_3 at room temperature, followed by 30 min of boiling to complete organic matter digestion [21]. Final filtration uses different class of filters: cellulose nitrate (0.22-μm and 0.45-μm pore size), glass fibers (0.22-μm and 0.70-μm pore size), and paper (22-μm pore size) filters. Alternatively, avoiding a filtration step, Ríos et al. [25] digested the soft tissue of mussels, and fish gastrointestinal tracts with a minimum volume of H_2O_2 (30%, 60 °C, 48 h) which was dried in clean Petri dishes.

Plastic Particle Quantification and Identification

Presence/absence of plastic items can be determined by the naked eye for larger particles or using a stereomicroscope for smaller size classes [36]. Although careful and trained visual sorting is an obligatory step, nowadays, further characterization is required to assess the total number of plastic particles, avoiding mis-, over-, or underestimations. Moreover, this information could provide information on the possible sources of the plastic debris.

Only 30% of publications (from the last 4 years) included a form of chemical characterization of the identified plastic. Vibrational spectroscopy (infrared and/or Raman) was used for the most publications [11, 19, 20, 22, 24, 28, 34, 35], while analysis of the elemental composition by scanning electron microscopy combined with energy dispersive X-ray spectroscopy (SEM/EDS or SEM/EDX) was used by Ríos et al. [25] and Forero López et al. [22].

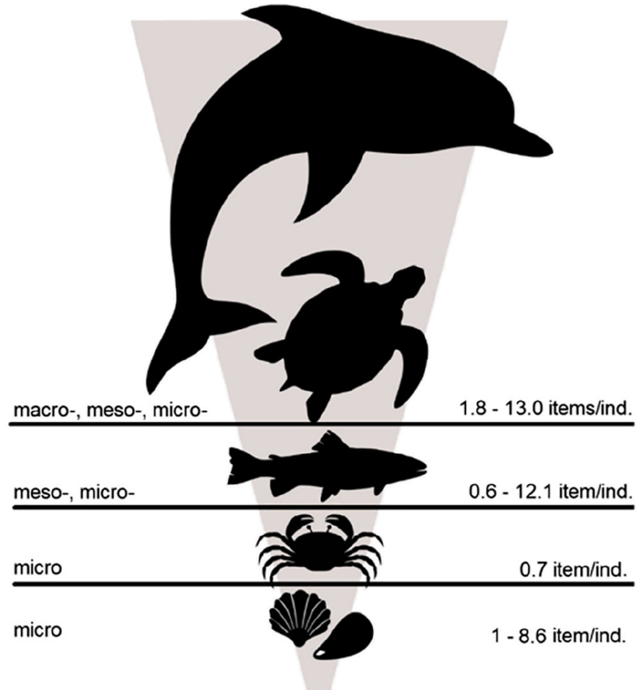

Fig. 2 Size range and concentration of plastic particles in marine organisms from Argentina. Item/ind., number of particles per individual

Environmental Spheres Analyzed in Argentina

Understanding the movement of pollutants over different sphere compartments is complex and has not been well established yet for plastic pollution. Scientists should first elucidate the “microplastics cycle” to understand its global fate [37]. Considering this, an approach to estimate plastic waste dynamics and distributions, considering all sizes (macro-, meso, micro-, and nanoplastic) at the different ecosystemic spheres will help to intercept their origin, interaction points between compartments, and the final destination. More than half of the research in Argentina has been carried out in the biosphere (52.9%), followed by hydrosphere (29.4%), and finally, in sediments and soils (lithosphere, 17.7%). There is currently no available data regarding microplastics in the atmosphere throughout Argentina [38]. Overall, less than 20% of the studies carried out in Argentina addressed more than one ecological compartment.

Biosphere

Within manuscripts analyzed in this review, 12 studied marine organisms, while 3 studied freshwater ecosystems (Table 1). A greater variety of species was addressed for the marine environment (from mussels to mammals and birds) in comparison to freshwater (fish and mussels). Plastic particles have been identified in the stomach contents and regurgitated pellets of the giant petrel (*Macronectes giganteus*). Although particle size or average concentrations per individual were not determined, plastic debris occurrence in the diet was more than 65% [7, 8]. Similarly, Yorio et al. [32] analyzed the plastic debris incidence in the stomach contents of breeding kelp gulls (*Larus dominicanus*) across a period of 5 years

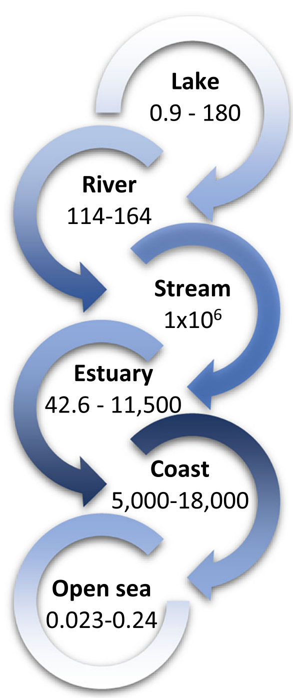

Fig. 3 Microplastics concentrations (items/m^3) in fresh and marine waters from Argentina

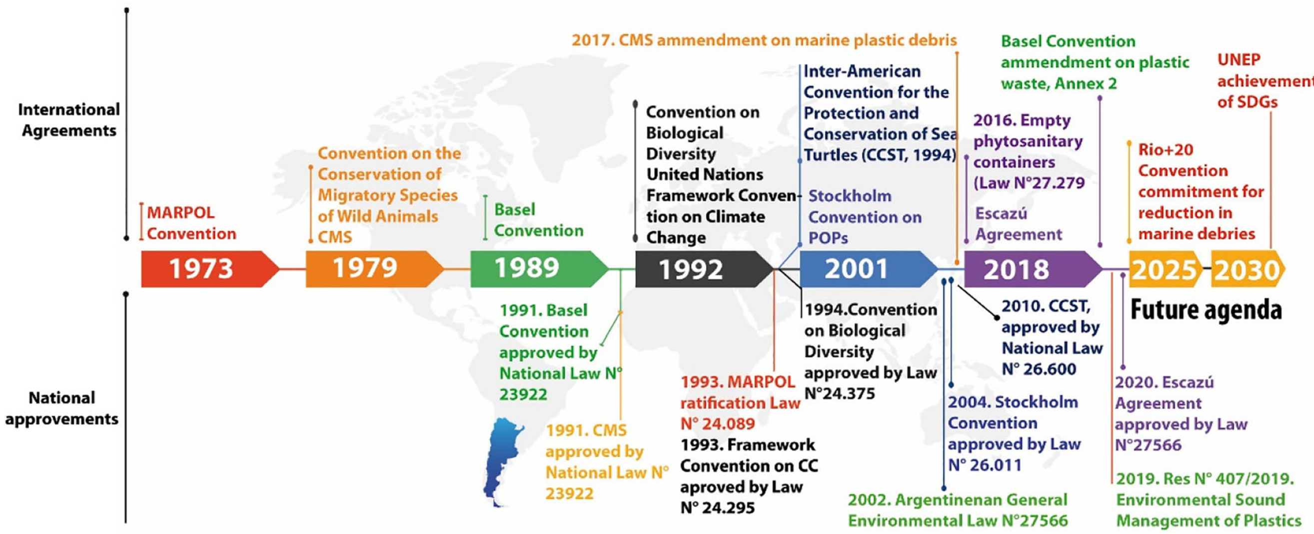

Fig. 4 Time-scale progression of the Plastic waste legislation at both international and national (own elaboration over a free vector template, freepik.com)

(2012–2017). Although several gull species feed in garbage dumps [39, 40], the plastics debris incidence in *L. dominicanus* was relatively low and no relation between plastic concentration and distance to garbage dumps was found [32].

Considering marine organisms, the first published research from Argentina reported plastic in gastrointestinal tracts of Franciscana dolphins (*Pontoporia blainvillei*) [9] and green turtles (*Chelonia mydas*) [30] from the estuarine and coastal marine zones of La Plata river. An average concentration of 1.8 item/ind. was found for dolphins and 13 items/ind. for turtles (Fig. 2). Although there are very few worldwide records concerning the interactions between cetaceans and plastic debris; reported concentrations in Argentine dolphins were similar to those in Brazil [41] and lower than those in Spain [42]. There is a significant body of research which attribute gastrointestinal tract injuries and death to plastic ingestion in sea turtles [43–47]. More recently, macro-plastic particles were identified in the gastrointestinal tract of a juvenile whale (*Eubalaena australis*) from Golfo Nuevo, the first account of plastic ingestion for this species [31].

Plastic particle ingestion by marine commercial fish was analyzed at the Bahía Blanca Estuary [12] and in Puerto Madryn coastal area [25]. Although both studies mainly showed the presence of microplastics, Arias et al. [12] also evidenced mesoplastics. In these studies, average concentrations ranged from 0.6 to 12.1 item/ind. (Fig. 2), a significantly higher range than other South American reports (0.15–1.06 items/ind.) [48–50]. Other marine organisms have also been analyzed, namely, crabs, oysters, shrimps, and mussels, showing average concentrations from 0.7 to 8.6 item/ind. (Fig. 2) [21, 25, 27, 34]. Plastic debris has been identified in mussels all over the world, with enormous variation in concentrations between them, possibly explained by the lack of standardized methods as reviewed by Li et al. [51]. Results obtained for Argentine coastal mussels (0.3 item/g w.w.) [25] were similar to those found in Germany, Belgium, France, and Finland, but lower than in China, Norway, and Indonesia, among others [51].

In regard to freshwater species, fish and mussels were studied in the most important rivers for Argentina: the Paraná and La Plata rivers [10, 19, 26]. In fish samples, a microplastic incidence of 100% was found, with a predominance of fibers and an average concentration of 15 item/ind., with the highest levels recorded in La Plata river (Fig. 2). This is possibly explained by the proximity to large urban conglomerates. In these studies, a relationship between microplastic concentrations, feeding habit or fish size could not be demonstrated [10], suggesting that gastrointestinal plastic levels might be more related to the environmental concentrations than the fish species characteristics. In a worldwide context, average freshwater fish microplastic concentrations in Argentina were similar to those reported in North America [52], but higher than those from European rivers [53–56]. In La Plata river, plastic particles were also analyzed in mussels where micro-sized fibers dominated, showing much lower concentrations than fish (average 0.43 item/ind.) and a positive correlation between size of individuals and accumulated microplastics [26].

Finally, Rumbold et al. [17] assessed different encrusting species on the surface of plastic debris, which were dominated by the barnacle *Amphibalanus improvisus*, followed by the bryozoan *Membranipora* sp., and then undetermined polychaetes and the mollusk *Ostrea* sp. These results showed that marine plastic debris can provide suitable settlement sites for the growth of various marine organisms.

Table 1 Plastic pollution researches from Argentina

Author and year of publication	Sample	Size range	Quantification
Acha et al., 2003	Marine water; 200 mm bottom trawl net	> 20 cm	Visually counted
Copello and Quintana 2003	Stomach contents of petrels	No data	Visually counted
Copello et al., 2008	Regurgitated pellets of petrels	No data	Visually counted
Denuncio et al., 2011	Gastrointestinal tract of dolphins	0.2–11.4 cm	Visually counted
Seco Pon and Becherucchi, 2012	Urban street transects (1425 m^2)	No data	Visually counted
González Carman et al., 2014	Gastrointestinal tract of turtles	0.5–>15 cm	Visually counted
Becherucci and Seco Pon, 2014	Urban street transects (1425 m^2)	No data	Visually counted
Denuncio and Bastida, 2014	Beach, five transect lines, parallel to the coast, 400 m length separated by 25 m	No data	Visually counted
Becherucci et al., 2017	Sand; 3 transects across the beach, 10 m between them	5–100 mm	Visually counted
Pazos et al., 2017	Gastrointestinal tract of freshwater fish	0.06–4.7 mm	Visually counted by optical stereomicroscope
Bletter et al., 2017	River sediment; manually. Macroplastics: transect parallel to the coast, 50 m length, 5 m wide. Mesoplastics: quadrant 1 m × 1 m × 3 cm, 5-mm steel sieve. Microplastics: microquadrant 25 × 25 × 3 cm, 350-μm stell sieve.	0.5 mm–2.4 m	Visually counted by optical stereomicroscope and microscope—FT-IR identification
Pazos et al., 2018	Freshwater; 36 μm plankton net	< 0.1–5 mm	Visually counted by optical stereomicroscope
Arias et al., 2019	Gastrointestinal tract of marine fish	0.2–5 mm	Visually counted by optical stereomicroscope
Ronda et al., 2019	Marine bottom sediment and seawater surface; 350-μm manta trawl net	0.15–> 5 mm	Visually counted by optical stereomicroscope
Fernández Severini et al., 2019	Gut content of oysters and marine water; 60-μm plankton net, Van Dor Bottle	0.17–5 mm	Visually counted by optical stereomicroscope
Bletter et al., 2019	River sediment; manually. Macroplastics: transect parallel to the coast, 50 m length, 5 m wide. Mesoplastics: quadrant 1 m × 1 m × 3 cm, 5-mm steel sieve. Microplastics: microquadrant 25 × 25 × 3 cm, 350-μm stell sieve. Gastrointestinal tract of freshwater fish	0.5 mm–macroplastic	Visually counted by optical stereomicroscope and microscope—FT-IR identification
Villagrán et al., 2020	Gills and gastrointestinal tract of crabs and marine water; 60-μm plankton net	< 0.2–5 mm	Visually counted by optical stereomicroscope
Rumbold et al., 2020	Lagoon beach, 46 km^2—encrusting species	0.09×10^{-3}–47.25×10^{-3} m^2	Visually counted
Alfonso et al., 2020a	Freshwater; 47-μm plankton net	< 0.1–5 mm	Visually counted by optical stereomicroscope
Alfonso et al., 2020b	Freshwater; 47-μm plankton net	< 0.1-5 mm	Visually counted by optical stereomicroscope —Raman identification
Pazos et al., 2020	Soft tissue of freshwater mussels	< 0.1-5 mm	Visually counted by optical stereomicroscope
Ríos et al., 2020	Soft tissue of marine mussel, gastrointestinal tract of marine fish, bottom marine water	0.05–4.97 mm	Visually counted by optical microscope —SEM-EDS identification
Yorio et al., 2020	Regurgitated pellets and stomach content of seagull	> 0.5 mm	Visually counted by optical microscope
Forero López et al., 2020	Particulate matter suspended in seawater	0.5–5 mm	Visually counted by optical stereomicroscope —FT-IR and SEM-EDX identification
Fernández Severini et al., 2020	Muscle tissue of marine shrimp	0.5–5 mm	Visually counted by optical stereomicroscope —Raman identification
Pérez et al., 2020	Soft tissue of marine mussels	0.03–2 mm	Visually counted by optical stereomicroscope —Raman and ATR infrared identification
Mitchell et al., 2020	River sediment. Manually. Macroplastics: transect parallel to the coast, 50 m length, 5 m wide. Mesoplastics: quadrant 1 m × 1 m × 3 cm, 5-mm steel sieve. Microplastics: microquadrant 25 × 25 × 3 cm, 350-μm stell sieve.	0.5 mm macroplastic	Visually counted by optical stereomicroscope —FT-IR identification
Montecinos et al., 2020	Freshwater, wastewater	0.01–5 mm	Visually counted by optical stereomicroscope —Raman identification
Alzugaray et al., 2020	Digestive tract of whale	25 mm–1 m	Visually counted

Hydrosphere

Across to the different environmental areas, freshwater samples from four published papers were analyzed from rivers, streams, and lakes. Although Blettler and Mitchell's studies were associated with the Paraná river course [11, 19, 20], they were based on sediment samples rather than water samples; therefore, they were considered in lithosphere sphere for this review (see next section). Pazos et al. [29] studied estuary water samples before the turbidity front (salinity < 0.5 PSU), and so, this was considered as a freshwater ecosystem analysis.

Freshwater microplastic concentrations were very variable and ranged from 0.9 to millions of particles per m^3, with the lowest values found in Patagonian lakes, which are commonly referred to as the most pristine areas in Argentina [24], and the highest levels found in a stream in the Pampas region [28]. In a worldwide context, the average levels were similar to those from Magdalena river in Colombia [57]. Values were approximately an order of magnitude higher than rivers analyzed in Africa [58], and four to thirty times smaller than some freshwater courses in China [59, 60]. The highest record of microplastics (1×10^6 items/m^3) found in Argentina was published by Montecinos et al. [28].

In marine environments, plastic concentrations in water were reported in five published papers from estuaries and coasts to the open sea. In these studies, microfibers were shown to be the main component, ranging from 0.14 items/m^3 in the open sea [18] to 18,000 items/m^3 in a Patagonian coastal zone [25]. When comparing levels from the open sea to other reports, microplastics concentrations were nearly half those reported from Brazil (~ 0.3 item/m^3) [61] and five times lower than European samples from the open sea [62, 63]. In Argentinian coastal waters, plastic concentrations were similar to the worldwide averages [64].

Microplastic transport from continental sources to the Argentinian open sea is possible to analyze, even without addressing temporal and spatial variability (Fig. 3). For instance, rivers and different effluent outlets have been identified as significant microplastic sources to the ocean [65]. In Argentina, lakes and the Paraná and La Plata rivers showed the lowest microplastic concentrations [23, 29] while stream records showed the maximum [28] (Fig. 3). Estuaries and coastal regions are heavily influenced by river runoff and wastewater discharge. Discharge from treatment plants and landfills have been reported to contribute a considerable proportion of microplastics at those environments [66]. Significant plastic contamination has been shown for Argentinean coastal waters [21, 22, 25, 27], while Argentinean open sea samples revealed some of the lowest microplastic levels recorded worldwide [18].

Lithosphere

Only a few studies have been conducted within the lithosphere, with 4 studies addressing river courses, 2 focused on sand from beaches, and a single study addressing seabed sediments. The expression of plastic debris levels in sediment samples varies between studies, which makes any direct comparison between studies difficult [67]. Given the different units used for plastic debris density in sediments from Argentina, only the type of sediment and plastic debris size were considered in this review.

Blettler et al. [11, 19] and Mitchell et al. [20] have simultaneously analyzed all plastic debris sizes in shoreline sediments from different areas of the Paraná river. Additionally, beach debris was assessed across the beaches with the greatest number of tourists [16, 68], where it was found that plastic debris was the most abundant debris in surface sands. Finally, there has been one recent analysis of plastic microfiber concentrations in marine sediments of the continental shelf [18].

Anthroposphere

There are two published surveys on the abundance and composition of urban litter in Mar del Plata, one of the major coastal cities of the country [69, 70]. Using sampling units (~ 1425 m^2), all visible litter was recorded and an average of 14.27 items/m^2 during daylight hours, and 9.5 items/m^2 in the early morning were found, with items including cigarette butts, papers, and plastic identified most frequently.

Future Perspectives for Argentina

Plastic litter arising from inappropriate disposal of products is the greatest global problem caused by this contaminant. Argentina's legislation regarding plastics and plastic waste has consistently grown during the recent decades. As shown in Fig. 4, the core of the national environmental laws follows the general timeline progression of the Multilateral Environmental Agreements (MEAs). A rationale for this is that Argentina's National Constitution sets that ratified multilateral agreements have a higher rank than the national laws, meaning that the approved MEAs set the milestones for the development of national legislation. For instance, following-on the Basel Convention (National Law No. 23.922), plastic waste is highly regulated in the country, controlling the movements of hazardous plastic waste and plastic waste that might not be considered hazardous but that is not sorted or prepared for direct recycling. Building on the Stockholm Convention on Persistent Organic Pollutants, the country also regulates additives and chemical compounds historically used as plastic additives (National Law 26.011). Although ratified two decades after the initial agreement, plastic pollution from ships is tackled based on the MARPOL Convention (National Law 24.292) (Fig. 4), while litter in marine and coastal ecosystems is considered based on the Convention on the Conservation of Migratory Species of Wild Animals, CMS (National Law No. 23.918). Other MEAs which have national representative laws include the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change (National Law No. 24.295), the Inter-American Convention for the Protection and Conservation of Sea Turtles (National Law No. 26.600), the Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean, Escazu Convention (National Law No. 27.566). Regarding waste management, National Laws No. 25.916 and 24.051 are the fundamental pillars that address issues beyond proper waste management. Adding to this, the first inclusion of the concept of Extended Producer Responsibility (EPR) was in 2016, when the standards for handling and disposal of empty phytosanitary containers was established (National Law No. 27.279). At present, the EPR and circular economy concepts are the main core of several ongoing laws and resolutions (e.g., Res No. 407/2019), which include all the stakeholders involved in the lifecycle of plastics.

Research Gaps in Argentina

Knowledge regarding plastic impacts in Argentina will lead to the development of the best regional strategies to mitigate the problem of plastic pollution, which will ultimately have a positive impact on a more global scale.

Within the Argentine biosphere, the impact of plants and insects as possible vectors of plastic particles remains unknown; however, this issue has been reported for other environments [71, 72]. Within the hydrosphere, the dynamics and distribution of plastic particles in groundwater and meltwater would be of interest since it has recently been identified in other parts of the world [73, 74]. With regard to the lithosphere, there is a lack of investigation in land uses, agricultural zones, and the effects of plastic debris in the physicochemical characteristics of soils [75]. There is very little information across the world concerning the role of atmospheric transport in the distribution and dynamics of plastic debris [76–78]. It is crucial to know not only the magnitude of the transport of these particles in the atmosphere and their total deposition rate (dry and wet), but also the risk that this transport presents to human health, since small particles and fibers can be inhaled and deposited in the lungs of children and adults [79].

Considering the planet as a whole, only a few researchers—which includes Argentina—have analyzed all particle sizes simultaneously for the same environment. This is an important gap to address since most of the Argentinian research concluded that microplastics came from the breakdown of the larger plastics. It is worth mentioning that Blettler et al. [11, 19] analyzed all sizes particles, performing a more global analysis of plastic litter impact, while the rest focused solely on the analysis of microplastics. On the other hand, the studies of Acha et al. [6], and those addressing sand beaches [16, 68] and urban transects [69, 70] excluded the smallest particles of plastic.

Research on nanoplastics in Argentina (and worldwide) is still a knowledge gap, although their unknown effects are potentially the most hazardous. It has been proposed that these particles less than 1 μm have greater effects on organisms at the cellular level since they could pass biological membranes and affect the functioning of cells, including blood cells and photosynthesis [80]. Nanoplastics could be released via the fragmentation of primary microplastics from commercial products or nanofragmentation of secondary microplastics [81].

Finally, linking toxicological effects to plastic particle ingestion is still a knowledge gap for the country. This question has been addressed worldwide in different organisms (in e.g., [82, 83]), however, only one study has successfully linked the number of ingested plastic particles to a biomarker of contaminant exposure [12].

Argentinean Scientific Engagement

In the search to understand the dynamics and distribution of plastic litter in Argentina and promote a scientific commitment to society, a national scientific network—SEPIA—has emerged to convene different research groups studying plastic pollution, following the expansion of research regarding this topic during the last 4 years. SEPIA (Science for Plastic Impact Argentina) is based on fostering the creation of appropriate environments to strengthen the bond between different actors with a commitment to solving the plastic pollution problem. Our goal is to set a reference baseline for decision-makers, NGOs, and other academic institutions, while aiming to:

- Stimulate plastic pollution research promoting the harmonization of methodologies.
- Increase awareness of plastic pollution in Argentinian citizens, while promoting new consumer cultures regarding our responsibility to minimize plastic waste.
- Facilitate communication channels between scientists and decision-makers.
- Engage with other national and international networks to match short-, medium-, and long-term objectives on a global scale.

In Argentina, the network includes at present more than 50 researchers from different academic institutions throughout the country.

Conclusions

The impact of plastic waste in Argentina has been progressively documented for two decades with a significant increase during the last 4 years. Specifically, research has been focused on one environmental compartment, with less than 20% addressing more than one environmental sphere simultaneously. Sixty percent of the research was focused on microplastics, and less than 20% has considered more than one size of plastic debris. Microfibers were the most commonly found particle classification in water courses with the lowest microplastic concentrations in lakes, and the Paraná and La Plata rivers, and the maximum in Pampa´s streams. Considering coastal waters, while values were similar to those reported worldwide, microplastics in marine species showed higher concentrations than reports from other South American countries. Freshwater organisms showed a microplastic incidence of 100%, with higher concentrations identified than from European rivers and similar levels to those reported in North America. In terms of plastic regulation, the national legislation timeline follows the principal international multilateral agreements and tends to include Extended Producer Responsibility and Circular Economy concepts in the ongoing projects and resolutions. To conclude, the identified scientific knowledge gaps include the evaluation of plastic degradation processes in the environment, plants air and insects as vectors of these pollutants, complete size range analyses, and the processes of accumulation and bioaccumulation of plastic through more than one environmental sphere, addressing possible ecotoxicological effects.

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Declarations

Conflict of Interest The authors declare no competing interests.

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References

Papers of particular interest, published recently, have been highlighted as:

- • Of importance
- •• Of major importance

1. Prata JC, da Costa JP, Lopes I, Duarte AC, Rocha-Santos T. Environmental exposure to microplastics: an overview on possible human health effects. Sci Total Environ. 2020;702:134455.
2. Cheshire A, Adler E, Barbière J, Cohen Y, Evans S, Jarayabhand S, Lavine. IOC guidelines on survey and monitoring of marine litter. UNEP:2013:186.
3. Lippiatt S, Opfer S, Arthur C. Marine debris monitoring and assessment: recommendations for monitoring debris trends in the marine environment. 2013 DOI: https://doi.org/10.25607/OBP-727.
4. GESAMP. Report of the 45th Session. Group of Experts on the Scientific Aspects of Marine Environmental Protection 2018.
5. Akhbarizadeh R, Moore F, Keshavarzi B. Investigating microplastics bioaccumulation and biomagnification in seafood from the Persian Gulf: a threat to human health? Food Addit Contam. 2019;2019(36):1696–708.
6. Acha EM, Mianzan HW, Iribarne O, Gagliardini DA, Lasta C, Daleo P. The role of the Río de la Plata bottom salinity front in accumulating debris. Mar Pollut Bull. 2003;46:197–202.
7. Copello S, Quintana FR. Marine debris ingestion by Southern Giant Petrels and its potential relationships with fisheries in the Southern Atlantic Ocean. Mar Pollut Bull. 2003;46:1513–5.
8. Copello S, Quintana F, Pérez F. Diet of the southern giant petrel in Patagonia: fishery-related items and natural prey. Endanger Species Res. 2008;6:15–23.
9. Denuncio P, Bastida R, Dassis M, Giardino G, Gerpe M, Rodríguez D. Plastic ingestion in Franciscana dolphins, Pontoporia blainvillei (Gervais and d'Orbigny, 1844), from Argentina. Mar Pollut Bull. 2011;62:1836–41.
10. Pazos RS, Maiztegui T, Colautti DC, Paracampo AH, Gómez N. Microplastics in gut contents of coastal freshwater fish from Río de la Plata estuary. Mar Pollut Bull. 2017;122:85–90.
11. Blettler MC, Ulla MA, Rabuffetti AP, Garello N. Plastic pollution in freshwater ecosystems: macro-, meso-, and microplastic debris in a floodplain lake. Environ Monit Assess. 2017;189:581.
12. Arias AH, Ronda AC, Oliva AL, Marcovecchio JE. Evidence of microplastic ingestion by fish from the Bahía Blanca estuary in Argentina, South America. B Environ Contam Tox. 2019;102: 750–6.
13. Sadekarpawar S, Parikh P. Gonadosomatic and hepatosomatic indices of freshwater fish Oreochromis mossambicus in response to a plant nutrient. World J Zool. 2013;8:110–8.
14. Al-Ghais SM. Acetylcholinesterase, glutathione and hepatosomatic index as potential biomarkers of sewage pollution and depuration in fish. Mar Pollut Bull. 2013;74:183–6.
15. Besley A, Vijver MG, Behrens P, Bosker T. A standardized method for sampling and extraction methods for quantifying microplastics in beach sand. Mar Pollut Bull. 2017;114:77–83.
16. Becherucci ME, Rosenthal AF, Seco Pon JPS. Marine debris in beaches of the Southwestern Atlantic: an assessment of their abundance and mass at different spatial scales in northern coastal Argentina. Mar Pollut Bull. 2017;119:299–306.
17. Rumbold CE, García GO, Seco Pon JP. Fouling assemblage of marine debris collected in a temperate South-western Atlantic coastal lagoon: a first report. Mar Pollut Bull. 2020;154:111103.
18. Ronda AC, Arias AH, Oliva AL, Marcovecchio JE. Synthetic microfibers in marine sediments and surface seawater from the Argentinean continental shelf and a Marine Protected Area. Mar Pollut Bull. 2019;149:110618.
19. Blettler MC, Garello N, Ginon L, Abrial E, Espinola LA, Wantzen KM. Massive plastic pollution in a mega-river of a developing country: sediment deposition and ingestion by fish (Prochilodus lineatus). Environ Pollut. 2019;255:113348.
20. Mitchell C, Quaglino MC, Posner VM, Arranz SE, Sciara AA. Quantification and composition analysis of plastic pollution in riverine beaches of the lower Paraná River, Argentina. Environ Sci Pollut Res. 2020:1–12.
21. Fernández Severini MD, Villagran DM, Buzzi NS, Sartor GC. Microplastics in oysters (Crassostrea gigas) and water at the

Bahía Blanca Estuary (Southwestern Atlantic): an emerging issue of global concern. Reg Stud Mar Sci. 2019;32:100829.
22. Forero López A, Truchet DM, Rimondino GN, Maisano L, Spetter CV, Buzzi NS, et al. Microplastics and suspended particles in a strongly impacted coastal environment: composition, abundance, surface texture, and interaction with metal ions. Sci Total Environ. 2020;754:142413.
23. Alfonso MB, Arias AH, Piccolo MC. Microplastics integrating the zooplanktonic fraction in a saline lake of Argentina: influence of water management. Environ Monit Assess. 2020;192:1–10.
24. Alfonso MB, Scordo F, Seitz C, Manstretta GMM, Ronda AC, Arias AH, et al. First evidence of microplastics in nine lakes across Patagonia (South America). Sci Total Environ. 2020;139385.
25. Ríos MF, Hernández-Moresino RD, Galván DE. Assessing urban microplastic pollution in a benthic habitat of Patagonia Argentina. Mar Pollut Bull. 2020;159:111491.
26. Pazos RS, Spaccesi F, Gómez N. First record of microplastics in the mussel *Limnoperna fortunei*. Reg Stud Mar Sci. 2020;38:101360.
27. Villagran DM, Truchet DM, Buzzi NS, Lopez ADF, Fernández Severini MD. A baseline study of microplastics in the burrowing crab (Neohelice granulata) from a temperate southwestern Atlantic estuary. Mar Pollut Bull. 2020;150:110686.
28. Montecinos S, Tognana S, Pereyra M, Silva L, Tomba JP. Study of a stream in Argentina with a high concentration of microplastics: preliminary analysis of the methodology. Sci Total Environ. 2020;760:143390.
29. Pazos RS, Bauer DE, Gómez N. Microplastics integrating the coastal planktonic community in the inner zone of the Río de la Plata estuary (South America). Environ Pollut. 2018;243:134–42.
30. González Carman VG, Acha EM, Maxwell SM, Albareda D, Campagna C, Mianzan H. Young green turtles, Chelonia mydas, exposed to plastic in a frontal area of the SW Atlantic. Mar Pollut Bull. 2014;78:56–62.
31. Alzugaray L, Di Martino M, Beltramino L, Rowntree VJ, Sironi M, Uhart MM. Anthropogenic debris in the digestive tract of a southern right whale (Eubalaena australis) stranded in Golfo Nuevo, Argentina. Mar Pollut Bull. 2020;161:111738.
32. Yorio P, Marinao C, Kasinsky T, Ibarra C, Suárez N. Patterns of plastic ingestion in Kelp Gull (Larus dominicanus) populations breeding in northern Patagonia. Argentina Mar Pollut Bull. 2020;156:111240.
33. Lusher AL, Hernandez-Milian G. Microplastic extraction from marine vertebrate digestive tracts, regurgitates and scats: a protocol for researchers from all experience levels. Bio-protocol. 2018;8: e3087–7.
34. Pérez A, Ojeda M, Rimondino GN, Chiesa I, Di Mauro R, Boy CC, et al. First report of microplastics presence in the mussel Mytilus chilensis from Ushuaia Bay (Beagle Channel, Tierra del Fuego, Argentina). Mar Pollut Bull. 2020;161:111753.
35. Fernández Severini MD, Buzzi NS, Forero López A, Colombo CV, Sartor GC, Rimondino GN, et al. Chemical composition and abundance of microplastics in the muscle of commercial shrimp *Pleoticus muelleri* at an impacted coastal environment (Southwestern Atlantic). Mar Pollut Bull. 2020;161:111700.
36. Norén F. Small plastic particles in coastal Swedish waters. Kimo Sweden. 2007;11.
37. Rochman CM, Hoellein T. The global odyssey of plastic pollution. Science. 2020;368:1184–5.
38. Zhang Y, Kang S, Allen S, Allen D, Gao T, Sillanpää M. Atmospheric microplastics: a review on current status and perspectives. Earth-Sci Rev. 2020;203:103118.
39. Lenzi J, Burgues MF, Carrizo D, Machín E, Teixeira-de MF. Plastic ingestion by a generalist seabird on the coast of Uruguay. Mar Pollut Bull. 2016;107:71–6.
40. Witteveen M, Brown M, Ryan PG. Anthropogenic debris in the nests of kelp gulls in South Africa. Mar Pollut Bull. 2017;114: 699–704.
41. Di Beneditto APM, Ramos RMA. Marine debris ingestion by coastal dolphins: what drives differences between sympatric species? Mar Pollut Bull. 2014;83:298–301.
42. Hernandez-Gonzalez A, Saavedra C, Gago J, Covelo P, Santos MB, Pierce GJ. Microplastics in the stomach contents of common dolphin (Delphinus delphis) stranded on the Galician coasts (NW Spain, 2005–2010). Mar Pollut Bull. 2018;137:526–32.
43. Bugoni L, Krause L, Almeida AO, Bueno AAP. Commensal barnacles of sea turtles in Brazil. MTN. 2001;94:7–9.
44. Tomás J, Guitart R, Mateo R, Raga JA. Marine debris ingestion in loggerhead sea turtles, Caretta caretta, from the Western Mediterranean. Mar Pollut Bull. 2002;44:211–6.
45. Witherington B. Ecology of neonate loggerhead turtles inhabiting lines of downwelling near a Gulf Stream front. Mar Biol. 2002;140: 843–53.
46. Stamper MA, Spicer CW, Neiffer DL, Mathews KS, Fleming GJ. Morbidity in a juvenile green sea turtle (Chelonia mydas) due to ocean-borne plastic. JZWM. 2019;40:196–8.
47. Lazar B, Gračan R. Ingestion of marine debris by loggerhead sea turtles, *Caretta caretta*, in the Adriatic Sea. Mar Pollut Bull. 2011;62:43–7.
48. Possatto FE, Barletta M, Costa MF, do Sul JAI, Dantas DV. Plastic debris ingestion by marine catfish: an unexpected fisheries impact. Mar Pollut Bull. 2011;62:1098–102.
49. Vendel AL, Bessa F, Alves VEN, Amorim ALA, Patrício J, Palma ART. Widespread microplastic ingestion by fish assemblages in tropical estuaries subjected to anthropogenic pressures. Mar Pollut Bull. 2017;117:448–55.
50. Limongi P, Lacerot G, Segura A. Plastic fibers in the gastrointestinal tract content of two South Atlantic coastal fish species with different trophic habits (Urophycis brasiliensis, Paralonchurus brasiliensis) in Punta del Diablo-Uruguay. Pan-Am J Aquat Sci. 2019;14:71–6.
51. Li J, Lusher AL, Rotchell JM, Deudero S, Turra A, Bråte ILN, et al. Using mussel as a global bioindicator of coastal microplastic pollution. Environ Pollut. 2019;244:522–33.
52. McNeish RE, Kim LH, Barrett HA, Mason SA, Kelly JJ, Hoellein TJ. Microplastic in riverine fish is connected to species traits. Sci Rep. 2018;2018(8):1–12.
53. Sanchez W, Bender C, Porcher JM. Wild gudgeons (Gobio gobio) from French rivers are contaminated by microplastics: preliminary study and first evidence. Environ Res. 2014;128:98–100.
54. Collard F, Gasperi J, Gilbert B, Eppe G, Azimi S, Rocher V, et al. Anthropogenic particles in the stomach contents and liver of the freshwater fish Squalius cephalus. Sci Total Environ. 2018;643: 1257–64.
55. Roch S, Walter T, Ittner LD, Friedrich C, Brinker A. A systematic study of the microplastic burden in freshwater fishes of south-western Germany-are we searching at the right scale? Sci Total Environ. 2019;689:1001–11.
56. Kuśmierek N, & Popiołek M Microplastics in freshwater fish from Central European lowland river (Widawa R., SW Poland). Environ Sci Pollut Res. 2020 1-5.
57. Martínez Silva P, Nanny MA. Impact of microplastic fibers from the degradation of nonwoven synthetic textiles to the Magdalena River water column and river sediments by the City of Neiva, Huila (Colombia). Water. 2020;12:1210.
58. Naidoo T, Glassom D, Smit AJ. Plastic pollution in five urban estuaries of KwaZulu-Natal. South Afr Mar Pollut Bull. 2015;101:473–80.
59. Zhao S, Zhu L, Wang T, Li D. Suspended microplastics in the surface water of the Yangtze Estuary System, China: first observations on occurrence, distribution. Mar Pollut Bull. 2014;86:562–8.

60. Zhao S, Zhu L, Li D. Microplastic in three urban estuaries. China Environ Pollut. 2015;206:597–604.
61. Garcia TM, Campos CC, Mota EMT, Santos NMO, de Santana Campelo RP, Prado LCG, et al. Microplastics in subsurface waters of the western equatorial Atlantic (Brazil). Mar Pollut Bull. 2020;150:110705.
62. Magnusson K. Microlitter and other microscopic anthropogenic particles in the sea area off Rauma and Turku. Finland Swedish Environ Instit Rep. 2014;4645:17.
63. Setälä O, Fleming-Lehtinen V, Lehtiniemi M. Ingestion and transfer of microplastics in the planktonic food web. Environ Pollut. 2014;185:77–83.
64. Barrows APW, Cathey SE, Petersen CW. Marine environment microfiber contamination: global patterns and the diversity of microparticle origins. Environ Pollut. 2018;237:275–84.
65. Rochman CM. Microplastics research—from sink to source. Science. 2018;360:28–9.
66. Kazour M, Terki S, Rabhi K, Jemaa S, Khalaf G, Amara R. Sources of microplastics pollution in the marine environment: importance of wastewater treatment plant and coastal landfill. Mar Pollut Bull. 2019;146:608–18.
67. Hidalgo-Ruz V, Gutow L, Thompson RC, Thiel M. Microplastics in the marine environment: a review of the methods used for identification and quantification. Environ Sci Technol. 2012;46:3060–75.
68. Denuncio PE, Bastida RO. Composition, distribution and waste management of Playa Grande, the most important touristic beach of Mar del Plata city, Argentina. Waste Manag. 2014. https://doi.org/10.1016/j.wasman.2014.01.013.
69. Becherucci ME, Seco Pon JP. What is left behind when the lights go off? Comparing the abundance and composition of litter in urban areas with different intensity of nightlife use in Mar del Plata, Argentina. Waste Manag. 2014;34:1351–5.
70. Seco Pon JP, Becherucci ME. Spatial and temporal variations of urban litter in Mar del Plata, the major coastal city of Argentina. Waste Manag. 2012;32:343–8.
71. Mateos-Cárdenas A, Scott DT, Seitmaganbetova G, van Pelt Frank NAM, AK JM. Polyethylene microplastics adhere to Lemna minor (L.), yet have no effects on plant growth or feeding by Gammarus duebeni (Lillj.). Sci Total Environ. 2019;689:413–21.
72. Oliveira M, Ameixa OM, Soares AM. Are ecosystem services provided by insects “bugged” by micro (nano) plastics? TrAC Trends Anal Chem. 2019;113:317–20.
73. Panno SV, Kelly WR, Scott J, Zheng W, McNeish RE, Holm N, et al. Microplastic contamination in karst groundwater systems. Groundwater. 2019;57:189–96.
74. Obbard RW, Sadri S, Wong YQ, Khitun AA, Baker I, Thompson RC. Global warming releases microplastic legacy frozen in Arctic Sea ice. Earth’s Future. 2014;2:315–20.
75. Wang J, Liu X, Li Y, Powell T, Wang X, Wang G, et al. Microplastics as contaminants in the soil environment: a mini-review. Sci Total Environ. 2019;691:848–57.
76. Dris R, Gasperi J, Saad M, Mirande C, Tassin B. Synthetic fibers in atmospheric fallout: a source of microplastics in the environment? Mar Pollut Bull. 2016;104:290–3.
77. Cai L, Wang J, Peng J, Tan Z, Zhan Z, Tan X, et al. Characteristic of microplastics in the atmospheric fallout from Dongguan city, China: preliminary research and first evidence. Environ Sci Pollut Res. 2017;24:24928–35.
78. Allen S, Allen D, Phoenix VR, Le Roux G, Jiménez PD, Simonneau A, et al. Atmospheric transport and deposition of microplastics in a remote mountain catchment. Nat Geosci. 2019;12:339–44.
79. Brauer ACM. Ambient atmospheric particles in the airways of human lungs. Ultrastruct Pathol. 2000;24:353–61.
80. Shen M, Zhang Y, Zhu Y, Song B, Zeng G, Hu D, et al. Recent advances in toxicological research of nanoplastics in the environment: a review. Environ Pollut. 2019;252:511–21.
81. Enfrin M, Lee J, Gibert Y, Basheer F, Kong L, Dumée LF. Release of hazardous nanoplastic contaminants due to microplastics fragmentation under shear stress forces. J Hazard Mater. 2020;384:121393.
82. Alomar C, Sureda A, Capó X, Guijarro B, Tejada S, Deudero S. Microplastic ingestion by Mullus surmuletus Linnaeus, 1758 fish and its potential for causing oxidative stress. Environ Res. 2019;159:135–42.
83. Jeong J, Choi J. Adverse outcome pathways potentially related to hazard identification of microplastics based on toxicity mechanisms. Chemosphere. 2019;231:249–55.