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Threats Underestimated in Freshwater Plastic Pollution: Mini-Review

Martín C. M. Blettler · **Karl M. Wantzen**

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Abstract Plastic pollution is one of the most acute environmental topics of our time. While there is a great scientific effort to tackle this problem, it has not always been well-coordinated or properly targeted. In this short review, we call for scientists to get involved in three crucial topics (threats) underestimated—or ignored—in freshwater systems: (i) plastic-species entanglement, (ii) plastic as nesting material, and (iii) macroplastic debris coming from mismanaged household solid waste. Reducing the knowledge gaps between marine and freshwater environments will be crucial to solute the plastic pollution problem effectively and globally. Therefore, we make a plea here to reinforce research activities on these three issues in freshwater environments worldwide.

Keywords Plastic pollution · Freshwater · Macroplastic · Entanglement · Nesting material

1 Introduction

Plastic has become an optimal material used in vast amounts of consumer products because it is lightweight, inexpensive, long lasting, and a good insulator. Unfortunately, within the last 35 years, scientists have realized that these useful attributes of plastics are what also make them detrimental to our environment (Sigler 2014). Rather than decomposing into molecular or further bio-gradable compounds, plastic waste only photodegrades into smaller pieces that negatively affect marine and freshwater ecosystems. In the world's oceans, the economic damage of plastic waste has been estimated to 22 billion of Euro (Beaumont et al. 2019).

Compared with the increasing amount of research published in the ocean, the research of plastic-debris in freshwater environments is still undervalued. As a result, some critical topics, relatively well understood in marine environments, remain underestimated—or totally overlooked—in freshwater systems (Blettler et al. 2018). Concerns about the impact of plastics on freshwaters are legitimate and should receive more scientific attention (e.g., Lebreton et al. 2017).

With the objective to contribute to a more holistic vision on environmental effects of plastic pollution, this short review highlights the least three crucial threats visibly underestimated in freshwater systems: (i) plastic-species entanglement, (ii) plastic-debris as nest-material, and (iii) macroplastic debris as a result of the mismanagement of urban solid waste.

2 Material and Methods

The literature review was based on the Scopus search engine (https://www.scopus.com). The Scopus search

M. C. M. Blettler (✉)
The National Institute of Limnology (INALI; CONICET-UNL), Ciudad Universitaria (3000), Santa Fe, Argentina
e-mail: mblettler@inali.unl.edu.ar

K. M. Wantzen
UNESCO Chair "River Culture - Fleuves et Patrimoine", Interdisciplinary Research Center for Cities, Territories, Environment and Society (CNRS UMR CITERES), Tour University, 37200 Tours, France

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was defined as follows: TITLE-ABS-KEY "entanglement" OR "entangled" OR "nest material" OR "nesting material" AND "plastic pollution" OR "plastic debris" OR "plastic contamination." Paper and reviews with no limits in years or subject area were considered (no book chapters). Note that this methodology was employed only for comparative reasons, i.e., to contrast marine with freshwater studies referred to "plastic-species entanglement" and "plastic-debris as nest-material" (objectives i and ii). Therefore, our objective was not to record all the existing literature in the world, but rather a represented sample for comparative purposes. Therefore, we do not try to catch the total amount of existing papers on the selected topics (i.e., studies out-side the specific keywords are missing), but we obtained a representative sample. Subsequently, an exhaustive manual checking of the results (paper by paper) was performed at the discretion of the authors of this study, which was crucial to avoid papers outside the topic, repetitions, etc. Furthermore, a key review paper was used to extract processed information: Blettler et al. (2018) (see this paper for methodological details). Referring to the size ranges, the plastic debris was termed macroplastic as > 2.5 cm (NOAA, Lippiatt et al. 2013).

3 Results and Discussion

The reviewed papers in this study are 171 in total (62 from Scopus and109 from Blettler et al. 2018). See "Supplementary data" section.

The Table 1 shows the scarcity of studies focused on plastic entanglement and nesting material in freshwater environments, and the clear dominance of microplastic over macroplastic studies in the same habitat.

Table 1 Percentage of peer-reviewing papers recorded on the topic of "plastic-species entanglement," "plastic-debris as nest-material," and "macroplastics" in freshwater ecosystems. Sources: Scopus for entanglement and nesting material (marine vs. freshwater; $n = 62$ articles reviewed); and Blettler et al. (June 2018) for macroplastic (macro vs. microplastic in freshwater; $n = 109$ articles reviewed)

Topic of research	Marine environment	Freshwater
Entanglement (%)	98.3	1.6
Nest-material (%)	16.6	0
Topic of research	Freshwater microplastic	Freshwater macroplastic
Macroplastics (%)	80	20

3.1 Plastic-species entanglement has not received attention in freshwater environments

Entanglement happens when an animal becomes caught by a plastic object (rope, fishing line, abandoned net, bag, etc.; NOAA 2014). Macroplastic debris entanglement reduces the ability to fly, swim, or run. Animals are also at risk of strangulation and suffocation by entanglement (Allen et al. 2012).

Over 690 different species of marine animals have been recorded as entangled in debris (Darom et al. 2017), and more than 230 studies in total have been published on this topic (see LITTERBASE n.d.). However, plastic-species entanglement has been completely neglected by scientists in freshwater systems (Table 1). In spite of the quantification of entanglements of megafauna that is difficult to assess for several reasons (detection and reporting biases or low detectability; Rodríguez et al. 2013), it has been successfully addressed in marine environments. Even if the scientific literature agrees that entanglement is low detectable in the ocean (Votier et al. 2011), it seems to be frequent in the freshwater system nearby large cities. The Fig. 1 shows some examples of aquatic species entangled in the Paraná (mega)River in Argentina, illustrating how common and dangerous entanglements can be in freshwater systems.

3.2 Use of plastic-debris as nest-material by freshwater birds

Plastic particles may end up in bird nests either by chance (if they are similar to natural particles) or may be particularly selected for their shape or color by birds using ornamental elements in their nests to increase their conspicuousness in the context of female mate choice (Canal et al. 2016). The presence of plastic material in nests has been widely recorded in nests of several marine bird species (e.g., de Souza Petersen et al. 2016; Wang et al. 2018a, b). The presence of plastic material in bird nests can reduce the survivability of both parent and chicks because they may consume or entangle themselves in the debris (Witteveen et al. 2017).

Although that phenomenon has been widely studied in marine birds, almost nothing is known about it in freshwater birds. However, personal field observations confirmed a great presence of plastic debris in bird nests of many freshwater species (Fig. 2). The record was done in the Negro (Brazil) and Paraná Rivers (Argentina), suggesting the necessity to address this issue in fluvial ecosystems.

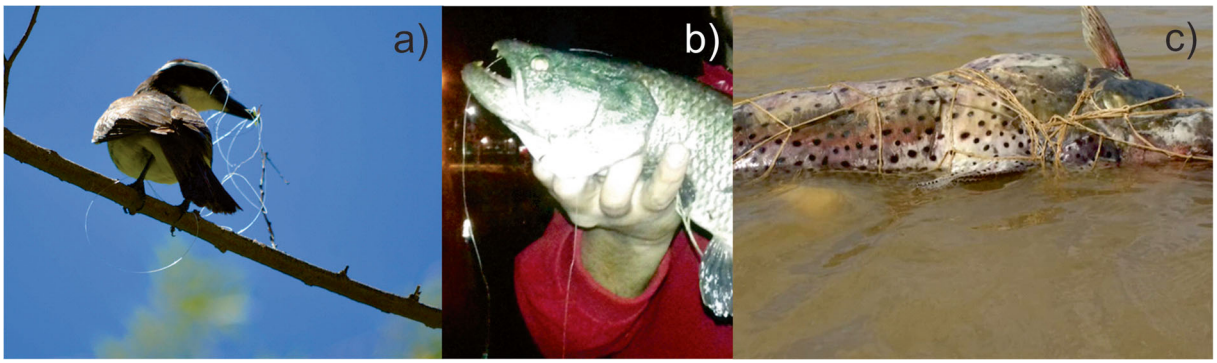

Fig. 1 Examples of aquatic vertebrates entangled with plastic debris in the Paraná River (Argentina). **a**) *Pitangus sulphuratus* entangled in a piece of line fish. **b**) *Hoplias malabaricus* caught alive with a piece of fish line, entering through the mouth and leaving by the gills. **c**) *Pseudoplatystoma corruscans* trapped in an abandoned fish net (with lethal consequence). Photo credit: César Machado

The amount of plastic trash ending up in the birds' nests appears to be increasing in freshwater systems, with dangerous and deadly results (Fig. 2c). As a direct effect, plastic particles in nests can reduce the survival rates of both parents and chicks because they may consume or entangle themselves in the debris (Witteveen et al. 2017), but little is known about the indirect impact of plastic nest material on the survival of fledglings due to changed physical (thermal resistance, water storage), hygienic (parasite development), and other unknown effects. We want to make a plea here to ornithologists to pay more attention to this growing but understudied ecological problem.

3.3 Macroplastics from mismanagement of urban solid waste remain poorly studied in rivers

Recently, Blettler et al. (2018) revealed the clear dominance of microplastic studies over macroplastic ones in freshwater environments worldwide (Table 1). According to these authors, less than 20% of the total surveys in freshwater systems have been focused on macroplastics. These authors suggest several reasons to explain that crucial result: (1) Microplastics have been identified as one of the top 10 emerging issues by the UNEP (2016), encouraging microplastic studies. (2) Microplastics are ingested by freshwater invertebrates and vertebrates (mainly fish; Triebskorn et al. 2019), which is of ecological and economic significance. (3) Smaller microplastics can be taken up by cells and translocate tissues (Khan et al. 2017). (4) Small plastic fragments may possibly have leaching rates of exogenous chemicals higher than those given by macroplastics, due to their proportionally greater surface (Wang et al. 2018a, b). These four reasons could explain why microplastics have received more attention than macroplastics by scientists so far.

However, we argue here that studies related to macroplastics, particularly from domestic solid waste

Fig. 2 Presence of plastic-debris in nest of freshwater birds. **a**) Nest of *Phacellodomus sibilatrix* with several plastic debris in- and outside (Paraná River, Argentina). **b**) Cables, bottles caps, bag fragments, spoons, pens, cloth pegs, bobby pins, and many other plastic debris found inside of one nest of *Pseudoseisura unirufa* (Negro River, Brazil). **c**) *Furnarius rufus* entangled in a piece of plastic used to build the nest (with lethal consequence; Paraná River, Argentina). Photo credits: Martín Blettler, Danilo Bandini Ribeiro, and Pablo Cantador, respectively

mismanagement, in freshwater ecosystems should be fostered for five reasons: (1) Recently, studies have estimated the amount of plastic ("solid load") exported from rivers into the ocean (Lebreton et al. 2017; Schmidt et al. 2017). Given the scarcity of field-data in rivers, these authors developed models based on indirect proxies. This methodological strategy evidenced the lack of macroplastic field data in rivers, preventing direct and accurate estimations. (2) Macroplastics represent a significantly greater input in terms of plastics weight compared with microplastics (> 100 times according to Schmidt et al. 2017). (3) Urban solid waste management is one of the main key issues to be addressed both from developed and developing countries. However, the domestic waste management in developing nations still remains strongly based on uncontrolled dumping (Guerrero et al. 2013). (4) Intercepting and removing macroplastics in rivers (e.g., using artisanal boom barriers or drainage nets) is an effective/low-cost action to avoid plastics reaching the ocean. On the contrary, the same action in the ocean is significantly more time consuming, expensive, and less effective due to the colossal scale of the ocean. Macroplastic removal from rivers using artisanal boom barriers or drainage nets can be cost-effective action compared to the marine plastic removal, which is significantly more time consuming, expensive, and less effective due to the colossal scale of the ocean. For example, The Ocean Cleanup project is a huge floating linear barrier deployed in the Great Pacific Garbage Patch. Beyond the skepticism of many researchers, the total cost of the system is the sum of 21 million euros (Forbes Media 2019). Finally, (5) macroplastic such as bags, bottles, food wrappers, and fishing lines are the most common items in oceans which researchers have reported animals entangled in (Witteveen et al. 2017). All these macro-items are also present in freshwater environments (Morritt et al. 2014; Blettler et al. 2017), suggesting that many fluvial species can be likewise impacted by macro-debris and therefore at risk.

In the following, we suggest two possible causes for the fact that freshwater macroplastics have yet been understudied in freshwaters:

Differences in levels of development Research on freshwater plastic pollution have been mainly carried out in industrialized countries (Blettler et al. 2018). This is not surprising since the best nations in sciences are high-income economies (OECD 2017). However, this disparity is particularly unsustainable from an environmental point of view, since (i) increasing population levels and the rise in consumption have greatly accelerated the solid waste generation rate in developing countries. However, waste collection and processing are still deficient in many low-middle-income countries (UNHSP 2016). (ii) Despite this, many developed countries (e.g., US, UK) benefit from cost savings associated with exporting plastic waste to developing countries with less stringent environmental laws (e.g., Thailand, India, Malaysia; Liu et al. 2018), causing severe environmental problems. (iii) The largest and populated river catchments in the world are located in developing countries (Latrubesse 2008), with the potential highest input of pollution to the ocean (due to the poor sanitary conditions above described).

As a result, riverine macroplastic debris are not so evident in developed countries due to their management of waste, which is not always the case in developing countries, where a simple walk on a riverside and the plastic waste spectacle is present. Probably, this led to scientists from developed nations to center their effort on freshwater microplastic rather than macroplastic.

A case of intellectual imperialism? Scientific imperialism is evident when it is detected a tendency to push a scientific idea (or topic of research) beyond the domain in which it was originally introduced (Alatas 2000). Many times, journal editors and researchers reproduce this dominance in order to attract new readers and publish more articles. This is particularly true in the case of microplastics, which became a hot topic of study in the last years (Bergmann et al. 2017a, b).

Accordingly, the authors suggest that microplastic pollution—as a topic of research—has been directly "imported" from developed countries to developing ones without scientific concerns or a critical view, i.e., without an agreement about its real importance in the context of the extreme levels of macroplastic pollution frequently found in rivers of emerging nations.

4 Conclusions

1. The impact of both "macroplastic entanglement" and "macroplastic as nesting-material" on freshwater fauna (and particularly birds) should be studied more intensively and compared with the marine environment. This holistic approach will allow scientists to design better solutions to reduce the ecological impact of plastic pollution, involving both

marine and freshwater ecosystems as the two sides of the same coin.

2. Scientists from developing countries concerned about freshwater plastic pollution should not try to reproduce the research that lead to the scientific enterprise of the developed nations. Rather, they need to re-think the topics of research appropriate to their local circumstances (considering economic, environmental, and social aspects), in attempting to solve the problems of their home countries. We suggest that more emphasis should be put on macroplastics in freshwater systems—particularly in large, populated, and highly polluted river basins of developing countries—whether accurate estimations of the river plastic emissions to the world's oceans are intended.
3. In spite of lacking accurate figures, the pollution of rivers with plastic (and the environmental impact) is evident. The most appropriate solution would be—of course—to produce less plastic and to recycle it better, or at least to hinder it from reaching the aquatic ecosystems by establishing stronger environmental legislation. As long as this is under way, a systematic cleanup of river ecosystems is urgently needed. The accurate assessment of the problem and technological development for plastic removal, however, are yet unsatisfying, and the transboundary position of many rivers hampers political consent to take action.

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