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When subsistence fishing meets conservation issues: Survey of a small fishery in a neotropical river with high biodiversity value

Guillaume Longin, Guy Fontenelle, Louis Bonneau de Beaufort, Chrystelle Delord, Sophie Launay, Raphaëlle Rinaldo, Gilles Lassalle, Pierre-Yves Le Bail, Jean-Marc Roussel

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Corresponding Author:	Jean-Marc Roussel, PhD INRAE Rennes, FRANCE
First Author:	Guillaume Longin
Order of Authors:	Guillaume Longin Guy Fontenelle Louis Bonneau de Beaufort Chrystelle Delord Sophie Launey Raphaëlle Rinaldo Gilles Lassalle Pierre-Yves Le Bail Jean-Marc Roussel, PhD
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Abstract:	<p>The inland fisheries sector is central for subsistence in many regions worldwide. The exploitation of fish resources is expected to increase along with the growing human population, with underlying conservation issues in regions with high biodiversity value. The small fishery of the Maroni River, French Guiana, is a hotspot of biodiversity and endemism where resource depletion is suspected. We surveyed 754 boat landings in seven villages located in the upper half of the watershed, representing > 6,300 fish during the study period (November 2013 - September 2014). Fishers used canoes with outboard engines almost exclusively (75%) and fished within 32 km of their villages. Most fish were caught in trammel nets (81%); the 20 most-landed species represented more than 87% of catches. Depending on the village, daily catches and biomass averaged 6-14 fish and 1.7-13 kg per boat landing, respectively. Seven control sites located outside of the fishing grounds were fished to identify potential differences in catch per unit effort and fish size. Per 100 m² of trammel net, mean catches ranged from 4-13 and 8-29 fish in the villages and control sites, respectively, while fish biomass ranged from 0.9-4 and 3.2-7 kg in villages and control sites, respectively. For all species combined, fish caught at control sites were bigger than those landed in villages. This difference was significant for nine of the most-landed species. Differences in fishing techniques and fish catches between villages illustrated the gradual disappearance of the ancestral subsistence fishing. Our results support indications that the fish community in the upper Maroni River is harvested intensively, address the issue of sustainability of the fishery there, and call attention to the need to conserve the river's remarkable biodiversity.</p>

1 **When subsistence fishing meets conservation issues: survey of a small fishery in a**
2 **neotropical river with high biodiversity value**

3 Longin G.^a, Fontenelle G.^b, Bonneau de Beaufort L.^c, Delord C.^b, Launey S.^b, Rinaldo R.^a,
4 Lassalle G.^b, Le Bail P.-Y.^d, Roussel J.M.^{b*}

5 a- Parc Amazonien de Guyane, 1 rue de la canne à sucre, F-97354 Rémire-Montjoly, France

6 b- INRAE, Institut Agro, UMR ESE, Ecology and Ecosystem Health, 65 rue de Saint-Brieuc, F-35000
7 Rennes, France

8 c- IRISA, UMR 6074, 65 rue de Saint-Brieuc, F-35000 Rennes, France

9 d- INRAE, UR LPGP, Fish Physiology and Genomics, campus de Beaulieu, Bâtiment 16A, F-35000
10 Rennes, France

11 **Abstract**

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34 decrease

35
36 *Corresponding author:

37 jean-marc.roussel@inrae.fr

38

39 **1. Introduction**

40 Small-scale fisheries are an important part of the fisheries sector in coastal marine areas and
41 freshwater (Allison and Ellis, 2001; FAO, 2008). They provide many human communities with
42 animal protein and income (FAO, 2008; Béné, 2009; Hallwass et al., 2011), but they remain
43 difficult to survey. They are usually based on several fish species, many fishing techniques, and
44 a variety of landing sites, which make it challenging to monitor them (Salas et al., 2007;
45 Chuenpagdee and Pauly, 2008; Castello et al., 2013). The lack of essential information, such as
46 fishing pressure and fish stocks, is a clear limitation to developing a sustainable approach to
47 small-scale fisheries (Dimitriadis et al., 2015). Usually, no data on regular landings (e.g.,
48 logbooks, samples, and statistics) exist to assess fish stocks or forecast fishing strategies, unlike
49 the large amount of data collected for larger commercial fisheries worldwide (Hilborn and
50 Walters, 1992; Gray, 2016). In addition, conventional fisheries science often fails to address
51 small fisheries because their social context is usually complex (Berkes, 2003), notably in poor
52 or developing countries where subsistence fishing may occur.

53 Subsistence fishing is defined as an activity that meets the nutritional needs of the fishers,
54 its family and eventually the community where he lives. It usually involves low-technology
55 gears, which may be part of traditional or cultural practices, and it is not primarily conducted for
56 commercial purpose (Berkes et al., 2001). The current context of globalization, however,
57 enhances new eating habits and the use of more efficient fishing gears such as trammel nets and
58 motor boats. In that case, the sale of fish surplus to obtain money in return can be more regularly
59 observed, and the line between subsistence and commercial fishing becomes blurred. For
60 instance, small inland fisheries are key sources of food for many people along large tropical
61 rivers (Mosepele, 2014; Begossi, 2010; Welcomme et al., 2010), but some communities have
62 started to shift toward the consumption of commercial food products and progressively left
63 subsistence fishing for commercial fishing. Therefore, ensuring the sustainability of these small
64 inland fisheries requires understanding the processes that occur during the transition from
65 ancestral to modern lifestyle and their consequences on fish stocks.

66 Tropical regions host many endemic species and high biodiversity (Abell et al., 2008),
67 which reinforces the need to manage the inland fisheries sustainably for conservation. On the
68 Maroni River in French Guiana, the small inland fishery faces the challenges of modernization,
69 resource decrease, and conservation issues. The watershed hosts 264 strictly freshwater fish
70 species, of which 17% are endemic (Le Bail et al., 2012). Nearly 60 of these species are
71 regularly fished, of which 20 are endemic. Despite the high biodiversity value of these fish
72 communities, the fishing pressure there has never been assessed, and no data exist on fish stocks
73 and their dynamics. Part of native people still depend on fish resources for their daily diet, and
74 several villages and communities are aware of the risk of declining resources, and the potential
75 threat to food availability in the future (Longin et al., 2021). Consequently, Parc Amazonien de
76 Guyane (the French national park of Amazonia), which manages this territory, is currently
77 unable develop suitable management policies to protect fish resources and ensure subsistence
78 fishing for people living along the Maroni River.

79 The present study aimed to define the small fishery of the upper Maroni River (UMR) by
80 bridging the information gap between fish resources and fishing activity. To do so, a
81 conventional fisheries survey (e.g., Pido et al., 1997; Rochet et al., 2008; Cerdeira et al., 2000;
82 Hallwass et al., 2011, 2013) was combined with participatory monitoring (e.g., Ticheler et al.,
83 1998, Silvano and Valbo-Jørgensen, 2008, Rochet et al., 2008; Hallwass et al., 2011, 2013) that
84 included native fishers. Our objectives were to map the fishing grounds of several villages in
85 the UMR, and analyze the abundance and biomass of fish landed, as well as their seasonal
86 variability per species. We estimated potential impacts of the fishery on fish populations by
87 assessing differences in the catch per unit effort (CPUE based on surface of trammel nets) and
88 size of catches between villages and remote, control sites located outside the fishing grounds.

89 We also explored the transition from ancestral to modern lifestyles by comparing the two major
90 indigenous communities in the UMR: the native Amerindian, who still have a subsistence
91 lifestyle, and the Bushinengue, descendants of African slaves who escaped and established
92 independent communities, and who recently began to adopt a modern lifestyle (Delpech, 1993).

93 **2. Methods**

94 *2.1. Study area*

95 The study was performed in the UMR, a river 610 km long that flows between Suriname and
96 French Guiana (Fig. 1). Approximately 5,500 people live in Maripasoula City, the main town
97 in the region, including natives from several communities and Europeans. The commune of
98 Maripasoula City has a regional airport, and food stores are supplied by plane from Cayenne,
99 the capital of French Guiana. Daily fishing activity is low in Maripasoula City, and fish landings
100 are difficult to monitor due to the scattered distribution of landing locations. Conversely, daily
101 fishing activities occur in 21 small villages located along the UMR. Two communities live in
102 the area: Bushinengue (Aluku ethnic group) and Amerindians (Wayana and Teko ethnic
103 groups), who live downstream and upstream of Maripasoula City, respectively. Bushinengue
104 fishers have access to the zone of *Abattis Cottica* (Fig. 1), which is known to be a productive,
105 fish-rich area (Le Bail, personal communication). After reaching agreement with the traditional
106 chiefs, we selected seven villages to represent these ethnic groups and the hydromorphological
107 characteristics of the UMR watershed (Fig. 1). The landings of 134 fishers (101 Amerindians,
108 33 Bushinengue, i.e., 55% of the fisher population) were surveyed from November 2013 to
109 September 2014 (Supplementary Table S1).

110 *2.2. Data collection*

111 The survey focused on fishing trips that lasted a maximum of 24 h (hereafter, “one-day fishing
112 trips”). We did not consider other techniques, such as traditional poisoning using a substance
113 derived from lianas or multi-day fishing expeditions, which occur on an occasional basis only
114 (Longin et al., 2021). The survey included four 15-day sampling periods: in November, to
115 represent the end of the long dry season; in February, to represent the end of the short wet
116 season; in May-June, for the middle of the wet season; and at the end of August, for the
117 beginning of the long dry season. To describe all fishing activity adequately, we hired one fisher
118 in each village to act as his village’s advisor. The advisor’s role was to collect information on
119 daily catches during the four periods of the survey. Advisors were trained for 1-3 days to
120 become comfortable with following the protocol.

121 For each boat landing, the power of the engine was noted, and the fisher was asked to locate
122 his fishing ground on a grid map (5 km × 5 km squares) with toponyms. The type and number
123 of fishing gear in the boat were noted: nets (gillnet or trammel), active lines (hand-held line,
124 wooden cane, rod and reel), sight fishing (trident, bow, spearfishing gun, cast-net), or passive
125 gear (baited traps, longlines). Length, height, and mesh size were noted for nets, and the actual
126 fishing period (day only, night only, or 24 h) was noted for each type of fishing gear. The
127 advisor then detailed the daily catches. Each fish was taxonomically identified to the species
128 level using a practical illustrated booklet with the 61 largest species living in the Maroni River,
129 based on information from Planquette et al. (1996), Keith et al. (2000), Le Bail et al. (2000),
130 and Le Bail et al. (2012). Correspondence between scientific names and the Aluku, Wayana
131 and Teko common names was based on Grenand et al. (2015). Then, fish total length (nearest
132 cm, from fish nose to end of caudal fin) and weight (nearest dg) were measured using a
133 measuring tape and spring balance, respectively.

134 Seven control sites located on major tributaries of the UMR (i.e., Litani, Marouini, Tampok,
135 and Waki) were surveyed from August 2014 to March 2016 to estimate impacts of the fishery
136 on fish populations. A minimum of two days of travel by boat was required to access each
137 control site from the nearest village, including exiting the water to pass rapids. Since there was

138 no other village in the vicinity, we assumed that fishing pressure was very low compared to
139 sites around villages. The control sites (Fig. 1) were: Apsik Icholi and Eléuélétepe (64 and 96
140 km upstream of Pidima village, respectively), Langa Soula and Wayo Gaan Soula (90 and 126
141 km upstream of Antecume-Pata village, respectively), Saut Tampok and Saut Pierkourou (33
142 and 130 km upstream of Kayodé village, respectively) and Saut l'Inspecteur (74 km upstream
143 of Kayodé). Four to five consecutive nights of sampling were performed at each site, where
144 nearly 1 km of river was prospected. The fish community was fished using trammel nets, which
145 were set in the evening and checked in the morning. Nets (1.5-2.0 m high, length >30m, 6-22
146 cm inner-outer panels mesh size) were chosen to match with characteristics of prevalent
147 trammel nets used by fishers in villages, for subsequent comparisons. Nets were positioned in
148 deep or in shallow zones, with very low flow or close to turbulent areas, parallel or
149 perpendicular to the bankside to cover the range of aquatic habitats available. The sampling
150 effort, expressed as the cumulative length of trammel nets set at night, was 860 m, 1,120 m,
151 1,470 m and 1,690 m respectively on Waki, Litani, Tampok and Marouini. Each fish was
152 taxonomically identified to the species level, then measured (nearest mm) and weighed (nearest
153 g).

154 2.3. Data analysis

155 Only eight boat landings corresponded to 24h fishing trips; the corresponding data were not
156 considered in subsequent analysis. Chi-squared tests were performed to identify significant
157 differences in numbers of one-day fishing trips between seasons and between communities.
158 Data were analyzed to identify the 20 most abundant fish species landed in the fishery.
159 Confusion was suspected between *Myloplus rubripinnis* and *M. ternetzi* at landing, so the two
160 species were considered as a single group (*M. rubripinnis/ternetzi*) for the rest of the analysis.
161 Based on fishing grounds reported by fishers on the grid map, catches located within a 10 km
162 radius of each other were then combined to perform maps of catches. For each species, length-
163 weight curves were plotted; erroneous records, i.e., individuals showing obvious mismatch
164 between length and weight data, were discarded (1% of data). Moreover, 8% of the fish were
165 gutted before landing, and we used the length/weight curves to estimate total weight of the fish.
166 Data from trammel nets of similar size (6-22 cm inner-outer panels mesh size, 1.5-2.0 m high,
167 length >30m) that were set at night were used to compare the catches of villages and control
168 sites. The number of catches was converted into CPUE (i.e., number or biomass of fish caught
169 per 100 m² of trammel net per night) for all species pooled. Although the advisors in each
170 village were trained to collect data, fish body-length data were marginally biased since the
171 caudal fin was sometimes excluded. Thus, fish weight data was preferred for subsequent
172 analyses. For all sites combined, fish body-weight distributions by species were divided into
173 three equal thirds (small, medium, and large fish), and the percentage of individuals in each of
174 the three categories was calculated for each species. Data were then aggregated (all species
175 combined) to assess differences in fish weight between villages and control sites. Differences
176 in fish body-weight between village and control sites were also compared by species when
177 catches of a species reached at least 100 fish in village and 100 fish in control site (sites
178 combined) and were distributed equally among seasons. Non-parametric Wilcoxon rank-sum
179 tests were performed to identify significant differences in species body-weight between village
180 and control sites.

181 3. Results

182 3.1. Fishing grounds

183 A total of 647 Amerindian and 107 Bushinengue boat landings were surveyed (Supplementary
184 Table S1). On average, Amerindians traveled a maximum distance of 16.5 km (ca. 45 min
185 depending on the flow and outboard engine power) vs. 32.5 km for Bushinengues (90 min).
186 Bushinengue and Amerindian fishing grounds did not overlap (Fig. 1). Fishing grounds of Loca

187 and Papaïchton were completely intertwined and included the zone of *Abattis Cottica*.
188 Conversely, Amerindian fishers preferred fishing grounds within 5-10 km of their villages.
189 Some Amerindian fishing grounds overlapped, except for fishers from Kayodé, who fished only
190 the Waki and Tampok Rivers (Fig. 1).

191 3.2. Fishing techniques

192 Regardless of the community, 75% of one-day fishing trips were performed using canoes with
193 outboard engines, most of which were 10-25 horsepower, although a few were 40-60
194 horsepower (Supplementary Fig. S2). The Bushinengues rarely used paddling (5% on average),
195 which the Amerindians used slightly more often (17% on average) to reach fishing grounds
196 near their village, especially in Pidima, Antecume-Pata, and Twenké. Fishers favored the use
197 of nets (81%) and passive gears (10%), active lines and sight fishing being less observed
198 (Supplementary Fig. S2). Passive gears were more frequently used in Kayodé (28% of the
199 fishing technics reported), while sight fishing was mostly observed in Twenké (17% of the
200 fishing technics). The trammel net was the most popular fishing gear; both the Bushinengue
201 and Amerindian communities used 30-50 m long trammel nets of 1.5-2 m high and 6-22 cm
202 (inner-outer panels) mesh size.

203 The average number of one-day fishing trips per fisher was similar for Amerindians and
204 Bushinengues (Supplementary Fig. S3), but the frequency varied greatly among the fishers:
205 some fished almost every day (up to 6 days per week), while others fished less than once per
206 week. The number of one-day fishing trips did not differ among seasons (Chi-squared test,
207 $p=0.83$, Supplementary Fig. S3). Amerindians tended to fish equally at night (55%) or during
208 the daytime (45%), while the Bushinengues preferred to fish at night (72%) (Supplementary
209 Fig. S3). Night fishing trips lasted ca. 12 h, which generally corresponds to the duration of night
210 at the UMR's latitude; fishers usually set trammel nets at dusk and picked them up at dawn.

211 3.3. Fish catches

212 The villages landed 63 species throughout the study period, representing 6,366 individual fish.
213 The 20 most-landed species represented 87% of individual fish landed (Fig. 2, and see Online
214 Supplementary Appendix B for a brief description of each species), of which *Pseudancistrus*
215 *barbatus* alone represented more than 12% of all catches (in number). Overall, 59% of all
216 catches came from three fish families: Serrasalminae (25% - *Myloplus rubripinnis/ternetzi*,
217 *Myloplus rhomboidalis*, *Myloplus planquettei*, *Tometes lebaili*, *Serrasalmus rhombeus*,
218 *Acnodon oligacanthus*), Doradidae (19% - *Platydoras costatus*, *Doras micropoeus*), and
219 Loricariidae (16% - *P. barbatus*, *Hemiancistrus medians*, *Hypostomus gymnorhynchus*). The
220 large fish *Hoplias aimara* represented 33% of biomass landed (but only 4% of numbers), while
221 all species of Serrasalminae, Doradidae, and Loricariidae represented 24%, 8% and 4% of the
222 biomass landed, respectively.

223 For all species combined, nets caught 81% of the fish. However, some species were caught
224 mainly with other techniques, such as *Hemisorubim platyrhynchos* (68% by longline), *M.*
225 *planquettei* (76% by rod and reel, and 11% by spearfishing gun), *H. aimara* (41% by baited
226 traps), *A. oligacanthus* and *H. gymnorhynchus* (19% and 15%, respectively, by cast-net), and
227 *T. lebaili* (25% by spearfishing gun). Among the 20 most-landed species, 7 were caught more
228 during the dry season, 9 during the wet season, and 4 species were caught evenly in all seasons
229 (Fig. 3).

230 3.4. Differences in catches between villages and communities

231 Amerindians landed 77% of all catches during the survey (Fig. 4), using mostly nets (78% of
232 catches, of which 96% were with trammel nets), passive gears (11%, essentially longlines)
233 active lines (6%), and sight fishing (5%). Bushinengues caught fish using mostly nets (90%, of
234 which 93% were with trammel nets), passive gears (7%, essentially traps) and active lines (3%),

235 and but never sight fishing. For all fishing techniques combined, the mean number of catches
236 per boat landing ranged from 6-9 fish in Amerindian villages vs. 13-14 fish in Bushinengue
237 villages (Supplementary Table S4). During the entire survey, 2,929 kg of fish was landed in
238 total (1,943 kg, i.e. 3.0 kg per boat landing by Amerindian, and 986 kg, i.e. 9.2 kg per boat
239 landing by Bushinengue) (Fig.4). Fishers from the Bushinengue village of Papaïchton landed
240 the largest fish biomass per one-day fishing trip (13 kg), while other villages landed a mean of
241 1.7-4.0 kg (Supplementary Table S4). Amerindians used mainly nets (47%), active lines (13%),
242 longlines (35%), and sight fishing (5%) to catch the biomass they landed, while Bushinengues
243 used mainly nets (56%), traps (39%), and active lines (5%) to catch the biomass they landed.

244 *H. aimara* represented 24% and 50% of the fish biomass landed by Amerindians and
245 Bushinengues, respectively, and Bushinengues often caught them with baited traps (54%). Both
246 communities successfully used active lines to capture other large fish species (e.g. *T. lebaili*,
247 *M. planquettei*, *M. rhomboidalis*, *S. rhombeus*, *B. falcatus*) (33% and 8% of the biomass landed
248 by Amerindians and Bushinengues, respectively). Amerindians specifically targeted *H.*
249 *platyrhynchus* using longlines and *H. gymnorhynchus* using cast-nets. Amerindians used sight-
250 fishing techniques to catch 25% of the biomass of *A. oligacanthus* and *T. lebaili*.

251 3.5. CPUE and fish body-weight

252 The mean area of trammel nets set at night ranged from 72 to 171 m² in Amerindian villages
253 (for Pidima and Kayodé, respectively) but reached 338 and 385 m² in the Bushinengue villages
254 of Papaïchton and Loca, respectively (Supplementary Fig. S3 and Table S5). However, the
255 lowest CPUEs (4-7 fish per 100 m² of trammel net) were recorded at Loca, Papaïchton, and
256 Kayodé, while a mean of 8-13 fish per 100 m² of trammel net were caught in other Amerindian
257 villages (Fig. 5A, Supplementary Table S5). In comparison, the CPUE at control sites ranged
258 from 8-29 fish per 100 m² of trammel net (Fig. 5A, Supplementary Table S5). For biomass, the
259 lowest yield was recorded at Loca and the highest at Papaïchton (0.9 and 4.0 kg of fish per 100
260 m² of trammel net, respectively), while the yields for Amerindian villages showed intermediate
261 values (1.5-3.1 kg). Yields ranged from 3.2-7.0 kg per 100 m² of trammel net at the control sites
262 (Fig. 5B, Supplementary Table S5).

263 For all fish species combined, fish caught by trammel nets at control sites tended to be larger
264 than fish landed in villages (Fig. 5C) except for Papaïchton and Kayodé. Thirteen species were
265 caught in sufficient numbers to compare fish CPUE and body-weight between villages and
266 control sites (Fig. 6). No significant difference (Wilcoxon test, $p > 0.05$) was found for five
267 species (*Ageneiosus enermis*, *Doras micropoeus*, *H. gymnorhynchus*, *Leporinus friderici*, *S.*
268 *rhombeus*); other eight species were significantly lighter ($p < 0.05$, Wilcoxon test) around
269 villages than at control sites (Fig. 6). Mean body mass was particularly lower around villages
270 for *Brycon falcatus* (-146 g, i.e. 32% lower), *Cynodon meionactis* (-41 g, 24% lower), *M.*
271 *rhomboidalis* (-400 g, 64% lower), *P. costatus* (-179 g, 47% lower), *P. barbatus* (-28 g, 26%
272 lower), and *Semaprochilodus varii* (-373 g, 56% lower). Weight differences were also
273 significant but less pronounced for *M. rubripinnis/ternetzi* and *H. aimara* (Fig. 6).

274 4. Discussion

275 Fish species richness in the tropical freshwater of Southeast Asia, Africa, and South America
276 is among the highest worldwide (Abell et al., 2008), which creates regional hotspots with high
277 biodiversity value and conservation issues. Studies have shown causal correlations between
278 biodiversity and ecosystem services (Tittensor et al., 2014), and conservation plans commonly
279 focus on both issues. Among important ecosystem services, inland fisheries provide low-cost
280 protein in areas where alternative food sources and employment are infrequent. Poor or
281 developing nations generally rely the most on these inland fisheries, among which the
282 importance of high-yield river fisheries has been demonstrated (McIntyre et al., 2016). Such
283 small fisheries are challenging to study, however, since they involve many fishers, fishing

284 techniques, landing sites and fish species (Salas et al., 2007; Chuenpagdee and Pauly, 2008;
285 Castello et al., 2013). In addition to ongoing environmental threats (e.g., habitat loss, pollution,
286 climate change), intensive harvesting of the most biodiverse rivers is a major concern for the
287 conservation and sustainability of these fisheries. Usually, no data on regular landings (e.g.,
288 logbooks) exist, as they do for commercial fisheries worldwide, and in the best cases, coarse
289 description of fisheries precludes rigorous assessment of effects of fishing on natural resources
290 (De Graaf et al., 2015).

291 The upper Maroni River (UMR) is a good example of a small continental fishery that
292 provides subsistence fishing in a context of high biodiversity, including conservation issues and
293 suspected resource depletion. Traditional fishing techniques are documented for the UMR
294 fishery (Hurault, 1985; Martin, 2014), but information on the fishery remains mostly in
295 narrative form and geographically limited (Moretti and Grenand, 1982; Chapuis, 1998, Pagezy
296 and Jégu, 2002, 2004; Richard-Hansen, 2002; Martin, 2014). Therefore, our detailed
297 description of the fishery of the Bushinengue and Amerindian communities could serve as a
298 baseline for future monitoring in the following decades. By combining a conventional survey
299 and participatory monitoring of native fishers, we assessed potential impacts on fish stocks by
300 comparing yield inside and outside the boundaries of the UMR fishery. For all species
301 combined, fish abundance per unit effort was lowest in villages in which large linear nets were
302 set up, especially Loca, Papaïchton, and Kayodé. Similarly, fish biomass per unit effort was
303 lower around villages than at control sites.

304 This apparent decrease in yield in the fishing grounds could indicate intensive harvest, but
305 the causal correlation between fishing pressure and fish abundance is not elucidated here since
306 we did not consider other environmental pressures (e.g., poor water quality, habitat
307 degradation), which could have decreased fish abundance around villages (Longin et al., 2021).
308 Moreover, the dominant species in catches may differ among fishing grounds based on their
309 habitat preferences, behavior, and the season. For instance, *Prochilodus rubrotaeniatus* uses to
310 move to feeding grounds downstream (Agostinho et al., 2007), and *H. medians* remains within
311 fast-flowing habitats (Le Bail et al., 2000) that are more frequent downstream of Loca and
312 Papaïchton in the *Abattis Cottica* (Fig. 1). *D. carinatus*, *L. friderici*, and *M. rubripinnis*
313 preferred lentic environments (authors' personal observation; Boujard et al., 1991; Planquette
314 et al., 1996), which are more common around Elahé and Kayodé. Indeed, caution is necessary
315 when analyzing aggregated yield data since they are difficult to understand in multispecies
316 fisheries (Lorenzen et al., 2006). In our case, catch per unit effort data by species was not
317 possible since many zero values (i.e., each species was caught in a small number of nets only)
318 in the data hampered analysis of differences between villages and control sites.

319 Analyzing differences in fish body-weight revealed an additional sign of intensive harvest
320 in the UMR fishery. Several studies support that prolonged periods of exploitation are
321 associated with both a decline in fish catches and fish size (Haedrich and Barnes, 1997; Froese,
322 2004, Hutchings, 2005). Theoretical and empirical studies also illustrate how life history traits
323 can be reshaped in harvested fish populations, notably toward slower somatic growth, smaller
324 body size and earlier maturation of individuals (Bouffet-Halle et al., 2021). All species
325 combined, we found a decrease in fish weight classes, especially around the Amerindian
326 villages of Pidima, Antecume-Pata, Twenké, and Elahé (Fig. 5). This general trend was
327 confirmed by the analysis of spatial differences in body-weight by species. Differences were
328 particularly obvious for the large and highly targeted *M. rhomboidalis*; fishers rarely landed
329 large individuals (>0.5 kg), while large individuals represented half of the captures of this
330 species outside the fishery grounds. Individuals of another highly targeted but small species, *P.*
331 *barbatus*, were 25% lighter around villages than outside the fishery grounds. Similar patterns
332 were observed for *B. falcatus* and *P. costatus*, which also suggests that these species are
333 harvested intensively. Converging patterns of body-size declines were reported for other

334 neotropical freshwater fish species, including *Prochilodus nigricans* (Bonilla-Castilo et al.,
335 2018), *Arapaima sp.* (Castello et al., 2011b), and several species of Loricariidae, Pimelodidae,
336 Scianidae and Serrasalminidae (Castello et al., 2011a). In the Maroni River, *H. aimara* was the
337 largest fish species landed. It was smaller on fishing grounds too, even if the difference with
338 control sites was not as stronger as anticipated for this popular species. The influence of a strong
339 exploitation on *H. aimara* body weight could have been masked, however, by the presence of
340 larger individuals in large downstream habitats, which are more suitable for this predatory
341 species.

342 The case of *S. varii* seems different: small fish were caught almost only inside the fishery
343 grounds, suggesting a different age-class distribution across the survey areas. For instance, a
344 closely related species that lives in the Amazon watershed, *S. insignis*, is a migratory species
345 that spawns in floodplains (Araujo-Lima and Ruffino, 2003; Goulding et al., 2018). For other
346 species such as *A. inermis* and *L. frederici*, however, body weight did not differ between
347 villages and control sites. They were caught mainly during the rainy season, when they reach
348 flooded forests for feeding (Agostinho et al., 2007), and it is possible that long-distance
349 movements of individuals between village and control sites decreased differences in body
350 weight. Moreover, *H. gymnorhynchus* is a small species (<20 cm long) with an elongated shape
351 that is difficult to capture with nets so results for it should be considered with caution. Finally,
352 fishers do not target *S. rhombeus*, an aggressive piranha that lives in deep habitats, because it
353 is dangerous and causes serious damage to nets. Therefore, fishing pressure on it would be too
354 low inside the fishery grounds to cause differences in body weight.

355 For several reasons, the exploitation rate in small-scale fisheries is expected to increase.
356 Poor communities depend more on freshwater fisheries than on marine or aquaculture sources
357 (McIntyre et al., 2016), and the growing population generally increases pressure on natural
358 resources. Moreover, there is a general trend for more efficient techniques, and motor boats and
359 nets are replacing traditional techniques (Isaac et al., 2004; Castello et al., 2011a; Hallwass et
360 al., 2011). During our investigations on the UMR, we observed traditional gear in fishers'
361 homes, such as bows and arrows, spears, wooden traps, and canes, but they rarely used them.
362 Comparing the Amerindian (Wayana and Teko) and Bushinengue (Aluku) communities in the
363 UMR illustrates this rapid transition from ancestral to modern lifestyles in French Guiana.
364 Bushinengue began adopting a modern lifestyle before Amerindian did. They rarely used
365 paddling and preferred motor boats to reach distant fishing grounds during one-day fishing
366 trips. They usually used trammel nets and caught more fish per fishing trip, but captured the
367 fewest fish per unit area of trammel net. Despite the intense fishing pressure in this community,
368 fish are no longer a main source of protein in the Bushinengue diet (Longin et al., 2021).
369 Bushinengue live in large villages of more than 1,000 inhabitants (Loca has ca. 1200 and
370 Papaïchton 2900), and fishers represented less than 2% of the population (Supplementary Table
371 S1). The annual biomass of landed fish extrapolated from our data is ca. 14 t, i.e., 10 g per
372 person per day. This low intake of animal protein from the river indicates that the Bushinengue
373 diet has mostly shifted toward imported and/or processed food, and that subsistence fishing has
374 mostly disappeared in their community. Conversely, Amerindians live in smaller villages (35-
375 180 inhabitants) in which fishers represent nearly 30% of the population, which indicates that
376 each family still eats fish from the fishery. The same extrapolation results in an annual biomass
377 of landed fish of 27 t, i.e., 115 g per person per day. Protein intake from the river remains
378 substantial, but has obviously decreased since the early 1960s, when Hurault (1965) reported
379 that the Amerindian Wayana ate 200-560 g of fish per person per day, depending on the season.
380 Nevertheless, many native people in the UMR region still depend on fish resources from the
381 river for their daily diet, and they are increasingly concerned about the risk of overexploitation
382 and resource depletion (Longin et al., 2021).

383 **5. Conclusion**

384 Our investigation confirms that a high fishing pressure on fish populations in the UMR region
385 is a plausible scenario. Most importantly, we found that yields were consistently low within the
386 fishery grounds, and that some highly targeted species showed typical signs of a prolonged
387 period of exploitation, especially a decrease in body weight. Our study focused only on one-
388 day fishing pressure, but multi-day fishing trips are increasingly popular and are supported by
389 powerful motor boats, generators, and freezers that allow fishers to go farther on the river and
390 to store fish. Based on the continued increase in the human population (+6.2% per year from
391 2011-2016, INSEE, 2019) and the shift from traditional fishing technics to modern and more
392 efficient ones, indications that the fish community is harvested intensively should alert local
393 authorities and managers. This seems to hold true even in the current context of the
394 modernization of eating habits and progressive loss of subsistence fishing. Our results call
395 attention to the need to conserve this unique biodiversity of the UMR, and they address the
396 sustainability of the fishery there. The participatory approach that we used in this study has
397 already informed fishers about the intensive pressure on fish resources from their river, the
398 threat to their unique ecological heritage, and the need to set up management rules toward a
399 sustainable fishery in the Maroni River.

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606
607

608 **Figure 1.** Fishery survey of the upper Maroni River (French Guiana). Control sites and fishing
609 grounds that correspond to the maximum distance per one-day fishing trips around each village
610 are shown.

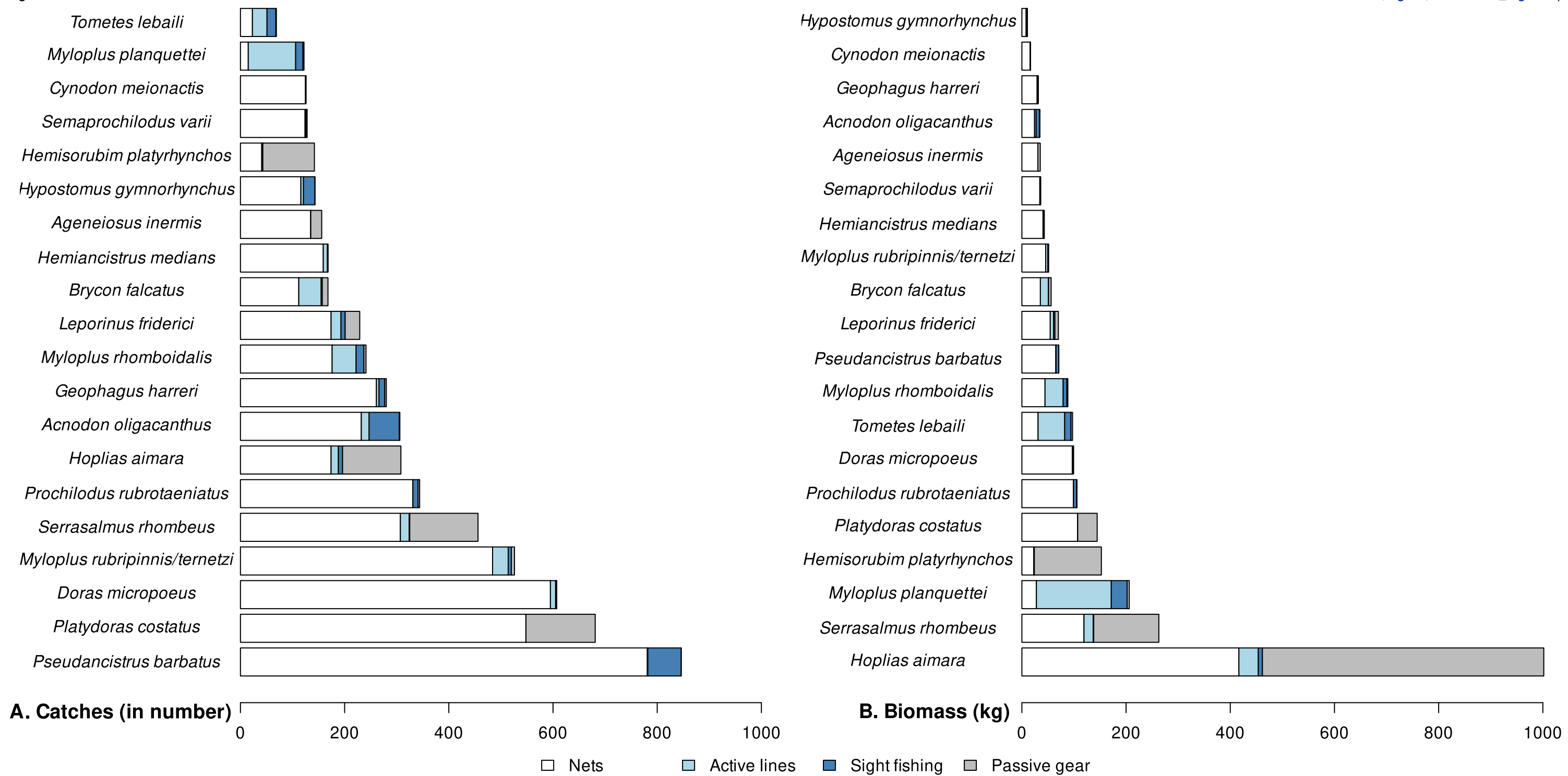
611
612 **Figure 2.** (A) Number of catches and (B) biomass landed for the 20 most-landed species by
613 main type of fishing gear.

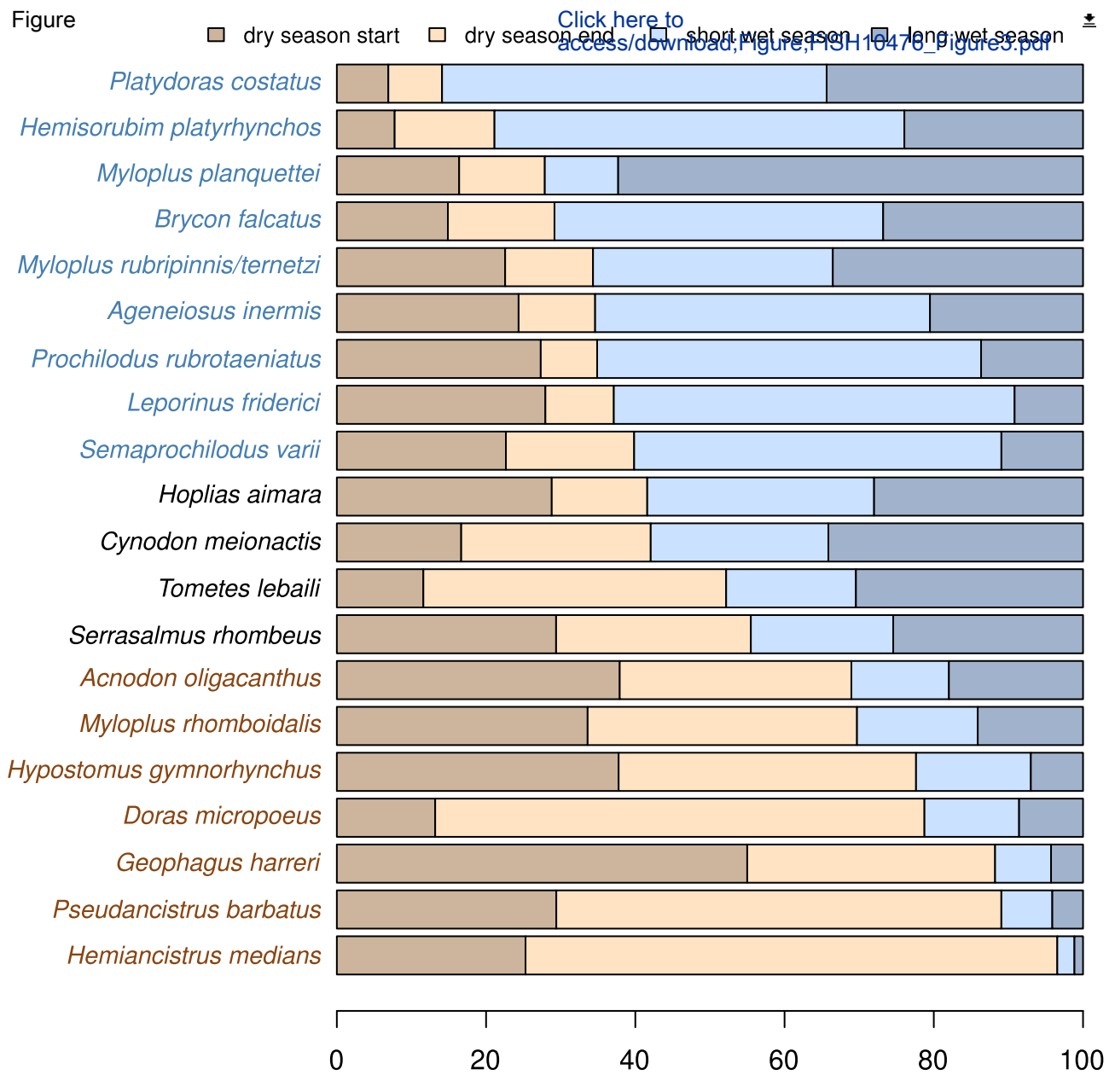
614
615 **Figure 3.** Percentage of catches for the 20 most-landed species by season. Font colors indicate
616 species caught mainly in the dry season (tan), wet season (blue), or throughout the year round
617 (black).

618
619 **Figure 4.** (A) Number of catches and (B) biomass landed by Bushinengue and Amerindian
620 fishers by main type of fishing gear.

621
622 **Figure 5.** Spatial distribution of all fish species caught with trammel nets in the village and
623 control sites: (A) number of fish per 100 m² of net, (B) fish biomass (in kg) per 100 m² of net,
624 and (C) fish body-mass classes. Circle sizes represent the number of captures used for
625 calculations at each site.

626
627 **Figure 6.** Individual body-weight of the 13 most-landed fish species at control sites (white)
628 and village fishing grounds (gray). Error bars represent 1.5 times the interquartile range. Stars
629 denote significant differences between village and control sites (Wilcoxon test; * $p < 0.05$; **
630 $p < 0.01$).

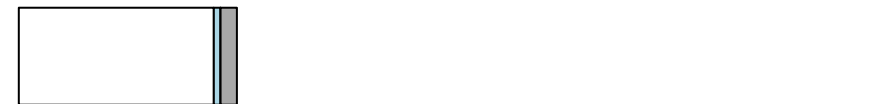




Figure

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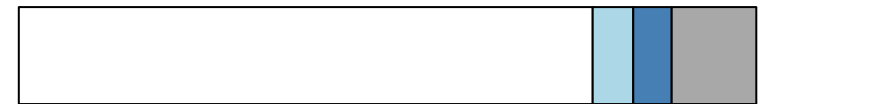
Bushinengue



Bushinengue



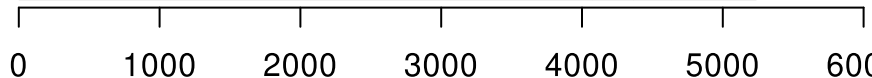
Amerindian



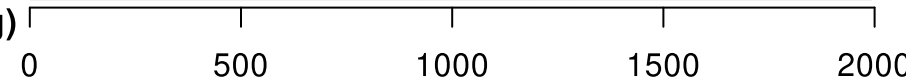
Amerindian



**Catches
(number)**



Biomass (Kg)

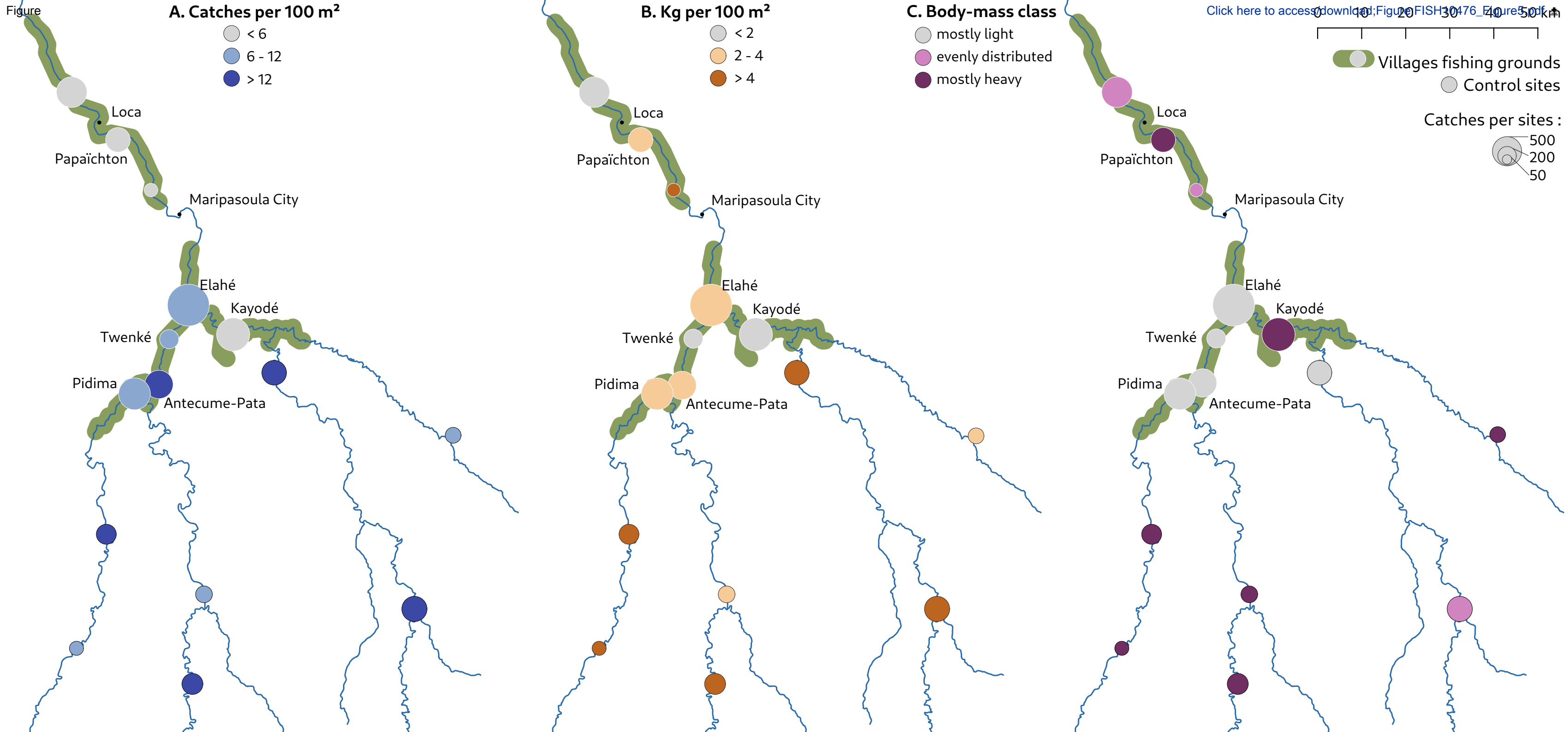


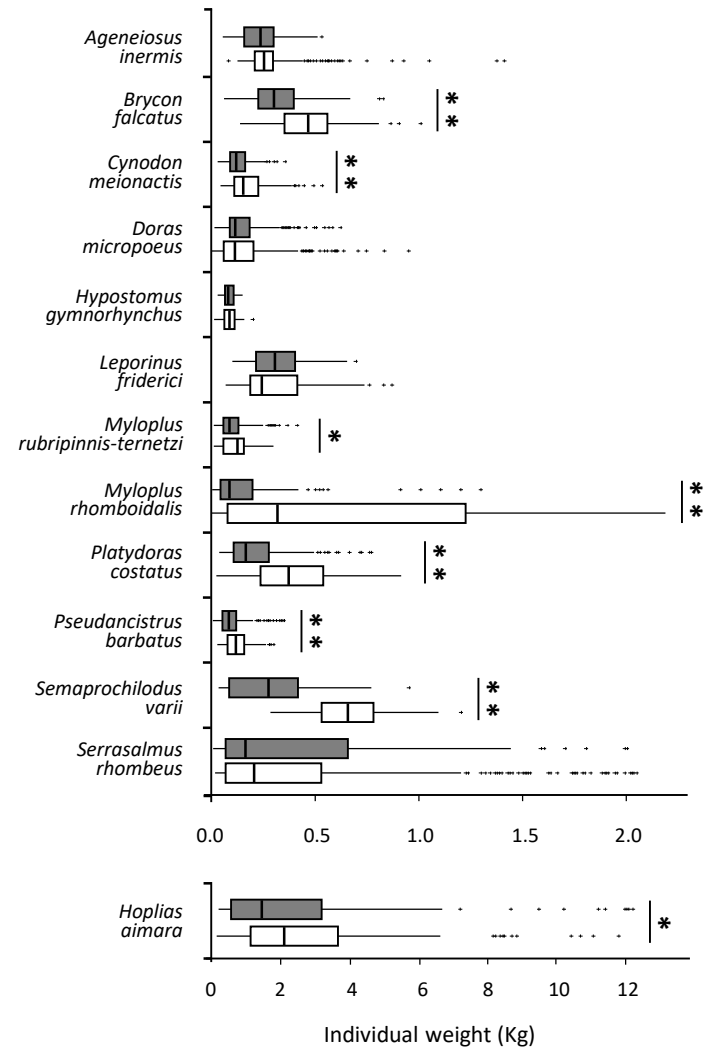
 Nets

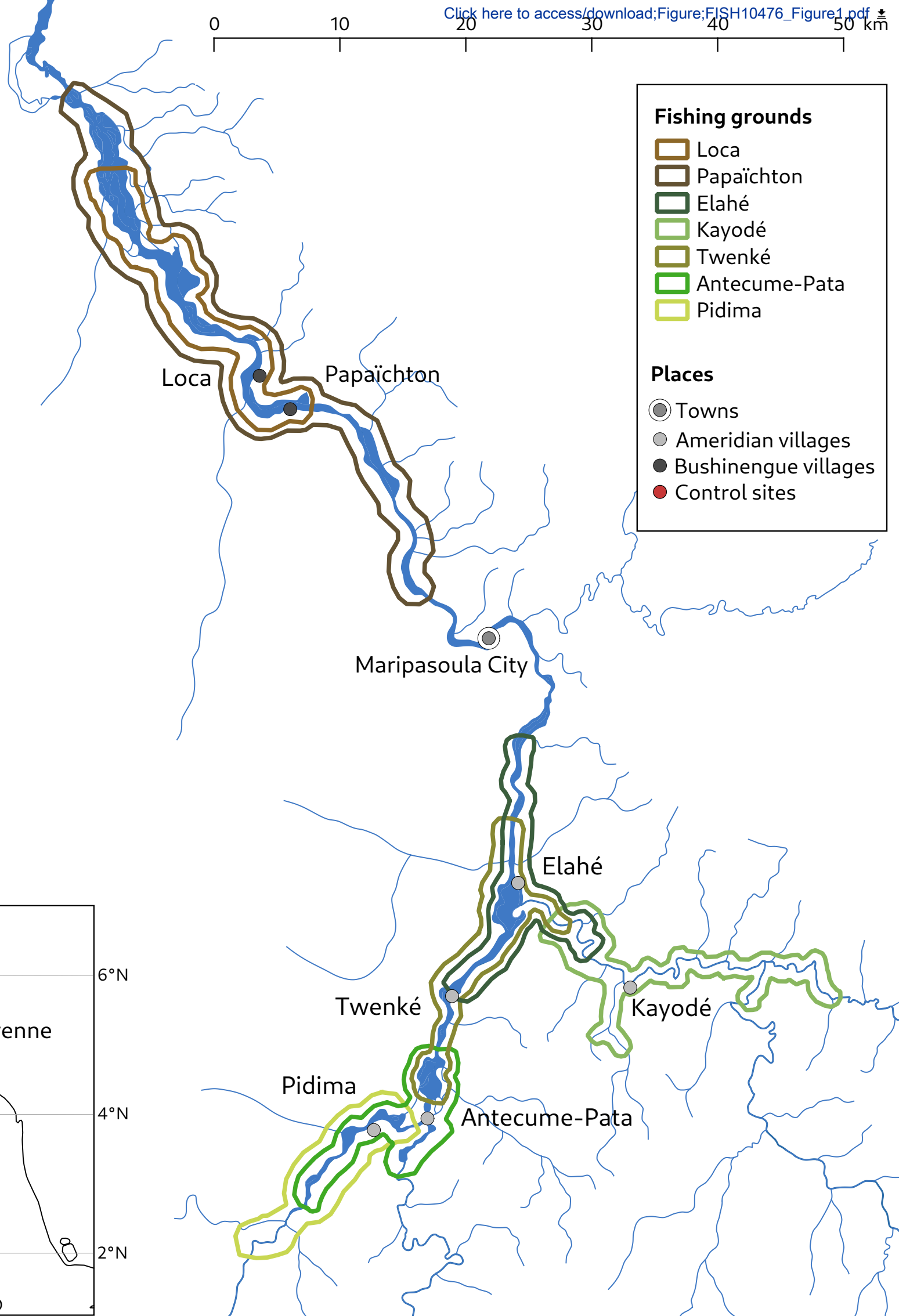
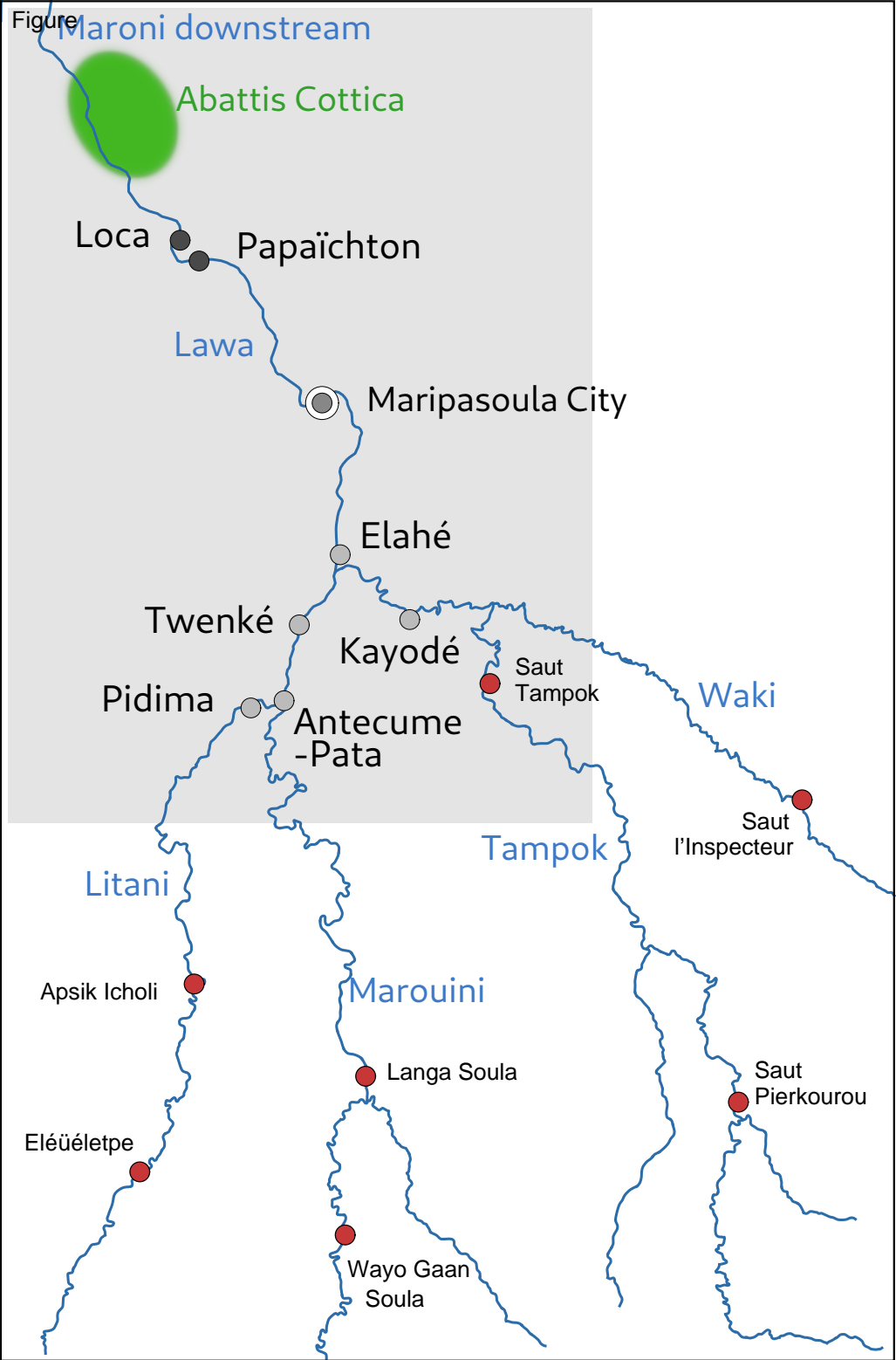
 Active lines

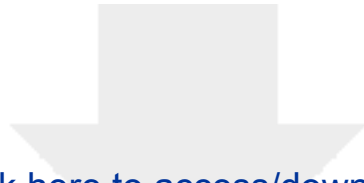
 Sight fishing

 Passive gear









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Jean-Marc Roussel, Guy Fontenelle and Pierre-Yves Le Bail conceived the idea, designed the project, developed the methodology, and supervised the project. Guillaume Longin supervised fieldwork, collected samples and compiled the data. Chrystelle Delord, Sophie Launey, and Raphaëlle Rinaldo helped collect samples and prepared the data. Gilles Lassalle assisted in data curation; Louis Bonneau de Beaufort analysed the data. Jean-Marc Roussel, Guy Fontenelle, Pierre-Yves Le Bail and Guillaume Longin wrote the article.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: