Increasing social risk and markets demand lead to a more selective fishing across the Pantanal wetland

André Valle Nunes[a,b,c*], Rafael Morais Chiaravalloti[d], Fabio de Oliveira Roque[b,c], Erich Fischer[b], Ronaldo Angelini[e], Karoline Ceron[f], Lucia Mateus[g], Jerry Penha[g]

[a] Instituto Nacional de Pesquisa do Pantanal, Cuiabá, Mato Grosso, Brazil

[b] Programa de Pós-Graduação em Ecologia e Conservação, Instituto de Biociências, Universidade Federal de Mato Grosso do Sul, Campo Grande, Mato Grosso do Sul, Brazil

[c] Knowledge Centre on Biodiversity - Brazil, Belo Horizonte, Minas Gerais, Brazil

[d] University College London, Anthropology Department, London, UK

[e] Department of Civil and Environmental Engineering, Universidade Federal do Rio Grande do Norte, Natal, Brazil

[f] Laboratório de Estrutura e Dinâmica da Diversidade (LEDDiv), Departamento de Biologia Animal, Instituto de Biologia, Universidade Estadual de Campinas - UNICAMP, Campinas, São Paulo, Brazil.

[g] Centro de Biodiversidade, Instituto de Biociências, Universidade Federal de Mato Grosso, Cuiabá, Brazil

* **Corresponding author**: André Valle Nunes

E-mail: tataupas@gmail.com

Abstract

Fishing connects people, aquatic systems, places, and fish consumer markets all around the world. Our understanding of the magnitude and intensity of these interactions are comparatively scarce for some regions, and to date have mostly yielded insights to understand socioecological linkages within marine fisheries. Here, we investigated how socio-demographic and economic factors are associated with fishing selectivity in the Brazilian Pantanal wetland using data from the continental commercial fishing sector from 18 fisher colonies. Our results show that increasing unemployment can lead to a more specialized or selective fishery. In addition, the watersheds where more selective fishing is practiced were those whose colonies are closer to the state capitals that make up the Upper Paraguay River Basin. The general results support that Pantanal wetland fishers do not follow the global pattern of fisheries in regions with low development, which tends to behave more as generalists than specialists. On the other hand, we provide evidence that specialized fishing selectivity is associated with external market demand in a socioeconomic coupling. We emphasize the importance of socioeconomic policies to reduce social vulnerability of fishers, and of management strategies to maintain fish stocks in wetlands.

Keywords: ecosystem services, inequality, social capital, inland fisheries, poverty, small-scale fisheries

1. Introduction

Fish provide food security worldwide through commercial and subsistence fishing (Béné, 2016). In 2020, 58.5 million people were involved in catching, processing, or selling fish in developing countries (FAO, 2022). For example, in Sub-Saharan Africa, the estimated annual value of fish catches in two of the three major rivers is between US$19-26 million (Kolding et al., 2016). In the Lake Chad basin, fishing provides 45% of regional household income, totaling US$45.1 million per year (Young et al., 2012). In the Lower Amazon, 84% of the households engage in fishing, representing 40% of local people's income (Almeida et al., 2002). While small-scale fisheries represent the bulk of fisheries-associated livelihoods and support income for millions of people, fishers are among the poorest in developing countries (Bené, 2003).

The impact of overfishing and other threats to fish populations causes declines in fish stocks which, in turn, can threaten the livelihood security of small-scale fishery communities (Berrouet et al., 2018; Bolaños-Valencia et al., 2019; Zarfl et al., 2019). The uncertainty of fishing return represents one of the main sources of instability for individuals, households, and communities (Allison et al., 2009). Although some groups may be able to adapt to novel scenarios of distribution and availability of fish, these adaptations do not necessarily lead to better livelihood (Silva et al., 2019). For example, drastic reductions in fish stock of valuable species may force people to move their effort to target others species that have higher return in catches, yet the market value may not be equal to the previous one. Also, livelihood adaptations (e.g. changes in fishing gears or target species) depend on existing cultural norms, social structures, access to technology and ability to deal with entry barriers that may hamper changes on livelihood strategies (Chiaravalloti et al., 2021).

Globalization is another source of insecurity for small-scale fishery communities. As the world becomes more connected to global fish trade, large-scale fishery companies and fish producers tend to dominate the market (Crona et al., 2015; Carlson et al., 2017). The market of fisheries is strongly associated with dynamic and complex relationships between environmental and socioeconomic issues through space and time, including distant regions of the world (telecoupling) (Carlson et al., 2018). Although part of these interconnections is placed on a global scale (Liu, 2017; Herzberger et al., 2019; Carlson et al., 2020; Tromboni et al., 2021), local market sales by commercial fishers can also be largely affected by the local economy (Crona et al., 2015). On the ground, this means that consumers' expectations and demands may guide fishing selectivity (Carlson et al., 2020). The productivity of the system (e.g. water properties, nutrient load), however, influences the availability of potentially target fish species, and fishing selectivity has been related to catch-per-unit-effort (CPUE) in many studied systems (Welcomme, 1985; Junk et al., 2007). In some cases, spatio-temporal fishery closures can increase fishing selectivity (Hall and Mainprize 2005), thus supporting that fishery management practices can also affect fishing selectivity across seasons and sites (Dunn et al., 2011).

The concepts of vulnerability and sensitivity have been used in a complementary way across an increasing number of studies, frequently applied for marine and coastal systems to understand fisheries and their links with environmental dynamics and external markets, thus representing valuable tools for management interventions (Ding et al., 2017; Thiault et al., 2017; Berrouet et al., 2018; Aswani et al., 2019). Vulnerability is the susceptibility of a system to an adverse impact or disturbance, and it varies across space and time (IPCC, 2001; Turner et al., 2003). Several factors contributing to increase the vulnerability of a system can influence fishing selectivity, such as adverse weather conditions, fluctuations in natural resources, price fluctuations, and variable access to markets (Macfadyen and Corcoran, 2002). These factors influence the vulnerability of fisheries stakeholders to enter or remain in poverty. Sensitivity, on the other hand, is the degree of a community's dependency on natural resources (Jara et al., 2020), which accounts for the proportion of the dependent population and the access to different income opportunities. However, despite sensitivity and vulnerability factors can improve our understanding of fishers' resilience in face of economic and environmental change, few studies have addressed these topics for inland fisheries (Camp et al., 2020; Chiaravalloti et al., 2021; Muringai et al., 2022).

Here we investigate the extent to which fishing selectivity (i.e., profile landed fish species) was explained by fisher's dependence on commercial fishing (sensitivity index) and their socioeconomic factors in the Upper Paraguay River Basin, which encompasses the Pantanal wetland in Brazil. Underpinned by the expectation that fishing behavior (i.e., selective vs. generalist) is associated with fishers and consumers' location and socioeconomic factors (Bieg et al., 2018; Tregidgo et al. 2021), we expected that fishers closer to larger cities would be more connected to consumers with greater purchasing power, which would increase the quantity of fish they trade and also a more specialist behavior. Likewise, fishers dependent on commercial fishing living in places with low economic development would have a more generalist behavior. We also expected the more generalist fishing to be more efficient in terms of landed biomass. Based on these assumptions, we therefore hypothesize that local sensitivity, efficiency (catch-per-unit-effort) in terms of landed fish biomass per day (FAO, 2002), distance to consumer center, and socioeconomic factors (socio-demographic, economic) dictate fisher's selectivity. This study documents the role of external factors on fishing selectivity in the largest continual wetland on the planet.

2. Material and Methods

2.1 Study region

The Upper Paraguay River Basin (UPRB) is located in central South America and comprises extensive plateaus (200 to 2333 m a.s.l.) and a large floodplain called the Pantanal (Figure 1). The climate is classified as Aw of Köppen, with a wet season from October to March and severe dry season from April to September. Annual rainfall varies from 800 to 1400 mm (Penatti et al., 2015). In south Pantanal, the flood pulse occurs between August and October and it takes between 3-4 months to pass through (Junk et al., 2006; Tomas et al., 2019), and north Pantanal the annual flood cycle begins in December and ends in June, with peaks during late February through April (Fantin-Cruz et al., 2011). The flood pulse in the Pantanal is a direct consequence of the rainfall on the extensive plateaus in the UPRB (the Maracaju, Guimarães, other mountain ranges) (Padovani, 2010). The UPRB has seen major changes in land use, especially on the plateaus where most fishing colonies are located. In 2016, 61% of the plateau was under human use, in contrast to only 13% on the floodplain (Guerra et al., 2020).

The majority of fishers in the UPRB are linked to fisher colonies. These fishers' associations originated in the 1920s, following Brazilian policies toward the defense of coastal and inland waters (Resende, 2011). However, they were only officially recognized in the Federal Constitution of 1988 (Tocantins et al., 2011). There are 18 fishers' colonies across the UPRB, 11 in the plateaus and 7 in floodplain area (Figure 1). The two Brazilian states encompassing the UPRB, Mato Grosso (MT) and Mato Grosso do Sul (MS), have their own legislations in terms of fishing and management (output and input rules), such as allowed fish species, sizes, and quotas. However, both states forbid the use of fishing nets. The fishing season opens (dry season) from February to September (MT) and March to October (MS). Fishers are allowed to use line and hook only. In 2018, when data are available, the commercial fishing sector generated ≈US$13.888 million (only first sale) related to approximately five thousand tons of fishery landings, and involved nearly 9,700 commercial fishers in the 18 colonies (ANA, 2020).

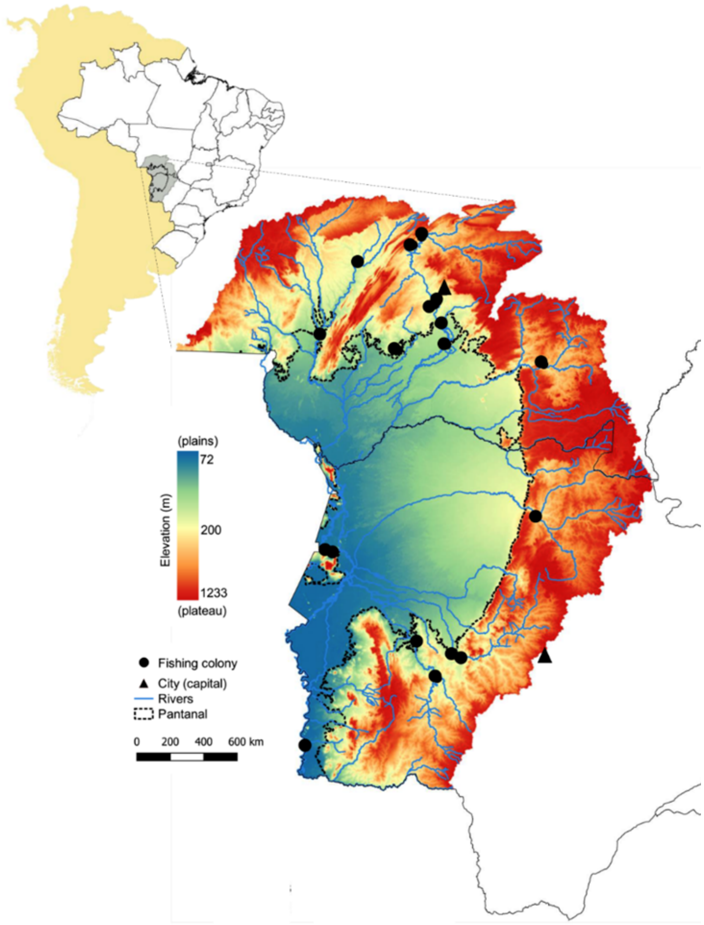

Figure 1. Location of the Upper Paraguay River Basin in South America and the 18 studied fishing colonies in the Brazilian states of Mato Grosso and Mato Grosso do Sul. Colour background indicates meters above sea level.

2.2 Data compilation

The landing dataset was obtained from the RH Paraguay Artisanal Fisheries Monitoring System report (ANA, 2020), which included the landing of 13 species of important commercial value for fisheries in the region, more a category called “others” that corresponds to 16 species of lesser commercial value which are short-distance migratory or non-migratory species (e.g. *Astyanax* spp., *Serrasalmus* spp., *Hoplias* spp., *Pimelodus* spp.), captured throughout the 2018 season (March-September). A total of 21,754 fisheries were monitored over this period, by approximately 7,000 commercial-artisanal fishers in 25 rivers of nine micro-watersheds. From the report, we also extracted: (1) the geographic coordinates of the colonies, (2) the number of fishers per colony (*F*), (3) landed biomass (kg) per species and river, and (4) catch-per-unit-effort (CPUE) as the biomass (kg) obtained per fisher-day (kg • day^{-1}) by micro-watersheds.

The socioeconomic indicators of the municipalities where the 18 colonies are located were obtained from the Brazilian Institute of Geography and Statistics (IBGE, 2010). The indicators used were Human Development Index (HDI), per capita gross domestic product (GDP), the number of formal employed (*E*) and unemployed in each municipality (*U*), and the total population of the municipality (*N*). We used the Dijkstra algorithm from the Google Maps Platform to calculate the shortest distances by roads (DIST; km) from each fishing colony to its capital (Cuiabá in Mato Grosso state or Campo Grande in Mato Grosso do Sul state). Although the region's rivers are almost entirely navigable, the transport of fish is exclusively done by road. We emphasize that each colony is part of a specific municipality. Sensitivity was calculated as an index of economic dependence of fishers on the fishing commercial for each colony; we used the socioeconomic sensitivity index (SENS) adapted from Thiault et al. (2018), as follows in Equation 1:

$$Sens = \frac{F}{F+E} \times \frac{N}{F+E} \times \frac{U}{N} \qquad \text{(Equation 1)}$$

where *F* is the number of fishers per colony; *E* is the number of people employed in the municipality; *U* is the number of people unemployed; and *N* is the population size in the municipality. Sensitivity ranges from 0 (low unemployment) to 1 (high unemployment).

2.4 Data analysis

To better understand fishing selectivity, we assessed the network topology (i.e., physical and logical arrangement of nodes and connections of a network) between the micro-watersheds and the fish species in terms of their landed kg, because mass better represents the interaction strength, and it is less sensitive to sampling bias than the number of individuals (Lewinsohn et al., 2006; Vizentin-Bugoni et al., 2016; Fründ et al., 2016). In the R packages bipartite and vegan (Dormann et al., 2008; Oksanen et al., 2017), we calculated the specialization degree (d' – i.e., selectivity) for each micro-watershed to identify the range from highly specialist (targeted species) to extremely general multispecies fisheries among the watersheds. The degree of specialization of fishery in each micro-watershed was calculated as the proportional distribution of observed links with the fish species in relation to the total number of possible links considering all fish species in the network (Blüthgen et al., 2006). Thus, it can be interpreted as deviation of the current frequencies of fish species from a null model which assumes that all species are linked in proportion to their availability. This metric varies from 0 (no specialization) to 1 (high specialization) (Blüthgen et al., 2006).

To assess how the sensitivity (SENS), socioeconomic factors (HDI, GDP, DIST), and fishing efficiency (CPUE) can influence fisher's selectivity-generality in terms of landed fish species (d') we used Generalized Linear Models (GLM) with Gaussian distribution and identity link function (Crawley, 2012). In the analysis of the topology of fisheries (fishing strategy data), our sample units were the micro-watersheds because the landed data were available per river, not per colony. Thus, we used the average of the predictive variables of each colony (municipalities) in the model (sociodemographic data). We tested for under dispersion in the residuals using the DHARMa package, which tests the quantiles of scaled simulated residuals against a uniform distribution (Hartig, 2020). Additionally, we also tested for multicollinearity among all predictor variables using the variance inflation factor (VIF). Values lower than 10 indicate no major collinearity issues (Legendre and Legendre, 1998). All analyses were performed in R language (R Core Team, 2018).

3. Results

The number of fishers sampled per colony varied from 36 to 160 (mean = 67; SD = 33; N = 18), and the population size of the municipalities in which the colonies are located varied from 15,002 to 551,098 people (mean = 85,183; SD = 132,881; N = 18). The mean number of employed people in these municipalities was 25,608 (SD = 60,824; N = 18), and the mean of unemployed people was 59,575 (SD = 76,037; N = 1072,348). Overall, 30% of the population presented a formal job while 70% were unemployed. Eleven municipalities (61%) presented HDI scores ranging from 0.600 to 0.693, and seven (39%) presented higher HDI, from 0.700 to 0.785. Mean GDP was ≈US$39,600 yr^{-1} (SD = 9,455; N = 18). Low dependence on fishery for sustenance was scattered across the UPRB municipalities, as the mean social sensitivity was 0.35 (SD = 0.29) to commercial artisanal fishers.

The watershed-fish network included nine watersheds and ~14 fish species (Figure 2). The specialization (d') of the micro-watersheds, representing the gradient of selectivity-generality regarding the landed fish species, ranged widely from 0.03 to 1 (mean = 0.09; SD = 0.03, N= 9). However, among the watersheds, those with the greatest specialization are still low with APA (d'= 0.11) Miranda (d'= 0.13), Cuiabá (d'= 0.14), Taquari and Coxim (d'= 0.14). The specialization (i.e., selectivity) on target fish species was positively related to social sensitivity among the watersheds, indicating that increase in unemployment can lead to a more specialized or selective fishery (Figure 3a, t = 3.226; p = 0.0485). In addition, the watersheds where more selective fishing is practiced were those whose colonies are closer to the state capitals (Figure 3b, t = -3.36; p = 0.0439). GDP, HDI, and CPUE were not significantly related with fishery specialization (Table 1).

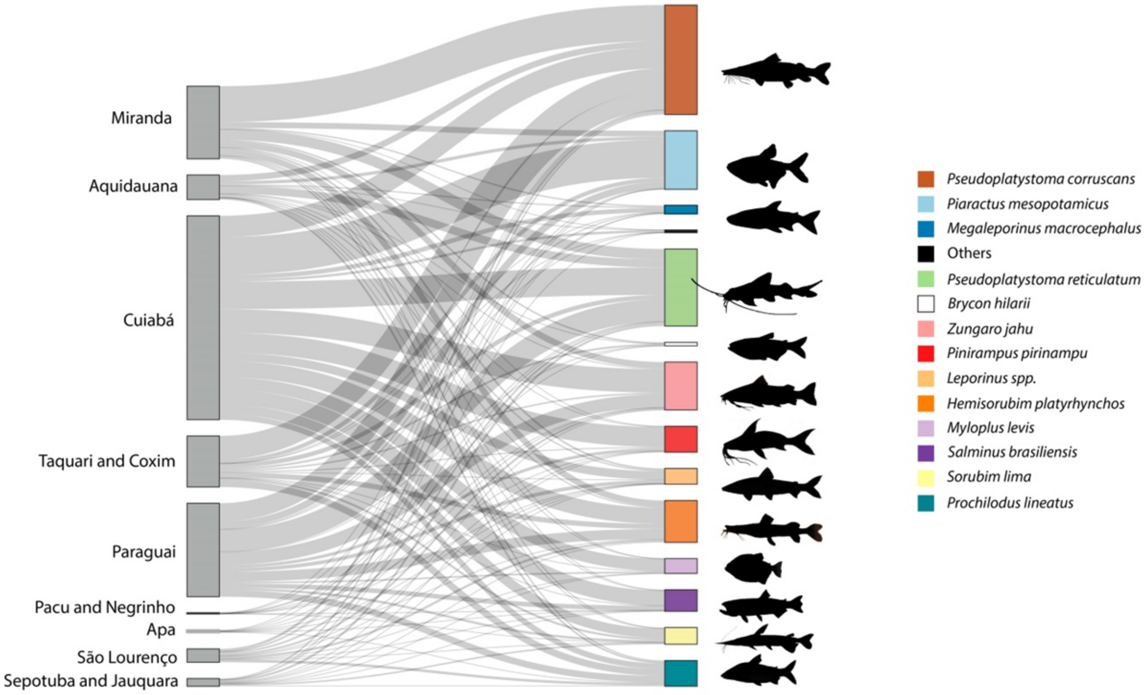

Figure 2. Watershed-fish species network across the Upper Paraguay River Basin in Brazil. The size of the rectangles corresponds the importance of each species in the network; lines indicate where fishes were captured (i.e., watersheds) and thickness corresponds to the landed fish biomass (kg) in the nine watersheds (grey rectangles) for the 14 fish species. “Others” correspond to short-distance migratory or non-migratory species (see ANA, 2020).

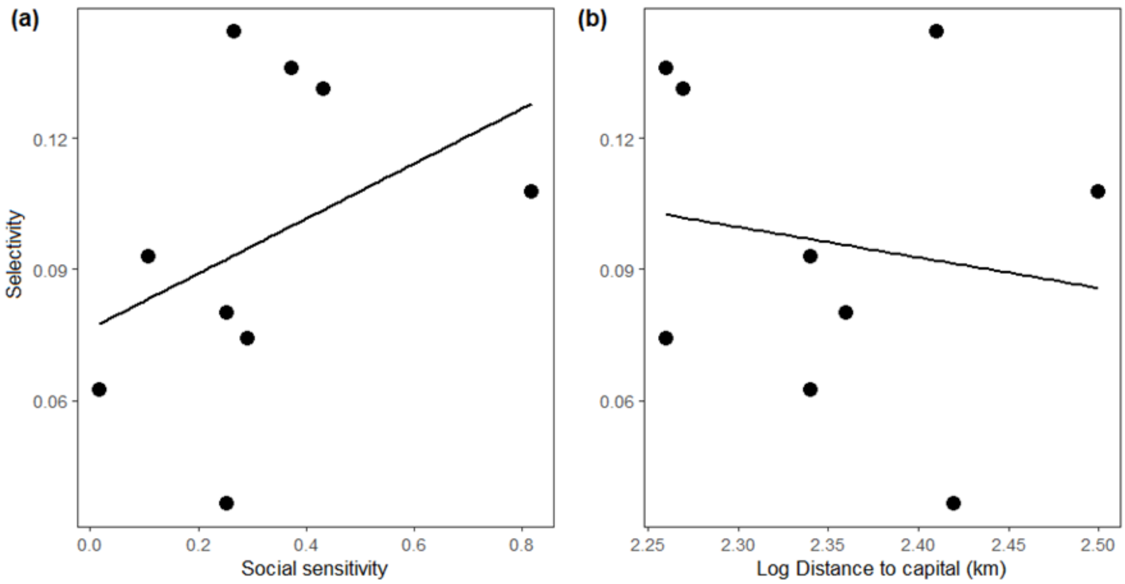

Figure 3. Fishery selectivity from specialist (higher selectivity) to generalist (lower selectivity) by micro-watershed in relation to (a) social sensitivity (SENS) and (b) geographic isolation from large urban centers, in the Upper Paraguay River Basin, Brazil.

Table 1. Estimates of effects of the socioeconomic characteristics on fishing specialist-generality (d') in nine micro-watersheds in the Upper Paraguay River Basin, Brazil. Bold highlights significant effects.

Variable	Estimate	SE	*t*	*p*
Intercept	-2.005	0.8062	-2.49	0.0887
Per capita income (GDP)	-0.0051	0.0029	-1.73	0.1826
Distance to capitals (DIST)	-0.0008	0.0002	-3.36	**0.0439**
Human Development Index (HDI)	3.2135	1.2576	2.55	0.0836
Socioeconomic sensitivity (SENS)	0.4186	0.1299	3.22	**0.0485**
Fishing Efficiency (CPUE)	0.0055	0.0029	1.87	0.1581

4. Discussion

Our study highlights that social sensitivity (indicating dependence on fishing) and distance to large consumer centers (state capitals) influence fishers' selectivity in the Upper Paraguay River Basin. Although we have restricted landings for ~14 species, our findings show that fishers tend to be more selective when they dwell in areas closer to large centers, probably with lower local employment. Higher selectivity in these regions may also depend on more experienced fishers targeting the fish stocks with the highest monetary return. Moreover, our results reveal that fishing selectivity in the UPRB seems to be associated with external market demand involving different municipalities (pericoupling) and within the watersheds (intracoupling). Thus, multiple scales couplings are likely important to predict the fisher´s degree of economic dependence on commercial fishing. The degree to which socioeconomic drivers dictate fishing selectivity has received little attention in previous studies, despite its critical role on natural resource-dependent communities (Bieg et al., 2018; Tregidgo et al., 2021). Below, we discuss potential explanations and implications that can support the varying degrees of economic dependence on fisheries in the UPRB watersheds, and highlight the importance of considering these factors in socioeconomic policy and resource management strategies of the wetlands to reduce social vulnerability and keep fish stocks and biodiversity.

Globally, commercial fishers from developed regions capture a tiny proportion of the available edible species (Bieg et al., 2018). At the same time, those who live in areas with low development tend to behave more like generalists than specialists (Bieg et al., 2018). Nonetheless, our results for the UPRB partially follow this global pattern (see Figure 3a). Although small-scale fishing has traditionally been an important cultural and economic activity, and one that supports thousands of households, the pattern we observe – an increase in unemployment can lead to a more specialized or selective fishery in groups close to consumer centers – may be driven by factors operating in different scales and regions. First, more experienced fishers who take fishing as their main job and source of income can be more selective and present in sites where there is greater commercial demand, close to large urban centers. Second, wealthier markets have consumers with greater purchasing power, which allow them to focus their consumption on species with higher economic value (Reddy et al., 2014). Given that people living in developed centers tend to focus their actions on economic opportunity, cash-based rather than a subsistence economy may encourage that behavior (Ruiz-Pérez et al., 2004; Stieglitz et al., 2016). Third, most of the time, local expectations and demands guide decisions to harvest and commercialize natural resources (Carlson et al., 2020). For example, in the Amazon, urban markets drive greater selectivity for fish species, with significantly less diversity in commercial catches (Tregidgo et al., 2021). Fourth, fish seems to be traded between the municipalities of the UPRB (Mateus et al., 2004), as we observed greater selectivity as the distance between colonies decreases. This suggests that all such possible interactions and flows within fisheries at local scales are robust features of intra-pericoupling socioeconomic systems. In summary, although these non-exclusive explanations can account for the pattern we found between fishing selectivity and socio-economic variables, currently based on the datasets available for the UPRB (see discussion below), we cannot figure out the parcel, magnitude and intensity of these interactions and linkages at local and large scales. So, as highlighted for marine fisheries (Pinsky and Fogarty, 2012; Österblom and Folke, 2015; Carlson et al., 2020), we still need better datasets that make it possible to integrate the management of natural resources with people (i.e socioecology) to understand the mechanisms driving selectivity in wetlands, such as the Pantanal.

We also observed that fishing communities with high unemployment and low alternative livelihoods are more selective. Although we did not classify fisheries based on how many and which species are caught (the relative fishing pressure is beyond the scope of this study), selective fishing can lead to narratives about local impacts on fisheries and influence public policies. Some studies have shown that highly selective fishing can have unintended consequences of destabilizing population dynamics, increasing the probability of local extinctions, and harming the economic market for exploited species (Anderson et al., 2008; McCann et al., 2016).

Assuming that selectivity can cause overfishing and declines in the income of fishers, at least close to the market centers, many potential management strategies can be suggested to reduce fisher's social vulnerability at the same time keep the fish stocks. These strategies should consider different arranges of governance, policy, social-participation, and level of uncertainties. First, as we showed, some fishers groups are more vulnerable than others, therefore policy interventions should be concerned in reducing sensitivity and increasing adaptive capacity. This specifically means finding ways to increase employment possibilities and increase alternatives for fishers temporarily switch to jobs hoping that catches will improve later (entering and leaving), and through fair and pro-poor labor policies and practices, and driving more generalist fisheries, fair trade, and green markets with diversification of fish species. Second, although well-managed species-specific fishing has shown that catches can be sustainable over the long term, it is believed that fishing spread over more species and sizes may result in higher long-term yields, as well as the economic sustainability of fisheries (Mangi et al., 2007; Little et al., 2010). For example, some African inland fisheries (lakes) have been observed to sustain high catches by harvesting a broad spectrum of species and sizes, providing highest yields and low structural impact on the ecosystem (Kolding et al., 2016, Zhou et al 2019). Diversifying target species is still an uncertain and controversial strategy for the Pantanal, partially because we have no information about the dynamic and movement of the species. However, we believe it is important to avoid fishers to leave the fishery or try to compensate the decline with increasing effort, switching to alternative and generally more efficient or destructive gears to catch specific species (McClanahan et al., 2005). In this way, we suggest that strategies to conciliate diversifying target species and maintain the income of the fishers should be focused on across the entire value chain, which means adding value to the different species and providing competitive access of small businesses and fishers to final consumers. In addition, monitoring and understanding the selectivity of fishing allows listing which species require more attention in terms of population management.

We did not detect an effect of per capita income, human development index, and fishing efficiency on fishery selectivity (see Table 1), even though these factors can affect fishing selectivity elsewhere, related to catchability and cultural preferences (Tsikliras and Polymeros, 2014; Bieg et al., 2018). HDI values consider education and health levels, so these two factors do not seem to affect fishing selectivity in the UPRB. However, the gradient of HDI values of the municipalities where the colonies are located was relatively short, probably contributing to the non-detection of potential effects. In addition, fishing efficiency may greatly depend on the gear types and all fishers across our colonies use similar technics - they fish in small canoes with line and fish hook.

We emphasize that our analysis is based on generalizations that may not play out on the ground as proposed in the models created. First, the socioeconomic data used to calculate socioeconomic sensitivity is based on the municipalities' population, rather than fishers' households. This may hide some important local differences. Second, in our model, we considered that fisher's income comes only from fishing. Therefore, possible alternative livelihoods that they change some of the variables analyzed were not considered. Third, we did not consider in our model possible variations in fish price, supply, and demand from consumers. These changes could also change some of the results in terms of sensitivity. Therefore, the results and conclusions of this paper should be read as a simpler version of the complex local reality. New models considering such a more complex and detailed version of the socio-ecological system would produce a more accurate understanding of the links between the socio-economic system and the fishing selectivity. It would also uncover whether the diversity of fishing catch is continuous throughout the year or it increases during a certain period of the year, such as greater selectivity in the months before the fishing season closes. Unfortunately, these data are quite precarious for most wetlands, the Pantanal is not an exception. We would only achieve such a more accurate understanding of reality through long-term monitoring of fishing stocks and socio-ecological systems.

In summary, addressing the dynamic between economic dependence of natural resources and diversification of practices and use of natural resources is particularly critical in the social and economic context that fishers are embedded in Brazil, especially in the Pantanal wetland. Our results clearly illustrate that an economy such as low employment and income possibilities, influences behavior, and linkages between the economy and natural resources. Although the structure of these interactions is complex, the link between socioeconomics and fishing selectivity shown here highlights the need for research on couplings and their coupled socioeconomic and ecological contributions. This includes biodiversity monitoring, alternative livelihoods, and programs focused on decreasing unemployment, which could protect the well-being of millions of fishers around the world.

Author contributions

AVN designed the study and analysis. AVN, FOR, EF, RMC, RA, KC, LM and JP jointly interpreted the results and wrote the paper.

Declaration of Competing Interest

The authors declare no competing interests.

Acknowledgements

This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq (grant numbers 300657/2019-6 and 153012/2022-6 to AVN, 307016/2015-3 to EF, and 307002/2019-5 to JP), and partially funded by Project Rede Pantanal from the Ministry of Science, Technology and Innovations of Brazil (FINEP Grant No. 01.20.0201.00), the São Paulo Research Foundation (FAPESP) (grant (#2020/12558-0 to KC). We especially thank Instituto Nacional de Pesquisa do Pantanal (INPP) for logistical support.

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