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4 **TITLE**

5 Massive plastic pollution in a mega-river of a developing country: sediment deposition and
6 ingestion by fish (*Prochilodus lineatus*).

7

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18

19

20 **KEY WORDS**

21 Plastic waste; South America; large river; macroplastic; secondary microplastic; fish
22 digestive tract.

23

24 **ABSTRACT**

25 The aim of this study was to determine the amount, composition and origin of plastic debris
26 in one of the world largest river, the Paraná River in Argentina (South America), focusing
27 on the impact of urban rivers, relationships among macro, meso and microplastic, socio-
28 political issues and microplastic ingestion by fish.

29 We recorded a huge concentration of macroplastic debris of domestic origin (up to 5.05
30 macroplastic items per m²) dominated largely by bags (mainly high- and low-density

31 polyethylene), foodwrapper (polypropylene and polystyrene), foam plastics (expanded
32 polystyrene) and beverage bottles (polyethylene terephthalate), particularly downstream
33 from the confluence with an urban stream. This suggests inadequate waste collection,
34 processing and final disposal in the region, which is regrettably recurrent in many cities of
35 the Global South and Argentina in particular.

36 We found an average of 4654 microplastic fragments m^{-2} in shoreline sediments of the
37 river, ranging from 131 to 12687 microplastics m^{-2} . In contrast to other studies from
38 industrialized countries from Europe and North America, secondary microplastics
39 (resulting from comminution of larger particles) were more abundant than primary ones
40 (microbeads to cosmetics or pellets to the industry). This could be explained by differences
41 in consumer habits and industrialization level between societies and economies.

42 Microplastic particles (mostly fibres) were recorded in the digestive tract of 100% of the
43 studied *Prochilodus lineatus* (commercial species).

44 Contrary to recently published statements by other researchers, our results suggest neither
45 macroplastic nor mesoplastics would serve as surrogate for microplastic items in pollution
46 surveys, suggesting the need to consider all three size categories.

47 The massive plastic pollution found in the Paraná River is caused by an inadequate waste
48 management. New actions are required to properly manage waste from its inception to its
49 final disposal.

50

51 **CAPSULE**

52 Massive plastic pollution in a mega-river from Argentina, mainly caused by inadequate
53 waste management.

54

55 **1. INTRODUCTION**

56 Plastic pollution is one of the great challenges for environmental management in our times.

57 Plastic debris is a combination of high persistence, low density, and extremely wide size

58 distribution. This causes the behavior of plastic debris to show a far wider variety than most

59 other materials, such as suspended fine sediments (Kooi et al. 2018). Plastic particles cause

60 severe damage to freshwater and marine ecosystems (Galloway et al. 2017). In the oceans

61 alone, the economic damage due to plastic pollution is estimated as high as 21 billion Euro

62 (Beaumont et al. 2019). In spite of a great scientific effort to tackle this problem worldwide

63 the state of our knowledge is yet deficient for different reasons. Firstly, despite wide

64 research efforts investigating plastic pollution in oceans, considerable less attention has
65 been paid on freshwater systems (Blettler et al. 2018). Nevertheless, this imbalance seems
66 to be reversing in the last years (e.g. Gündoğdu et al. 2018; Battulga et al. 2019; Mani et al.
67 2019; van Wijnen et al. 2019; Zhang et al. 2019).

68 Secondly, research on freshwater plastic pollution have been mainly carried out in
69 industrialized countries (the Global North; Rochman et al. 2015; Blettler et al. 2018). This
70 is not surprising due to the bias in the scientific output between the Global North and the
71 Global South (Guterl 2012). However, this disparity causes concern, as increasing
72 population levels, rapid urbanization, informal settlements, and the rise in consumption
73 levels have greatly accelerated the solid waste generation rate in the Global South, where
74 waste collection, processing and final disposal is still poor (Minghua et al. 2009; United
75 Nations Human Settlements Programme 2016).

76 Thirdly, there is a clear dominance of microplastic over macroplastic studies in freshwater
77 environments worldwide (less than 20% of the total surveys in freshwater systems have
78 been focused on macroplastics; Blettler et al. 2018). Consequently, more
79 macroplastics studies in freshwaters are urgently required since: i) studies estimating the
80 amount of plastic exported from rivers into the ocean are limited due to the scarcity of
81 field-data in rivers (Lebreton et al. 2017, Schmidt et al. 2017); ii) global studies estimating
82 the amount of plastic exported from rivers into the ocean have evidenced a significantly
83 (>100 times) greater input in terms of weight of macroplastics (compared with
84 microplastics, Schmidt et al. 2017); iii) removing macroplastics in rivers (e.g. using
85 artisanal boom barriers) is an effective/low-cost action to avoid plastics reach the ocean but,
86 on the contrary, the same action on microplastic is virtually impossible. Microplastics can
87 be categorized by their source. Primary microplastics are purposefully made to be that size

88 (e.g. microbeads used in cosmetics and personal care products, virgin resin pellets used in
89 plastic manufacturing processes), while secondary microplastics are the result of larger
90 items of plastic breaking down into smaller particles (Weinstein et al. 2016). Studies
91 indicated that wastewater treatment plants (WWTPs) play an important role in releasing
92 primary microplastics to the environment (Ou and Zeng 2018; Gündoğdu et al. 2018).

93 Fourthly, the largest rivers in the world (also called mega-rivers) are located in developing
94 countries (see Latrubesse et al. 2008). The great discharges, basin sizes and poor sanitary
95 conditions of people living in these catchments, potentially increase the amount of plastic
96 debris flowing through mega-rivers to the ocean. However, information about plastic
97 pollution in mega-rivers of developing countries is still very scarce (Pazos et al. 2017,
98 Blettler et al. 2018), even though all the plastic input conveyed by rivers is eventually
99 released into oceans (Morritt et al. 2014) or accumulated in estuaries (Vermeiren et al.
100 2016).

101 Fifthly, the ingestion of microplastics by fish, and the associated risks to human health,
102 remain major knowledge gaps (Santos Silva-Cavalcanti et al. 2017), even though the major
103 inland fisheries are located precisely in the most plastic polluted rivers (Lebreton et al.
104 2017) of the Global South (FAO 2016). The above suggests an urgent need to focus
105 monitoring efforts in the most polluted rivers, specially where inland fisheries are crucial
106 for local consumption and economies, as it is the case with the Paraná River.

107 Taking into account the rationale outlined above, the objectives of this study were to
108 determine: i) the amount, origin and composition of plastic debris deposited in sediments of
109 a mega-river (Paraná River), ii) the plastic input conveyed by an urban stream joining the
110 Paraná River; iii) quantitative relationship between macro, meso and microplastics in

111 sediments; iv) microplastic ingestion by *Prochilodus lineatus*, an iliophagous fish (that
112 feeds mud containing detritus and associated organisms).

113

114 **2. MATERIALS AND METHODS**

115 **2.1. Study area**

116 La Plata basin is one the ten largest fluvial basins of the world, draining five countries
117 (southern part of Brazil, the northern of Argentina, Bolivia, Uruguay and Paraguay),
118 accounting for 17% of the surface area of the South America and supporting 19 large cities
119 (with a population greater than 100,000 inhabitants). The Paraná River is the largest river of
120 this basin, ranking ninth among the largest rivers of the world, according to its mean annual
121 discharge to the Atlantic Ocean ($18,000 \text{ m}^3 \text{ s}^{-1}$; Latrubesse 2008). However, this river is
122 also one of the world's top-ten rivers at risk due to anthropogenic pressure (Wong et al.
123 2007).

124 The study took place near Paraná city (Argentina), located on its eastern shore of the river,
125 with a population of about 300,000 inhabitants. The collection, processing and final
126 disposal of waste of this city is still deficient resulting in strongly polluted urban streams.

127 We selected three sampling areas in the Paraná River bank sediments: upstream of the city
128 (Escondida beach), in the city (Thompson beach, a municipal public beach), and in an
129 island located in front of the city (Curupí island; Figure 1). Thompson is a recreational
130 beach influenced by the mouth of a strongly polluted urban river ("Las Viejas" stream) that
131 flows through the Paraná city. Fish were caught in the vicinity of the sampling sites. Due to
132 flow conditions, we expected that the upstream site would be the least polluted, followed by
133 Curupí island, whereas Thompson beach, is influenced by the strongly polluted "Las
134 Viejas" stream crossing the city.

135

136 >>>>>> Figure 1.

137

138 **2.2. Sampling.**

139

140 We selected 2 transects of 50 m in length and 3 m wide for the macroplastic survey (Noik
141 and Tuah 2015) in each sampling area. Transects were selected parallel to the riverbank,
142 randomly chosen, and covering more than a 20% of the shoreline section (Lippiatt et al.
143 2013). All visible macroplastic items on the surface of each transect were collected by
144 hand.

145 Plastic debris was sorted according to size and classified as macroplastic (> 2.5 cm),
146 mesoplastic (5 mm to 2.5 cm), or microplastic (≤ 5 mm). This classification is currently
147 used by the UNEP (Cheshire et al. 2009), NOAA (Lippiatt et al. 2013) and MSFD (2013).
148 We collected mesoplastic debris from triplicate samples (1 m^2) randomly located into each
149 macroplastic-transects (after macroplastic being picked up; Lippiatt et al. 2013).

150 Mesoplastics particles were carefully removed from the top 3 cm of sediments of each 1 m^2
151 quadrat (using stainless steels of 5 mm mesh size to sieved the sediments). In a similar way,
152 we took microplastics samples also per triplicate from the macroplastic-transects but using
153 smaller quadrats ($0.25 \times 0.25 \text{ m} \times 3 \text{ cm}$ depth; Klein et al. 2015). Mesoplastic particles were
154 hand-picked in the field using stainless steels (5 mm mesh size), while microplastic
155 samples were directly transferred to the laboratory for processing.

156 All sampled (macro and mesoplastics and sediment with microplastics) were transferred to
157 the laboratory for further analyses (see below).

158 *Prochilodus lineatus* (locally called “Sábalo”) is a dominant detritivorous fish species of
159 great importance for commercial and artisanal fishing (Espínola et al. 2016). For the
160 analysis of fish, we obtained 21 fresh specimens that were caught with gill nets of 14 and
161 16 cm between opposite knots at the respective sites of the study area, respecting local
162 policies. Fish were caught in the early morning hours and transported to the laboratory on
163 ice within 3 hours. For each individual, total length (cm) was measured and the body total
164 weight (g) was also determined. Afterward, fish samples were cut open using a scalpel and
165 gastrointestinal tracts were removed and immediately placed in clean glassware in order to
166 minimize the risk of laboratory contamination (Bessa et al. 2018). In addition to the
167 methods described below, we also noted the color of the eaten particles in order to identify
168 potential preferences.

169 In order to avoid contamination from microplastics, potentially present in the laboratory
170 environment, the use of cotton lab coats, gloves and mask was mandatory. Moreover,
171 glassware and working place were cleaned with solution of ethanol (96%) before starting
172 all experiments in order to conserve a sterile environment. From the beginning of the
173 operations until the observation under the microscope, the samples were covered with
174 aluminium foil.

175 The organic matter presents in the samples was digested with hydrogen peroxide (H_2O_2)
176 (30%) at 60°C (Pazos et al. 2017; Jabeen et al. 2017). According to Sujathan et al. (2017),
177 H_2O_2 is an oxidizing agent that no changes or bleach the structure of microplastic particles.
178 According to our environmental principles, all sampling campaigns were performed using
179 kayaks (zero emission and free noise pollution).

180

181 **2.3. Samples analysis and processing.**

182 Macroplastic particles were washed, counted and classified in the laboratory (item by item).
183 The classification accounted for their functional origin (e.g. food wrappers, packaging,
184 beverage bottles, shopping bags, personal care products, etc.) following the NOAA
185 (Lippiatt et al. 2013) and resin composition. The ASTM International Resin Identification
186 Coding System (RIC 2016) was used to recognise the plastic resin used in manufactured
187 macroplastics (Gasperi et al. 2014). As the later procedure was not always possible to use
188 (sometime this code is lost or not clearly visible), we used a FT-IR Spectrophotometer
189 Shimadzu IR Prestige 21™ to identify the plastic resin (Song et al. 2015).
190 According to Gündoğdu and Çevik (2017), mesoplastics were counted and classified in:
191 Styrofoam, hard plastic, fishing line, and films.
192 Microplastic separation was performed following the method proposed by Masura et al.
193 (2015). Thus, full samples were dried at 60°C per 24hs, weighed and sieved through a
194 stainless steel sieve of 350 µm mesh size using a Retsch™ sieve shaker. The remaining
195 material was transferred to a 1L beaker for wet 30% peroxide oxidation (H₂O₂), and located
196 on a hot plate set at 60°C until all organic material digested (Yonkos et al. 2014). After
197 completion, H₂O₂ was washed using distilled water through a 350 µm mesh size.
198 Afterwards, a concentrated saline NaCl solution (1.2 g cm⁻³) was added and strongly stirred
199 for about one minute (Hidalgo-Ruz et al. 2012). Afterward, the supernatant with floating
200 microplastics was extracted and washed with distilled water for further processing. This last
201 step was repeated as many times as it was needed in order to catch every floating plastic
202 particle.
203 Microplastics were separated from other materials (present in the supernatant) and
204 classified under a Boeco™ zoom stereo microscope and a Nikon™ binocular microscope
205 (10–40x). We used the criteria suggested by Norén (2007) to identify microplastics.

206 However, items of doubtful origin were analysed with a FT-IR Spectrophotometer in order
207 to confirm (or reject) their plastic composition (Frias et al. 2014; Li et al. 2016). Spectra
208 ranges were set at 4000–400 cm^{-1} , using the IRsolution Agent software. The resulting
209 spectra were directly compared with the reference library databases.

210 Microplastics were classified in Styrofoam (trademarked brand of closed-cell extruded
211 polystyrene foam), hard plastic, film, fiber and fiber-roll (very large fibers twisted),
212 according to Castañeda et al. (2014) and Gündoğdu and Çevik (2017).

213

214 **2.4. Data analyses**

215 Tables and figures were created to identify presence, abundance and type of plastic debris
216 in order to compare the sampling sites between each other. Correlations were performed
217 among the different plastic size ranges. In order to test spatial patterns of similarity in the
218 abundance and type of microplastics, a Canonical Analysis of Principal (CAP) coordinates
219 was performed. The CAP is a constrained ordination analysis that calculates unconstrained
220 principal coordinate axes followed by canonical discriminant analysis on the principal
221 coordinates to maximize the separation between predefined groups (Anderson, 2004). The
222 Bray-Curtis dissimilarity index and 999 permutations were the parameters selected in this
223 procedure. Subsequent one-way Permutational Multivariate Analyses of Variance
224 (PERMANOVA) (Anderson, 2001) was conducted to determine differences between scores
225 of the CAP Axis 1.

226 Statistical analyses were carried out using the CAP software Version 1.0 (Anderson, 2004)
227 and the MULTIV software, version 2.4.2 [Pillar, 2004], with a statistical significance level
228 was $p < 0.05$.

229

230 **3. RESULTS**

231 3.1. Macroplastics.

232 We recorded a total of 18 categories of macroplastic debris (based on the NOAA's
233 classification; Lippiatt et al. 2013); being bag, foodwrapper, Styrofoam and beverage bottle
234 the most abundant particles, representing almost the 80% of the total (Table 1).

235

236 >>>>> Table 1.

237

238 The three sampling sites have strong differences in amount (number of items) and type of
239 macroplastic debris (Figure 2a). Thus, Escondida beach (4 km upstream Paraná city)
240 showed the lower values (52 macro-items per transect; 150m²), with a heterogeneous
241 composition of plastic types (13 different categories) but dominated by fishing lines (23
242 items). The Curupí island (in front of the Paraná city), was dominated by only 2 types of
243 macroplastics: beverage bottles (81) and Styrofoam fragments (99). Finally, the Thompson
244 beach (slightly downstream to the Las Viejas outlet) showed a clear dominance of shopping
245 bags (490; many different colors and textures) and food wrappers (202.5), having the
246 highest amount of plastics: 757.5 items per transect (i.e. 5.05 macroplastic particles per m²),
247 14 times more than the Escondida beach. By far, the most abundant plastic resins were
248 HDPE, LDPE, PP and PS in the Thompson beach, EPS and PET in the Curupí island and
249 Nylon in the Escondida beach. Cellulose acetate, Polyester and PVC resins were found at
250 low densities.

251

252 >>>>> Figure 2.

253

254 3.2. Mesoplastics.

255 In contrast to macroplastics, mesoplastics had the highest abundance in the Escondida
256 beach (55.6 items m⁻²), followed by Curupí island (35.5 items m⁻²) and Thompson beach
257 (only 18.5 particles per m²; Figure 2b). The average abundance of mesoplastic was close to
258 46 items m⁻², being foam plastic (Styrofoam) the dominant category (41.1 items m⁻²) (Table
259 2).

260

261 >>>>>Table 2.

262

263 3.3. Microplastics.

264 Films and fibers were the dominant items in the microplastic samples (Table 3). An average
265 of 4654 microplastic fragments (per m²) was found in shoreline sediments of the three
266 sampling (beaches and island). An average of 12687 micro-particles m⁻² (81% of the total)
267 were recorded in the Thompson beach, but only 131 in the Curupí island (Figure 2c).
268 Microplastic film and fibber were extremely abundant in the Thompson beach.

269

270 >>>>> Table 3.

271

272 The CAP (and subsequent PERMANOVA) showed significant differences in abundance
273 and type of microplastics between the three beaches (sampling sites) (p-values= <0.003;
274 Sum of squares (Q) within groups= 2.829) (Figure 3).

275

276 >>>>> Figure 3.

277

278 Table 4 shows that the density values of the size classes (macro, meso and microplastic)
279 were not surrogate of each other (no correlations were detected). While some weak
280 tendencies could be detected (ex.: high concentration values of macro and microplastics in
281 the Thompson beach), they were not statistically significant. Particularly, the mesoplastic
282 abundance showed a completely independent tendency. For ex.: lowest values of
283 macroplastic were found in the Escondida beach, but mesoplastic showed the highest
284 concentration in the same beach. While the highest concentrations of macro- and
285 microplastics were found in the Thompson beach, the mesoplastic concentration there was
286 the lowest one.

287

288 >>>>> Table 4.

289

290 3.4. Fish ingestion.

291 All fish were contaminated with at least one microplastic. The number of items recorded in
292 the digestive tracts of adult *P. lineatus* averaged 9.9 microplastic particles, The maximum
293 value of microplastic particles recorded in an individual was 27 (Figure 4). Particle sizes
294 ranged between 0.5 to 3mm and recorded colours were blue (most of them), black, yellow,
295 red and transparent.

296

297 >>>>> Figure 4.

298

299 **4. DISCUSSION**

300 ***4.1. Massive plastic concentration: geo-political issues and societies.***

301 Macroplastic materials are the most visible form of plastic pollution. Blettler et al. (2017)
302 reported an average of 172.5 macroplastic items per transect of 150 m² (~1.15 items m²) in
303 a floodplain lake of the Paraná River, located only 18km from our sampling area. In the
304 present study, we found almost twice that amount: 340.8 macroplastics per 150 m² (~2.27
305 m²).

306 While several studies on macroplastics have been performed in water surface of rivers
307 (Gasperi et al. 2014; Faure et al. 2015; Baldwin et al. 2016; Lahens et al. 2018) and lakes
308 (Faure et al. 2015), macroplastic studies in riverine sediments are still scarce, especially for
309 beaches. Some examples include Imhof et al. (2013) in the Garda lake (Italy) and Faure et
310 al. (2015) in 6 lakes of Switzerland. However, direct comparison with the present study are
311 unfeasible since these authors considered macroplastics as the particles higher than 5mm
312 (including mesoplastic size).

313 The great amount of macroplastic debris recorded in the Thompson beach and Curupí
314 island, as well as the origin of them (household waste, Table 1), suggest a deficient waste
315 collection, processing and final disposal in the Paraná city. Waste management is one of the
316 key environmental issues concerning urban hydrosystems on a global scale, however, in the
317 Global South it still remains strongly based on uncontrolled dumping and/or littering
318 (Guerrero et al. 2013). As a result, serious environmental problems (Al-Khatib et al. 2010)
319 and increasing plastic pollution (Battulga et al. 2019) occur, particularly in freshwater
320 systems. Municipalities in low-income countries are spending lower proportion of their
321 budgets on waste management, and yet over 90% of waste in low-income countries is still
322 openly dumped (Kaza et al. 2018). In addition, increasing population levels and the rise in
323 consumption levels have greatly accelerated the solid waste generation rate in Argentina

324 (waste generation rates: 1.14 kg/capita/day; Kaza et al. 2018). The present study shows, in
325 part, this global trend.

326 Most of the macroplastics recorded in the present research were shopping bags, followed by
327 food wrappers and foam packaging (almost 80%; Table 1). The first communities to
328 embrace the anti-plastic bag norm were in the Global South, with those in the Global North
329 only doing so much more recently (Clapp and Swanston, 2009). However, an anti-plastic-
330 bag municipal ordinance was not adopted in the Paraná city before 2017.

331 Results from available microplastics studies in freshwater systems are extremely variable
332 according to the used methodology used (e.g. grab sampler, sediment core, manta net,
333 pump, etc), size range reported (including nanoplastic), reporting unit (e.g. m^2 , m^3 , l, kg),
334 environment (river, lake, reservoir, estuary, sewage, etc), and sampling compartment (water
335 surface or column, bottom or beach sediment, etc). As a result, comparisons between
336 worldwide studies are very difficult. We found an average of 5239 microplastics m^{-2} (size
337 range: 0.35-5mm) in bank sediments of the Paraná River, ranging from only 75 to a
338 maximum of 34443 microplastics m^{-2} (Table 3). Castañeda et al. (2014) found about 13832
339 m^{-2} polyethylene microbeads, retained by a 0.5 mm sieve, from industrial effluents in the
340 St. Lawrence River sediments (Canada). Klein et al. (2015) have record about 228-3763
341 microparticles kg^{-1} in shore sediments of the Rhine and Main rivers in Germany
342 (microplastic size: 0.2-5 mm). Moreover, Su et al. (2016) have reported a range of 15-1600
343 microplastics l^{-1} (>0.3 mm) in the Middle-Lower Yangtze River (China), Wang et al.
344 (2016) recorded 178-544 microplastics l^{-1} (<5 mm) in the Beijiang River sediments, and
345 Peng et al. (2017) found 410-1600 microplastics kg^{-1} (0.05-5 mm) in some rivers of
346 Shanghai, most of them fragments, spheres and fibers.

347 Blettler et al. (2017), using the same methodology as the present study, have recorded a
348 much lower average of 704 microplastics m^{-2} (size range: 0.35-5mm) in beach sediments of
349 lentic environments of the Paraná River (a floodplain lake located 18 km from the sampling
350 area of the present study). Xiong et al. (2018) reported 50-1292 microplastics m^{-2} (>0.1
351 mm) in the Qinghai Lake (China); most of them were films, fibers and foams.
352 In spite of the limitations and weaknesses of the above comparisons (i.e. different size
353 ranges, units, environments), available information suggest a significant microplastic
354 pollution present in sediments of the Paraná River.
355 The variation of microplastics abundance and type between sampling sites was statistically
356 significant (Figure 4), showing a clear differentiation per sampling beach. Thompsons
357 beach showed the highest concentration of microplastics, while Escondida revealed the
358 most heterogeneous distribution (sampling stations ranged from low to high microplastic
359 concentration).
360 Microplastic can occur either in a primary (beads) or secondary form (originating from the
361 breakdown of larger plastic items; Cole et al. 2011). The relative importance of primary
362 versus secondary sources of microplastics is still unknown. We found both of them, but the
363 secondary ones were considerably more abundant (Table 3).
364 Particular attention should be paid to synthetic clothes, which are an important source of
365 fibers via washing (Conkle et al. 2018). In our study, fiber was the only primary
366 microplastic (Cole et al. 2013) recorded. However, it should be noted that some authors
367 consider fiber as secondary (e.g.: Dris et al. 2015). Other primary microplastics such as
368 microbeads, capsules or pellets (used in cosmetics and personal care products, industrial
369 scrubbers used for abrasive blast cleaning and virgin pellets used in plastic manufacturing
370 processes, respectively) were absent. Similar lack of microbeads was observed in the

371 Yangtze River (Zhang et al. 2015) and the Three Gorges Reservoir (Zhang et al., 2017) in
372 China, the Saigon River in Vietnam (Lahens et al. 2018), and the Paraná River estuary in
373 Argentina (Pazos et al. 2018). Nevertheless, a great presence of microbeads was observed
374 in the Rhine and St. Lawrence Rivers (Mani et al. 2015 and Castañeda et al. 2014,
375 respectively) and in Laurentian Great Lakes (Eriksen et al. 2013). In some countries
376 benefiting from advanced waste treatment facilities (mainly in Europe and North of
377 America), secondary microplastics releases are even lower than primary microplastics
378 (Gouin et al. 2015). Losses of primary microplastics can occur during the production,
379 transport or recycling stages of plastics, or during the use phase of products containing
380 microplastic (e.g. microbeads originated from facial cleansers widely used in developed
381 nations; Napper et al. 2015; Gouin et al. 2015). This contrasts with secondary microplastics
382 that mostly originate from mismanaged waste during the disposal of products containing
383 plastics (Boucher and Friot 2017). The absence of microbeads in the Paraná River system
384 could be explained by these differences in consumer habits and waste management between
385 societies and countries. Herein, almost 50% of the recorded microplastics were film
386 particles (as a secondary product of advanced bag breakdown process), 33.1% fibers (used
387 in textiles) and 18.7% resulting from larger particles of plastic of uncertain origin breaking
388 down into smaller items (probably beverage bottle, foodwrapper and foams) (Table 3). In
389 contrast, other studies in rivers from developing countries have reported a dominance of
390 microplastic fibers (Zhang et al. 2015; Lahens et al. 2018), even in the Paraná River estuary
391 (Pazos et al. 2018).

392 The variable ratios between macro- or mesoplastics in our study have shown that these data
393 cannot serve as surrogates for microplastics monitoring (Table 4). This is important since

394 surveys of macroplastics debris can be easily conducted by volunteers, who have played
395 important roles in many debris monitoring programs (Ribic et al. 2012).

396

397 ***4.2. Role of urban streams in plastic dissemination.***

398 Urban rivers and streams suffer from multiple interactive stressors, especially in the Global
399 South (Wang et al. 2012; Wantzen et al. 2019). In this study, Las Viejas urban stream
400 seems to play a crucial role transporting huge amounts of waste plastics and depositing
401 them into the Thompson beach, immediately downstream to the confluence with the Paraná
402 River (Figure 1d). This sampling area showed the highest concentration of macro and
403 microplastic debris (Figure 2 and 4). Las Viejas stream flows all through the Paraná city,
404 concentrating and transporting the municipal solid waste improperly managed. According
405 to Xu et al. (2019) the development of sewer systems has not caught up with the
406 urbanization speed in developing countries, with serious consequences for urban river water
407 quality. Thus, many urban rivers become the end points of plastic pollution (McCormick et
408 al. 2014, 2016). In the same way as rains and severe floods can dramatically increase the
409 plastic levels in the sea (Gündoğdu et al. 2018), it is highly probable that the same
410 phenomenon operates in urban streams discharging to large river systems.

411 On the other side, the Curupí island showed an average of 190 macroplastics per transect
412 (against 780 in the Thompson and only 52 in the Escondida beach; Table 1). This sampling
413 site was dominated by two domestic items: beverage bottles and foam packaging fragments
414 (Styrofoam; Figure 2). We hypothesize that these plastics arrived from Las Viejas stream.
415 Floating waste is transported by the Paraná River current and dominant southern winds
416 unto the Curupí island shores. This process could be facilitated by the high buoyancy of
417 these items (EPS density: 11-32 kg m⁻³; while density of PET is 950 kg m⁻³ bottles initially

418 float due to the air trapped inside). Otherwise, shopping bags and food wrappers (most
419 abundant items in the Thompson beach) were not recorded in the island which is, probably,
420 related to their low buoyance (density of HDPE: 950 kg m^{-3} ; LDPE: $917\text{-}930 \text{ kg m}^{-3}$, PP:
421 946 kg m^{-3} ; PS: 1066 kg m^{-3}).

422 Finally, there are no urban river confluences in the Escondida beach, which was the least
423 polluted sampling area. This beach showed a completely different plastic debris
424 composition. While shopping bags, Styrofoam and beverage bottles were present, the
425 dominant item was fishing line. It suggests that the main impact is given by the beach
426 users, most of them artisanal and sports fishermen, and not by municipal waste poorly
427 treated coming from large cities upstream.

428 The most common plastic polymers recorded in this study were HDPE, LPDE, PP, PS and
429 EPS, which can be very harmful to wild fauna (Kyaw et al. 2012). Moreover, PP and PS
430 have been extensively recorded in food wrappers particles (Table 1). Finally, EPS (often
431 referred as StyrofoamTM) products (takeout containers, dispensable cups, foam trays, etc)
432 were widespread found in our study (Table 1). EPS is commonly reported as one of the top
433 items of debris recovered from shorelines and beaches worldwide (Lee et al., 2013; Ocean
434 Conservancy 2017). As a result, EPS products are now discussed for a ban in several
435 countries (UNEP 2018). In the present study, EPS was the most abundant mesoplastic
436 debris (almost 90%; Table 2). Zbyszewski et al. (2014) and Driedger (2015) reported a
437 similar proportion in mesoplastics from the Great Lakes.

438

439 ***4.3. Ingestion of plastic by fish and potential impacts***

440 Today, the ingestion of plastic has been reported in approximately 150 fish species
441 worldwide (Jabeen et al. 2017), causing internal blockages and injury to the digestive tract

442 of fish (Cannon et al. 2016; Nadal et al. 2016). We recorded microplastics in the digestive
443 tract of 100% of the sampled *P. lineatus* specimens, corroborating a similar study in the
444 Paraná River estuary (Pazos et al. 2017). The latter could be explained from the
445 detritivorous feeding strategy of this species and the high amount of microplastics recorded
446 in the study area. Thus, the occurrence frequency of microplastics in fish from Paraná River
447 seems to be higher than in other South American rivers. For example, in the Amazon
448 estuary and northern coast of Brazil microplastics were found in 13.8% of digestive tracts
449 examined (Pegado et al., 2018), 23 % and 13.4 % in the Goiana estuary (Possatto et al.
450 2011 and Ramos et al. 2012, respectively). However, we recognize that the low number of
451 specimens studied here does not allow generalizations.

452 In our study, most of the recorded microplastics in fish were fibers (90%). In agreement,
453 several studies worldwide have also reported greater number of ingested fibers compared to
454 other microplastic types (Neves et al. 2015; Bellas et al. 2016; Nadal et al. 2016; Pazos et
455 al. 2017). The reasoning behind the dominance of fibers is the diverse nature of this
456 microplastic type, which may originate from the degradation of clothing items, furniture
457 and fishing gear. Indeed, washing (through a washing machine) a single item of synthetic
458 clothing resulted in the release of about 2000 microfibers (Browne et al. 2011; Carney
459 Almroth et al. 2018). Mesoplastics ingested by fish were not recorded in this study. In fact,
460 this range size has been scarcely recorded in fish digestive tracts (Jabeen et al. 2016).

461

462 **5. CONCLUSIONS**

463 1. The recorded plastic debris concentration (macro, meso and microplastics) was several
464 times higher than the values previously reported in the Paraná River floodplain.

465 Comparisons with other studies worldwide are still difficult, since methodological

466 protocols are not yet standardized; however, they suggest massive pollution levels in this
467 mega-river of South America.

468 2. Macroplastics recorded herein have a domestic origin (shopping bags, food wrappers,
469 beverage bottles and packaging foam fragments), suggesting an inadequate waste
470 collection, processing and final disposal in the region, which is regrettably recurrent in the
471 Global South. The further research must not overlook macroplastics in this geopolitical
472 region, particularly if reliable estimates of global plastic waste entering to the ocean from
473 rivers are intended.

474 3. Secondary microplastics (originated from the breakdown of larger plastic items) were
475 more abundant than primary ones (manufactured as microbeads, capsules, pellets used in
476 industry). Microbeads (commonly found in industrialized regions) were absent in the
477 Paraná River. This finding contrasts with studies performed in freshwater environments of
478 developed countries, suggesting a difference in consumer habits and levels of
479 industrialization between societies and economies from the developed and developing
480 world.

481 4. Most of the recorded plastic debris proceed from a highly polluted urban stream, which
482 runs through the Paraná city. Urban rivers, particularly in the Global South, are vulnerable
483 to different urban processes and activities that cause pollution and degradation of the water
484 ecosystem.

485 5. We recorded microplastic particles in the digestive tract of 100% of *P. lineatus*
486 specimens, most of them were fibers. While we recognize the low number of collected fish,
487 this finding evidenced that microplastics have penetrated in the aquatic food webs and
488 ecological niches in the Paraná River, reinforcing the necessity of more studies.

489 6. Contrary to our expectations, the macroplastic or mesoplastic items would not serve as
490 surrogates for microplastic surveys (and vice versa), suggesting that all plastic debris sizes
491 should be considered in further studies.

492

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498

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753

754 CAPTIONS

755 **Figure 1.** Location of the Paraná River (study area, Entre Ríos Province, Argentina) in the
756 Global South (a). Escondida beach (b), Curupí island (c), and Thompson beach (at the
757 confluence of Las Viejas urban stream with the Paraná main channel) (d).

758

759 **Figure 2.** Bubble chart showing macro- (a), meso- (b) and microplastic (c) densities at each
760 sampling area. Where: f-w: foodwrapper, sty: Styrofoam, b-b: beverage bottle, fishing-line,
761 h-p: hard-plastic piece, fib: fibber.

762

763 **Figure 3.** Ordination plot of the Canonical Analysis of Principal coordinates (CAP)
764 showing significant differences in abundance and type of microplastics between the three
765 sampling sites (Escondida beach, Thompson beach, Curupí island).

766

767 **Figure 4.** Microplastic particles (fibers and others) found in the digestive tracts of *P.*
768 *lineatus*. Number of items (a), fibers and a piece of plastic film (b).

769

770 **Table 1.** Type (origin/use), density per transect (150 m²), standard deviation, abundance
771 (%) and resin composition of macroplastic debris (total and per sampling site). Where,
772 HDPE: high-density polyethylene; LDPE: low-density polyethylene; PP: Polypropylene;
773 PS: Polystyrene; EPS: Expanded polystyrene; PET: Polyethylene terephthalate; Nylon: dry
774 polyamide; PE: Polyethylene; PVC: Polyvinyl chloride.

775

776 **Table 2.** Type, density (m²), standard deviation, and abundance (%) of mesoplastic debris
777 per sampling site.

778

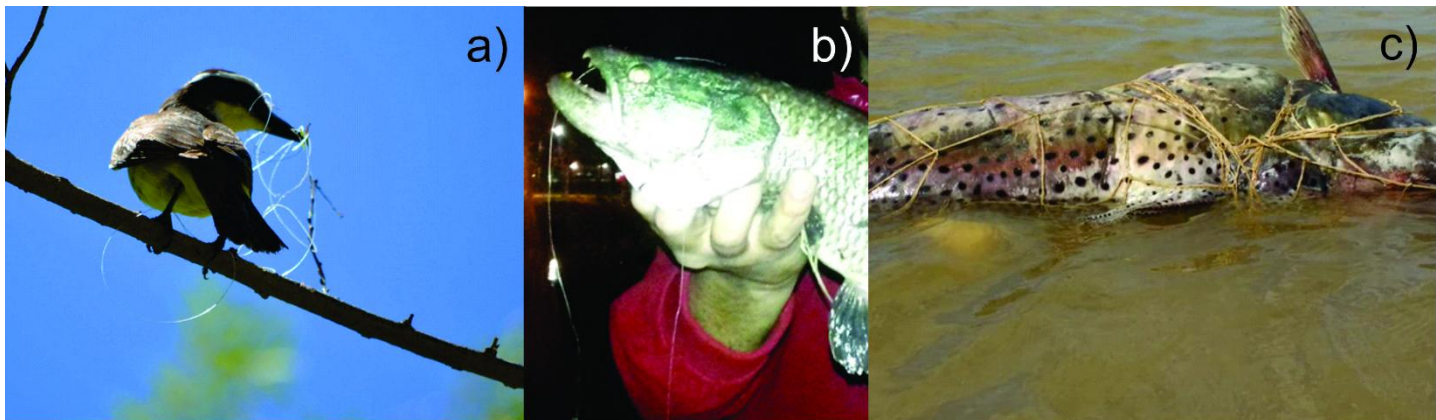
779 **Table 3.** Type, density (m²), standard deviation, and abundance (%) of microplastic debris
780 per sampling site.

781

782 **Table 4.** Correlations among the different plastic seize ranges.

783

784 **Images and figures:**



785



786

“Islands” of macroplastic debris flowing in urban rivers

Freshwater birds are using garbage as nesting material



Birds become entangled in freshwater debris (fishing line)

Abandoned fishing nets are killing freshwater fish

787

788

789

790

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

791