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

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A R T I C L E I N F O

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A B S T R A C T

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 > 6300 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 m^2 of trammel net, mean catches ranged from 4 to 13 and 8–29 fish in the villages and control sites, respectively, while fish biomass ranged from 0.9 to 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.

1. Introduction

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

Subsistence fishing is defined as an activity that meets the nutritional needs of the fishers, its family and eventually the community where he lives. It usually involves low-technology gears, which may be part of traditional or cultural practices, and it is not primary conducted for commercial purpose (Berkes et al., 2001). The current context of globalization, however, enhances new eating habits and the use of more efficient fishing gears such as trammel nets and motor boats. In that case,

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the sale of fish surplus to obtain money in return can be more regularly observed, and the line between subsistence and commercial fishing becomes blurred. For instance, small inland fisheries are key sources of food for many people along large tropical rivers (Mosepele, 2014; Begossi, 2010; Welcomme et al., 2010), but some communities have started to shift toward the consumption of commercial food products and progressively left subsistence fishing for commercial fishing. Therefore, ensuring the sustainability of these small inland fisheries requires understanding the processes that occur during the transition from ancestral to modern lifestyle and their consequences on fish stocks.

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

The present study aimed to define the small fishery of the upper Maroni River (UMR) by bridging the information gap between fish resources and fishing activity. To do so, a conventional fisheries survey (e.g., Pido et al., 1997; Rochet et al., 2008; Cerdeira et al., 2000; Hallwass et al., 2011, 2013) was combined with participatory monitoring (e.g., Ticheler et al., 1998; Silvano and Valbo-Jørgensen, 2008; Rochet et al., 2008; Hallwass et al., 2011, 2013) that included native fishers. Our objectives were to map the fishing grounds of several villages in the UMR, and analyze the abundance and biomass of fish landed, as well as their seasonal variability per species. We estimated potential impacts of the fishery on fish populations by assessing differences in the catch per unit effort (CPUE based on surface of trammel nets) and size of catches between villages and remote, control sites located outside the fishing grounds. We also explored the transition from ancestral to modern lifestyles by comparing the two major indigenous communities in the UMR: the native Amerindian, who still have a subsistence lifestyle, and the Bushinengue, descendants of African slaves who escaped and

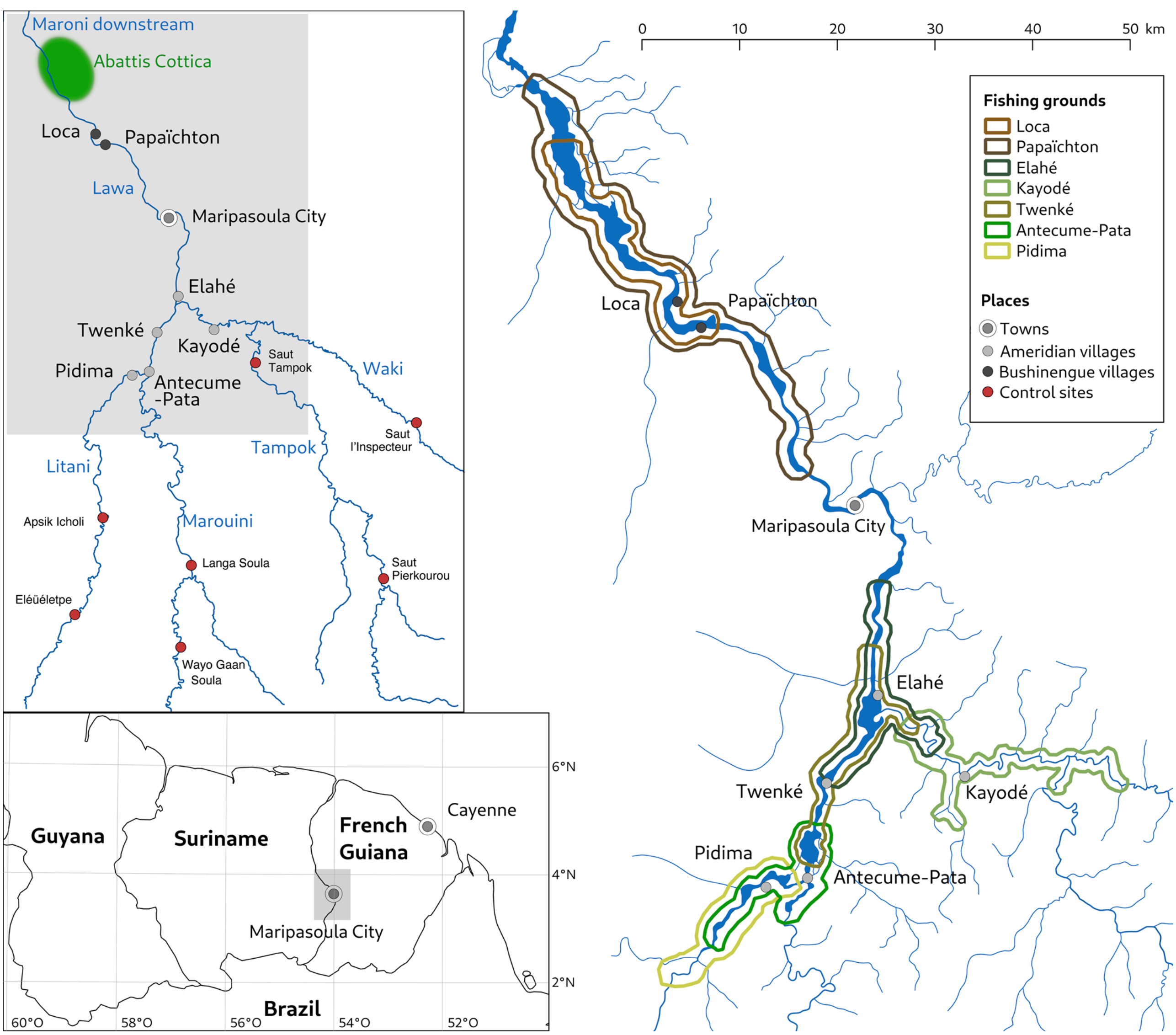

Fig. 1. Fishery survey of the upper Maroni River (French Guiana). Control sites and fishing grounds that correspond to the maximum distance per one-day fishing trips around each village are shown.

established independent communities, and who recently began to adopt a modern lifestyle (Delpech, 1993).

2. Methods

2.1. Study area

The study was performed in the UMR, a river 610 km long that flows between Suriname and French Guiana (Fig. 1). Approximately 5500 people live in Maripasoula City, the main town in the region, including natives from several communities and Europeans. The commune of Maripasoula City has a regional airport, and food stores are supplied by plane from Cayenne, the capital of French Guiana. Daily fishing activity is low in Maripasoula City, and fish landings are difficult to monitor due to the scattered distribution of landing locations. Conversely, daily fishing activities occur in 21 small villages located along the UMR. Two communities live in the area: Bushinengue (Aluku ethnic group) and Amerindians (Wayana and Teko ethnic groups), who live downstream and upstream of Maripasoula City, respectively. Bushinengue fishers have access to the zone of *Abattis Cottica* (Fig. 1), which is known to be a productive, fish-rich area (Le Bail, personal communication). After reaching agreement with the traditional chiefs, we selected seven villages to represent these ethnic groups and the hydromorphological characteristics of the UMR watershed (Fig. 1). The landings of 134 fishers (101 Amerindians, 33 Bushinengue, i.e., 55 % of the fisher population) were surveyed from November 2013 to September 2014 (Supplementary Table S1).

2.2. Data collection

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

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

Seven control sites located on major tributaries of the UMR (i.e., Litani, Marouini, Tampok, and Waki) were surveyed from August 2014 to March 2016 to estimate impacts of the fishery on fish populations. A minimum of two days of travel by boat was required to access each control site from the nearest village, including exiting the water to pass rapids. Since there was no other village in the vicinity, we assumed that fishing pressure was very low compared to sites around villages. The control sites (Fig. 1) were: Apsik Icholi and Eléüéletpe (64 and 96 km upstream of Pidima village, respectively), Langa Soula and Wayo Gaan Soula (90 and 126 km upstream of Antecume-Pata village, respectively), Saut Tampok and Saut Pierkourou (33 and 130 km upstream of Kayodé village, respectively) and Saut l’Inspecteur (74 km upstream of Kayodé). Four to five consecutive nights of sampling were performed at each site, where nearly 1 km of river was prospected. The fish community was fished using trammel nets, which were set in the evening and checked in the morning. Nets (1.5−2.0 m high, length >30 m, 6−22 cm inner-outer panels mesh size) were chosen to match with characteristics of prevalent monofilament trammel nets used by fishers in villages, for subsequent comparisons. Nets were positioned in deep or in shallow zones, with very low flow or close to turbulent areas, parallel or perpendicular to the bankside to cover the range of aquatic habitats available. The sampling effort, expressed as the cumulative length of trammel nets set at night, was 860 m, 1120 m, 1470 m and 1690 m respectively on Waki, Litani, Tampok and Marouini. Each fish was taxonomically identified to the species level, then measured (nearest mm) and weighed (nearest g).

2.3. Data analysis

Only eight boat landings corresponded to 24 h fishing trips; the corresponding data were not considered in subsequent analysis. Chi-squared tests were performed to identify significant differences in numbers of one-day fishing trips between seasons and between communities. Data were analyzed to identify the 20 most abundant fish species landed in the fishery. Confusion was suspected between *Myloplus rubripinnis* and *M. ternetzi* at landing, so the two species were considered as a single group (*M. rubripinnis/ternetzi*) for the rest of the analysis. Based on fishing grounds reported by fishers on the grid map, catches located within a 10 km radius of each other were then combined to perform maps of catches. For each species, length-weight curves were plotted; erroneous records, i.e., individuals showing obvious mismatch between length and weight data, were discarded (1% of data). Moreover, 8% of the fish were gutted before landing, and we used the length/weight curves to estimate total weight of the fish. Data from trammel nets of similar size (6−22 cm inner-outer panels mesh size, 1.5−2.0 m high, length >30 m) that were set at night were used to compare the catches of villages and control sites. The number of catches was converted into CPUE (i.e., number or biomass of fish caught per 100 m^2 of trammel net per night) for all species pooled. Although the advisors in each village were trained to collect data, fish body-length data were marginally biased since the caudal fin was sometimes excluded. Thus, fish weight data was preferred for subsequent analyses. For all sites combined, fish body-weight distributions by species were divided into three equal thirds (small, medium, and large fish), and the percentage of individuals in each of the three categories was calculated for each species. Data were then aggregated (all species combined) to assess differences in fish weight between villages and control sites. Differences in fish body-weight between village and control sites were also compared by species when catches of a species reached at least 100 fish in village and 100 fish in control site (sites combined) and were distributed equally among seasons. Non-parametric Wilcoxon rank-sum tests were performed to identify significant differences in species body-weight between village and control sites.

3. Results

3.1. Fishing grounds

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

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

3.2. Fishing techniques

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

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

3.3. Fish catches

The villages landed 63 species throughout the study period, representing 6366 individual fish. The 20 most-landed species represented 87 % of individual fish landed (Fig. 2, and see Online Supplementary Appendix B for a brief description of each species), of which *Pseudancistrus barbatus* alone represented more than 12 % of all catches (in number). Overall, 59 % of all catches came from three fish families: Serrasalmidae (25 % - *Myloplus rubripinnis/ternetzi, Myloplus rhomboidalis, Myloplus planquettei, Tometes lebaili, Serrasalmus rhombeus, Acnodon oligacanthus*), Doradidae (19 % - *Platydoras costatus, Doras micropoeus*), and Loricariidae (16 % - *P. barbatus, Hemiancistrus medians, Hypostomus gymnorhynchus)*. The large fish *Hoplias aimara* represented 33 % of biomass landed (but only 4% of numbers), while all species of Serrasalmidae, Doradidae, and Loricariidae represented 24 %, 8% and 4% of the biomass landed, respectively.

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

3.4. Differences in catches between villages and communities

Amerindians landed 77 % of all catches during the survey (Fig. 4), using mostly nets (78 % of catches, of which 96 % were with trammel nets), passive gears (11 %, essentially longlines) active lines (6%), and sight fishing (5%). Bushinengues caught fish using mostly nets (90 %, of which 93 % were with trammel nets), passive gears (7%, essentially traps) and active lines (3%), and but never sight fishing. For all fishing techniques combined, the mean number of catches per boat landing ranged from 6 to 9 fish in Amerindian villages vs. 13–14 fish in Bushinengue villages (Supplementary Table S4). During the entire survey, 2929 kg of fish was landed in total (1943 kg, i.e. 3.0 kg per boat landing by Amerindian, and 986 kg, i.e. 9.2 kg per boat landing by Bushinengue) (Fig. 4). Fishers from the Bushinengue village of Papaïchton landed the largest fish biomass per one-day fishing trip (13 kg), while other villages landed a mean of 1.7–4.0 kg (Supplementary Table S4). Amerindians used mainly nets (47 %), active lines (13 %), longlines (35 %), and sight fishing (5%) to catch the biomass they landed, while Bushinengues used mainly nets (56 %), traps (39 %), and active lines (5%) to catch the biomass they landed.

H. aimara represented 24 % and 50 % of the fish biomass landed by Amerindians and Bushinengues, respectively, and Bushinengues often

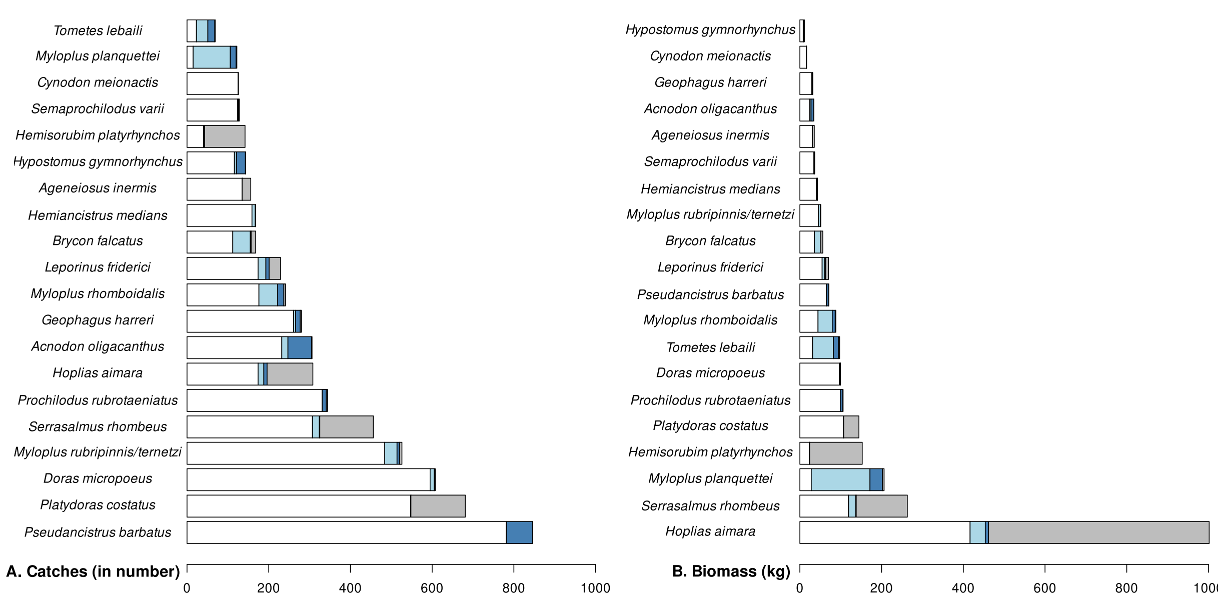

Fig. 2. (A) Number of catches and (B) biomass landed for the 20 most-landed species by main type of fishing gear.

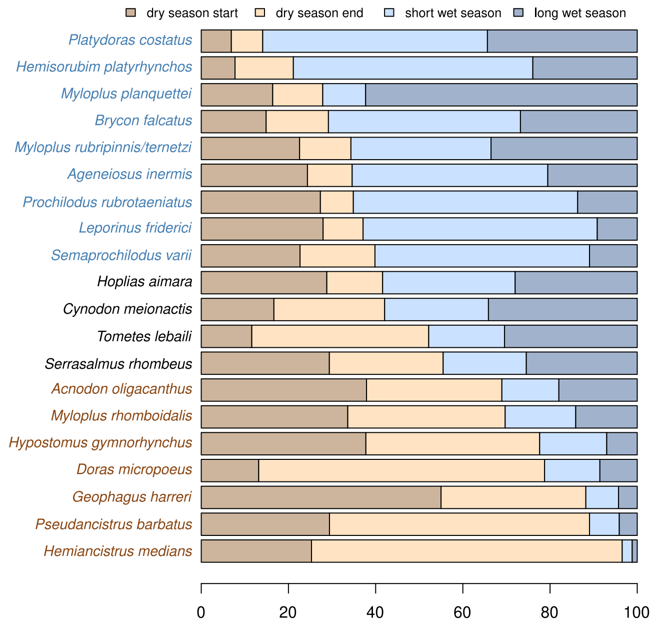

Fig. 3. Percentage of catches for the 20 most-landed species by season. Font colors indicate species caught mainly in the dry season (tan), wet season (blue), or throughout the year round (black).

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

3.5. CPUE and fish body-weight

The mean area of trammel nets set at night ranged from 72 to 171 m^2 in Amerindian villages (for Pidima and Kayodé, respectively) but reached 338 and 385 m^2 in the Bushinengue villages of Papaïchton and Loca, respectively (Supplementary Fig. S3 and Table S5). However, the lowest CPUEs (4–7 fish per 100 m^2 of trammel net) were recorded at Loca, Papaïchton, and Kayodé, while a mean of 8–13 fish per 100 m^2 of trammel net were caught in other Amerindian villages (Fig. 5A, Supplementary Table S5). In comparison, the CPUE at control sites ranged from 8 to 29 fish per 100 m^2 of trammel net (Fig. 5A, Supplementary Table S5). For biomass, the lowest yield was recorded at Loca and the highest at Papaïchton (0.9 and 4.0 kg of fish per 100 m^2 of trammel net, respectively), while the yields for Amerindian villages showed intermediate values (1.5–3.1 kg). Yields ranged from 3.2−7.0 kg per 100 m^2 of trammel net at the control sites (Fig. 5B, Supplementary Table S5).

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

4. Discussion

Fish species richness in the tropical freshwater of Southeast Asia, Africa, and South America is among the highest worldwide (Abell et al., 2008), which creates regional hotspots with high biodiversity value and conservation issues. Studies have shown causal correlations between biodiversity and ecosystem services (Tittensor et al., 2014), and conservation plans commonly focus on both issues. Among important ecosystem services, inland fisheries provide low-cost protein in areas where alternative food sources and employment are infrequent. Poor or developing nations generally rely the most on these inland fisheries, among which the importance of high-yield river fisheries has been demonstrated (McIntyre et al., 2016). Such small fisheries are challenging to study, however, since they involve many fishers, fishing techniques, landing sites and fish species (Salas et al., 2007; Chuenpagdee and Pauly, 2008; Castello et al., 2013). In addition to ongoing environmental threats (e.g., habitat loss, pollution, climate change), intensive harvesting of the most biodiverse rivers is a major concern for the conservation and sustainability of these fisheries. Usually, no data on regular landings (e.g., logbooks) exist, as they do for commercial fisheries worldwide, and in the best cases, coarse description of fisheries precludes rigorous assessment of effects of fishing on natural resources (De Graaf et al., 2015).

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

This apparent decrease in yield in the fishing grounds could indicate intensive harvest, but the causal correlation between fishing pressure and fish abundance is not elucidated here since we did not consider other environmental pressures (e.g., poor water quality, habitat degradation), which could have decreased fish abundance around villages

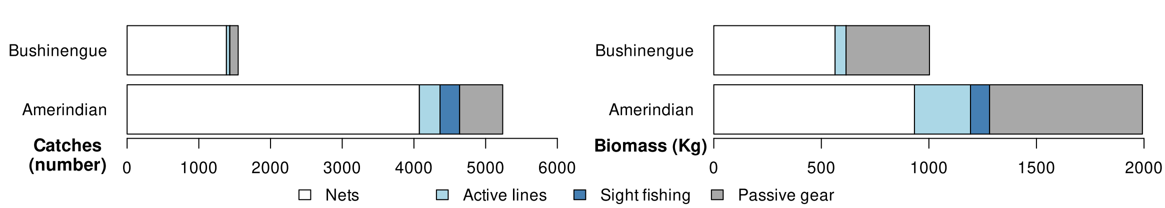

Fig. 4. (A) Number of catches and (B) biomass landed by Bushinengue and Amerindian fishers by main type of fishing gear.

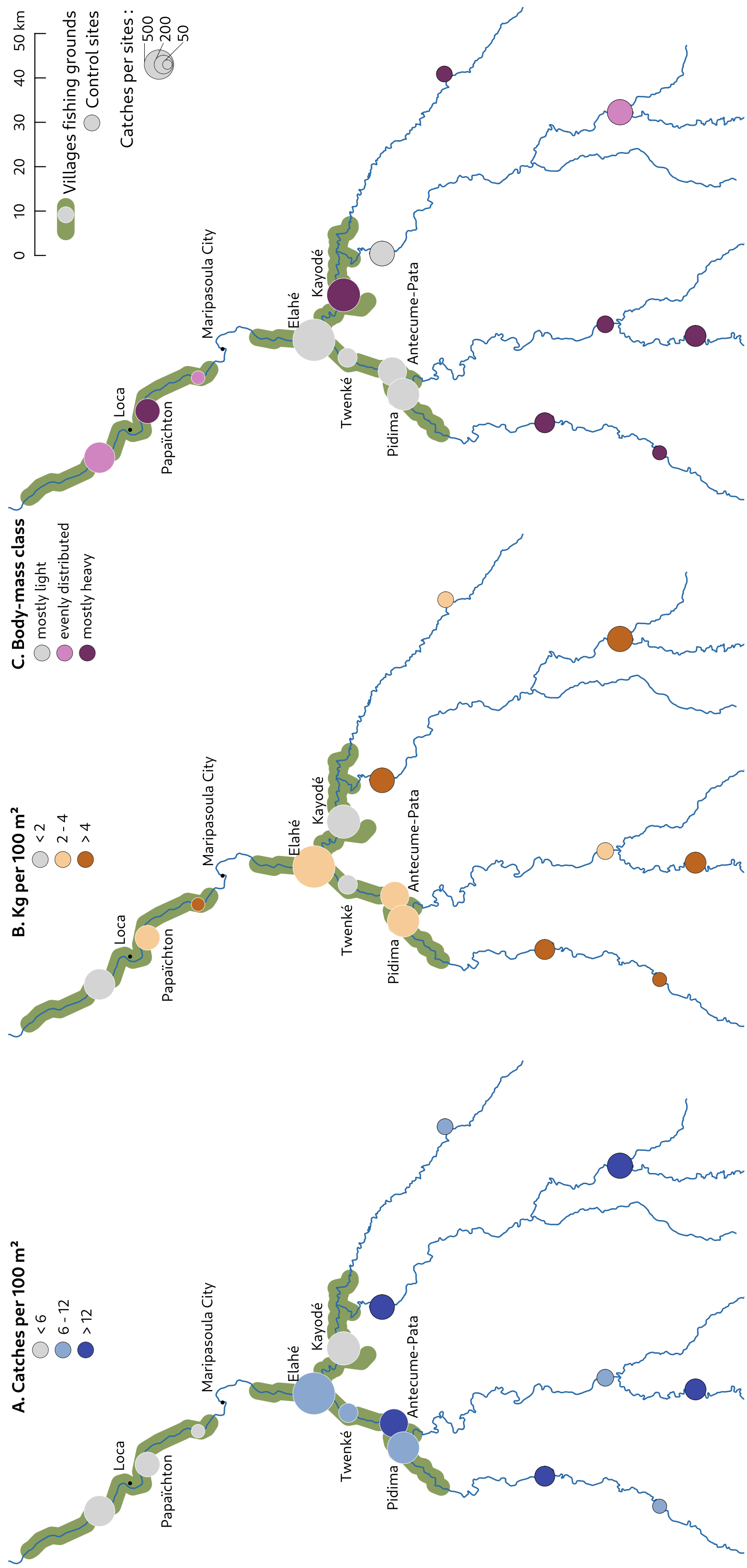

Fig. 5. Spatial distribution of all fish species caught with trammel nets in the village and control sites: (A) number of fish per 100 m^2 of net, (B) fish biomass (in kg) per 100 m^2 of net, and (C) fish body-mass classes. Circle sizes represent the number of captures used for calculations at each site.

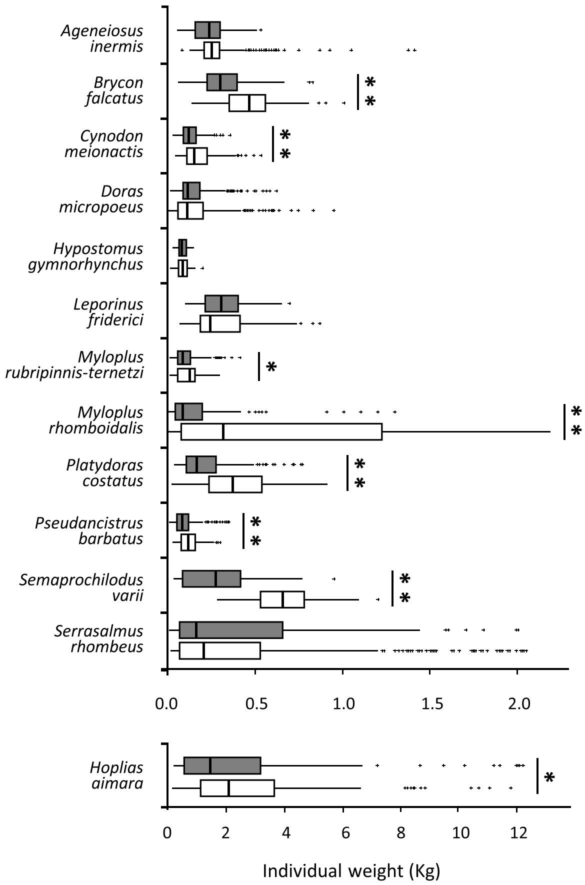

Fig. 6. Individual body-weight of the 13 most-landed fish species at control sites (white) and village fishing grounds (gray). Error bars represent 1.5 times the interquartile range. Stars denote significant differences between village and control sites (Wilcoxon test; * $p < 0.05$; ** $p < 0.01$).

(Longin et al., 2021). Moreover, the dominant species in catches may differ among fishing grounds based on their habitat preferences, behavior, and the season. For instance, *Prochilodus rubrotaeniatus* uses to move to feeding grounds downstream (Agostinho et al., 2007), and *H. medians* remains within fast-flowing habitats (Le Bail et al., 2000) that are more frequent downstream of Loca and Papaïchton in the *Abattis Cottica* (Fig. 1). *D. carinatus*, *L. friderici*, and *M. rubripinnis* preferred lentic environments (authors' personal observation; Boujard et al., 1991; Planquette et al., 1996), which are more common around Elahé and Kayodé. Indeed, caution is necessary when analyzing aggregated yield data since they are difficult to understand in multispecies fisheries (Lorenzen et al., 2006). In our case, catch per unit effort data by species was not possible since many zero values (i.e., each species was caught in a small number of nets only) in the data hampered analysis of differences between villages and control sites.

Analyzing differences in fish body-weight revealed an additional sign of intensive harvest in the UMR fishery. Several studies support that prolonged periods of exploitation are associated with both a decline in fish catches and fish size (Haedrich and Barnes, 1997; Froese, 2004; Hutchings, 2005). Theoretical and empirical studies also illustrate how life history traits can be reshaped in harvested fish populations, notably toward slower somatic growth, smaller body size and earlier maturation of individuals (Bouffet-Halle et al., 2021). All species combined, we found a decrease in fish weight classes, especially around the Amerindian villages of Pidima, Antecume-Pata, Twenké, and Elahé (Fig. 5). This general trend was confirmed by the analysis of spatial differences in body-weight by species. Differences were particularly obvious for the large and highly targeted *M. rhomboidalis*; fishers rarely landed large individuals (>0.5 kg), while large individuals represented half of the captures of this species outside the fishery grounds. Individuals of another highly targeted but small species, *P. barbatus*, were 25 % lighter around villages than outside the fishery grounds. Similar patterns were observed for *B. falcatus* and *P. costatus*, which also suggests that these species are harvested intensively. Converging patterns of body-size declines were reported for other neotropical freshwater fish species, including *Prochilodus nigricans* (Bonilla-Castillo et al., 2018), *Arapaima sp.* (Castello et al., 2011b), and several species of Loricariidae, Pimelodidae, Scianidae and Serrasalmidae (Castello et al., 2011a). In the Maroni River, *H. aimara* was the largest fish species landed. It was smaller on fishing grounds too, even if the difference with control sites was not as stronger as anticipated for this popular species. The influence of a strong exploitation on *H. aimara* body weight could have been masked, however, by the presence of larger individuals in large downstream habitats, which are more suitable for this predatory species.

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

For several reasons, the exploitation rate in small-scale fisheries is expected to increase. Poor communities depend more on freshwater fisheries than on marine or aquaculture sources (McIntyre et al., 2016), and the growing population generally increases pressure on natural resources. Moreover, there is a general trend for more efficient techniques, and motor boats and nets are replacing traditional techniques (Isaac et al., 2004; Castello et al., 2011a; Hallwass et al., 2011). During our investigations on the UMR, we observed traditional gear in fishers' homes, such as bows and arrows, spears, wooden traps, and canes, but they rarely used them. Comparing the Amerindian (Wayana and Teko) and Bushinengue (Aluku) communities in the UMR illustrates this rapid transition from ancestral to modern lifestyles in French Guiana. Bushinengue began adopting a modern lifestyle before Amerindian did. They rarely used paddling and preferred motor boats to reach distant fishing grounds during one-day fishing trips. They usually used trammel nets and caught more fish per fishing trip, but captured the fewest fish per unit area of trammel net. Despite the intense fishing pressure in this community, fish are no longer a main source of protein in the Bushinengue diet (Longin et al., 2021). Bushinengue live in large villages of more than 1000 inhabitants (Loca has ca. 1200 and Papaïchton 2900), and fishers represented less than 2% of the population (Supplementary Table S1). The annual biomass of landed fish extrapolated from our data is ca. 14 t, i.e., 10 g per person per day. This low intake of animal protein from the river indicates that the Bushinengue diet has mostly shifted toward imported and/or processed food, and that subsistence fishing has mostly disappeared in their community. Conversely, Amerindians live in smaller villages (35–180 inhabitants) in which fishers represent nearly 30 % of the population, which indicates that each family still eats fish from the fishery. The same extrapolation results in an annual biomass of landed fish of 27 t, i.e., 115 g per person per day. Protein intake from the river remains substantial, but has obviously decreased since the early 1960s, when Hurault (1965) reported that the Amerindian Wayana ate 200−560 g of fish per person per day, depending on the season.

Nevertheless, many native people in the UMR region still depend on fish resources from the river for their daily diet, and they are increasingly concerned about the risk of overexploitation and resource depletion (Longin et al., 2021).

5. Conclusion

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

Authors contributions

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 Raphaelle 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 Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

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