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Climate change negative effects on the Neotropical fishery resources may be exacerbated by hydroelectric dams

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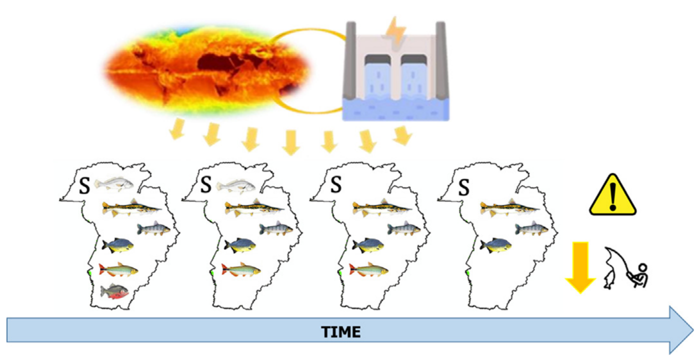
HIGHLIGHTS

- Climate change and river fragmentation by dam is a threat for fishery resources in the Upper Paraguay River Basin.
- Climate change may cause the decrease of the migratory fish richness over time in the Upper Paraguay River Basin.
- Progressive loss of suitable habitat may be accentuated with river fragmentation by dams in the Upper Paraguay River Basin.

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change is now recognized as a reality and along with human pressures such as river fragmentation by dams, amplifies the threats to freshwater ecosystems and their biodiversity. In the Brazilian portion of the Upper Paraguay River Basin (UPRB) that encompasses the Pantanal, one of the largest tropical wetlands in the world, in addition to the high biodiversity found there, fisheries are an important ecosystem service mostly supported by migratory fishes. We estimated the current range of migratory fish of commercial interest, also assessing the climate change effects predicted on the distribution patterns. Then, we assessed the effects of future climate on fish richness, and combining species ranges with routes blocked by artificial dams investigated possible impacts on fishery and food security in the UPRB. Climate change will induce range contraction between 47% and 100% for the species analyzed, and only four migratory fish may have suitable habitat until the end-of-century. The local richness will reduce about 85% in the basin. River fragmentation by dams acting together with climate change will prevent upstream shifts for most fish species. About 4% of present range and up to 45% of future range of migratory fish should be blocked by dams in UPRB. Consequently, this will also negatively affect fishery yield and food security in the future.

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1. Introduction

Climate change influences the hydrological aspects altering river water levels, river flow and flood regimes in inland waters (Xenopoulos et al., 2005; Ficke et al., 2007; Van Vliet et al., 2011). In response, it is expected that freshwater species ranges (i.e., geographic distribution area) will contract or expand following favorable climate conditions (Pecl et al., 2017). Fish species are sensitive to changes in environmental conditions (Ruaro et al., 2019), since migratory fish synchronize their growth and reproduction with temperature and rainfall conditions (Lopes et al., 2017). Fish assemblages are rearranged, and local richness patterns shift according to suitable habitats available in the geographical space (Lawler, 2009). When climate change interacts with anthropogenic activities, the harmful effects on the freshwater ecosystem and its biodiversity are amplified (Reid et al., 2019). Specifically, river fragmentation by hydroelectric power plants (hereafter, dams) modifies local habitats, decreases river–floodplain connectivity, and blocks migration routes affecting the life cycle of migratory species (Agostinho et al., 2008; Latrubesse et al., 2017). Given that freshwater fish are confined to watershed boundaries and have limited dispersal capacity due to natural barriers of riverine landscapes, climate modifications could cause severe and lasting damages on fish fauna, since they cannot easily to find a suitable habitat (Grant et al., 2007). Therefore, the combined effects of climate change and river fragmentation amplify the threats to ichthyofauna both by the loss of habitats suitable and splitting the fish distribution area, respectively (Carvajal-Quintero et al., 2019; Dias et al., 2017; Herrera-R et al., 2020).

Migratory fish depend on river connectivity to move upstream-downstream to find suitable habitats for reproduction and feeding (McIntyre et al., 2016). These species are considered keystone species because they affect energy flow and material transport across the entire river basin (even in the adjacent terrestrial system) via subsidies, disturbance, and trophic interactions (Flecker et al., 2010, McIntyre et al., 2016). Also, some species are effective seed dispersers and reductions in their abundance or functional extinctions also negatively impact terrestrial ecosystems (Araújo et al., 2021). However, migratory fish are disproportionately threatened compared to other fish groups (Darwall and Freyhof, 2016) because they depend on different and spatially distant habitats to complete their life cycle, being more exposed to threats of freshwater ecosystems (Robinson et al., 2009; Reid et al., 2019) resulting in global decline (Deinet et al., 2020). Most migratory fish are larger animals and have high-quality animal protein making them targets in the inland fisheries that often concentrate only a few species of the total diversity (Agostinho et al., 2005; Hallwass and Silvano, 2016; Duponchelle et al., 2021).

Freshwater fish of tropical watersheds are expected to be highly affected by climate change and river fragmentation by dams (Radinger et al., 2017; Herrera-R et al., 2020; Barbarossa et al., 2021). The fishery ecosystem service for traditional local communities on tropical regions are based on the extraction of fish directly from the river and mostly supported by migratory fishes (Mateus et al., 2011; Lynch et al., 2016; Phang et al., 2019). In this sense, if climatically suitable habitats for the target species of fishing cease to exist, fisheries and food security will be negatively affected (Sabo et al., 2017). Knowledge about how climate change effects on freshwater fish could be reflected in fishery ecosystem services is still in its infancy. In this context it is important to emphasize that the ecosystem services provided by freshwater fish represents a socio-ecological question and actions are necessary to conserve them to ensure income and food for millions of people worldwide (Phang et al., 2019). Then, it is necessary to assess the combination of the effects of climate change and river fragmentation by dams on fishery resources in order to create strategic management plans focused on fish at large spatial scales and evaluate the costs and benefits of hydropower on socio-ecological issues (Ziv et al., 2012; Barbarossa et al., 2020).

Here, we assess the climate change effects on freshwater migratory fishes and the potential impacts of the river fragmentation by dams on fishery resources in the Brazilian Upper Paraguay River Basin (UPRB). Predictions of future extreme climate events (Marengo et al., 2016; Thielen et al., 2020), and impacts of planned hydroelectric plants on fish migratory routes in the UPRB (Medinas de Campos et al., 2020) show how this watershed tends to be impacted in the future. Yet, regional species-level assessment of the combined effect of climate change and river fragmentation by dams is lacking. We used Ecological Niche Models (ENMs) to evaluate the effects of climate change on the spatial and temporal distribution patterns of migratory fish of interest in commercial fishery in the UPRB. We first predict their potential distribution at current time until the end-of-this century (2030, 2050, 2070, 2090) and identify the main environmental variables that drive the species distribution patterns. Next, we evaluate the current and future richness patterns and predict that in future scenarios there will be loss of species richness in the river basin. Then, we overlap scenarios of potential migration routes blocked by dams (Medinas de Campos et al., 2020) under potential distribution of migratory fish to predict the loss of suitable habitats at current time due to hydroelectric operating, and to evaluate the loss of suitable habitats with the installation of planned and operating hydroelectric power plants in the watershed. Finally, we evaluated the prospective implications that climate change and dams may have on fisheries and food security, and hence on the life quality of traditional human populations of the UPRB.

2. Material and methods

2.1. Study area

The Upper Paraguay River Basin (UPRB) located in Central South America is one of the most aquatically diverse watersheds in the world with about 300 fish species described (Britski et al., 2007; Harris et al., 2005; Junk et al., 2006). Although UPRB cover Paraguay, Bolivia, and Brazil, its largest area 361,338 km^2, 61% is in the Brazilian states of Mato Grosso and Mato Grosso do Sul (Thielen et al., 2020; Fig. 1). It encompasses the Pantanal, a large tropical wetland and Ramsar site, highly dependent on hydrological flooding for ecosystem functions (Junk et al., 2014). Surrounding the UPRB is the Planalto (plateau) region, a high relief where the rivers that supply the Pantanal flow from (Girard, 2011). The climate is tropical-humid, with a mean annual temperature between 22.5 and 26.5 °C, and precipitation ranging from 800 to 1600 mm. The rainy season is between October and April, while the dry season is between May to September (Alvares et al., 2013).

The elevation difference between the plateau and floodplain supports the hydroelectric potential that attracts the energy sector to the region (Ely et al., 2020). However, stopping access to the river headwater is worrying because migratory fish have seasonal movements upstream in the Planalto region to spawn, since these water bodies represent their reproductive sites (Costa and Mateus, 2009; Ziober et al., 2012; Barzotto and Mateus, 2017). For this study, we included data from the Brazilian portion of UPRB that is divided into 11 sub-basins in the central sub-basin of the Pantanal and others distributed in the Planalto region (ANA, 2018; Fig. 1). Here, we consider data available for 36 hydroelectric plants in operating in the Brazilian area of the UPRB, 29 are categorized as small hydroelectric plants (SHP) and seven are considered large hydroelectric plants (LHP). The sub-basin of the Paraguay River has the largest number (15) of hydroelectric plants operating, followed by the São Lourenço (9), Cuiabá (7), Itiquira (4) and Taquari (1) rivers. There are already 104 planned projects, 101 SHP and three LHP. The sub-basins with the largest number of planned projects are the Paraguay with 41 projects, followed by the Taquari (29), Cuiabá (12), São Lourenço (10), Itiquira (7), Negro (4) and APA (1). There are no hydroelectric plants operating or planned in the sub-basin of Pantanal, Aquidauana, Miranda and Nabileque (Medinas de Campos et al., 2020; Fig. 1).

2.2. Species data and conservation status

We obtained presence records for fish species from ichthyology experts' fieldwork and online databases (see online Supplementary Material - Species data). We considered a total of 542 occurrence records of

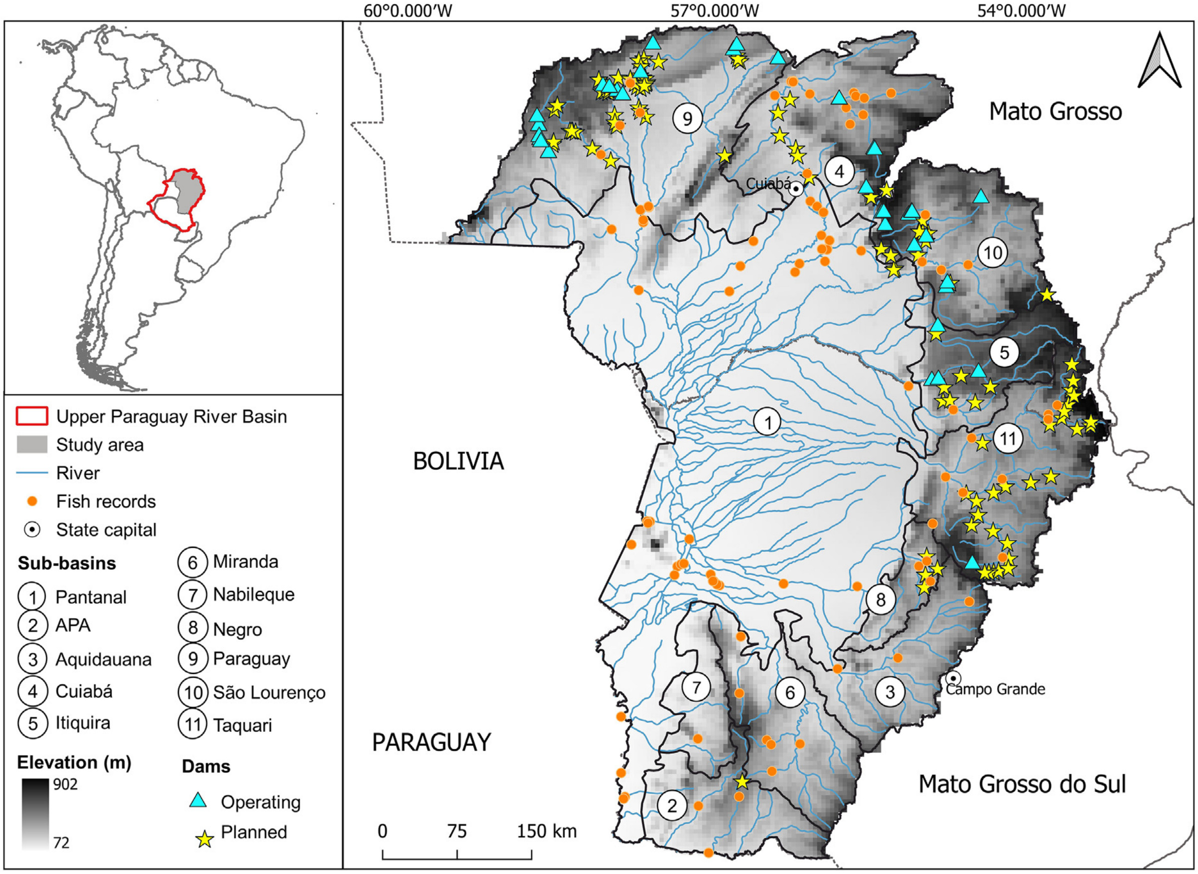

Fig. 1. Study area. The Upper Paraguay River Basin is situated in central South America. Highlight to occurrences records of fish sampling, sub-basins and the locations of the operating hydroelectric and planned future in study area in Brazil.

14 freshwater fish species, belonging to five families and two orders (Supplementary Material - Table S1). Our final dataset contains migratory fish species (Carolsfeld et al., 2003) which commercial and recreational importance is based on past studies that included interviews or reports about fish landings in the PHR (Netto and Mateus, 2009; Mateus et al., 2011; Catella et al., 2016; Massaroli et al., 2021).

We included native fish species important for commercial fishing, those used for recreational fishing such as *Salminus brasiliensis* and *Metynnis mola* (Table S1). Regarding the conservation status, the species such as *Piaractus mesopotamicus*, *Pseudoplatystoma corruscans*, *Brycon hilarii*, and *Zungaro jahu* are classified as near threatened (NT), other species are classified as least concern (LC) and three not included in Red List (ICMBio/MMA, 2018).

2.3. Environmental variables

We used 19 bioclimatic and elevation variables as possible predictors at 2.5 min (~21 km^2) resolution from the WorldClim database version 2.1 (https://worldclim.org/data/wordclim21.html; Fick and Hijmans, 2017), being the current time refers to climate data an average of data from 1970 to 2000 (Table S2). To avoid problems associated with multicollinearity, the predictors were selected by the variance inflation factor (VIF, Zuur et al., 2010) and we retained only the variables with VIF values <10 (Dormann et al., 2012) and correlation value |0.5| using the function *vifstep*() and *vifcor*() from R package sdm (Naimi et al., 2014; Naimi and Araújo, 2016). The retained predictor for species modeling were temperature annual range (BIO 7), precipitation of warmest quarter (BIO 18), precipitation of coldest quarter (BIO 19), and elevation.

We also used the same subset of environmental variables projections to 2030, 2050, 2070, and 2090 available on Wordclim 2.1 version. The projection climate for 2030 corresponds to time period data from 2021 to 2040, 2050 corresponds from 2041 to 2060, 2070 corresponds from 2061 to 2080 and 2090 corresponds from 2081 to 2100. We used the downscaled data from three general circulation models (GCMs), namely BCC-CSM2-MR, CanESM5, and MIROC6 (CMIP6, Eyring et al., 2016). These GCMs characterize the wide variety of models based on the latest update on expected future climate change projections (Brunner et al., 2020), and we used the SSP3-7.0 this scenario is the middle term between the optimistic and pessimistic scenarios and predicts an atmospheric temperature increasing of up to 4.1 °C on average until the-end-century (Eyring et al., 2016).

We used two methods to determine the importance of the variables: Estimate the importance of each variable in the model, the higher the value, more importance the predictor variable has on the model (Murray and Conner, 2009) and show the relationship between the probability of occurrence of the species and each climate variables. For each plot, the response is modeled for one climate variable while the other environmental variables are held constant at its mean (Elith et al., 2005). For this, we used the function *varImp*() and *rcurve*(), respectively, available in the R package sdm (Naimi and Araújo, 2016).

2.4. Ecological Niche Models

The spatial distribution records were associated with environmental data to characterize environmental conditions experienced by species to predict their potential geographic distribution (Peterson et al., 2011). We used the sdm package (Naimi and Araújo, 2016) to develop the ensemble forecasting (Araújo and New, 2007) of ecological niche modeling (Peterson and Soberón, 2012), and the output models were combined to generate a single prediction. For each species, we used eight models of conceptually and statistically different, likelihood-based estimators. Two adopted for presence-only data: Domain (Gowar distance; Carpenter et al., 1993), and Bioclim, and six based on regression and machine learning use presence and pseudo-absence data (or background data): Generalized

Linear Models ('glm'), Generalized Additive Models ('gam'), Flexible Discriminant Analysis ('fda'), Multiple Adaptive Regression ('mars'), Support Vector Machine ('svm') and Boosted Regression Trees ('brt', Friedman, 2001). We generated a random sample of 10,000 sites for the modeling of each species (with minimum 23 occurrences) and used 30 runs of subsampling or bootstrapping (for five species with occurrence records below 30) replication methods by splitting data into training and test datasets (70:30). Models were parameterized using default options of the sdm package (Naimi and Araújo, 2016).

The predictive performance of models followed the overall statistics of the combined model, those with highest values of the Area Under the Curve (AUC) and True Skill Statistic (TSS). The AUC metric aggregates the ROC (Receiver Operating Characteristic) threshold whose values range between 0 and 1, where models with AUC values closer to 1 have better fit (Jiménez-Valverde, 2012). The TSS metric considers the error of commission and omission (Sensitivity + Specificity −1), with values ranging from −1 to +1, where values closer to −1 predictive abilities unimproved from a random model, while values closer to zero indicate a low performance randomly expected, and values closer to +1 indicate a perfect fit, and minimize both overprediction and omission error rates (Allouche et al., 2006). The current and future ensembles were weighted according to the TSS criterion. The average of GCMs was calculated for future projections ensembles. The continuous suitability predictions of each ENM were converted into a binary map for each species, the number of occupied pixels (i.e., species presence) corresponds to potential range. Next, we overlapped binary maps of all species and created a richness map for each time. The maps were on regular geographic grid with 31,005 pixels in a spatial resolution of the 4625 km of latitude and longitude (~21 km^2 of area). All analyses were conducted using the R program (R Core Team, 2020).

2.5. Impact to river fragmentation by dams under potential range of migratory fish and fishery

We used the raster generated by Medinas de Campos et al. (2020), where they identified natural and artificial barriers in the river system in the UPRB. Barrier rasters have three categories: accessible rivers, naturally blocked rivers and rivers blocked by dams (more details in the Supplementary Material - Barrier Raster). To evaluate the impact of river fragmentation by dams under potential range of fishes, we combined the barrier raster with binary maps (presence/absence) of current and future (2030) range of each migratory fish resulting in three scenarios: (i) accessible river and present species; (ii) naturally blocked rivers and present species; and (iii) rivers blocked by dams and present species. There weren't any combinations with blocked rivers and the absence of species in any time period. We measured the percent of potential range of migratory fish that was or could be blocked by artificial dams.

In addition, we assess how fisheries will be impacted in the sub-basin perspective. First, we quantify the locals (i.e., pixels) that have one to 14 species present in the richness map of each period named as suitable habitat available. Therefore, we assume that these suitable habitats available are fishing areas based on the local richness of fish. Next, we overlapped the barrier raster with current and future (2030) fish richness map and calculated the percentage of the suitable habitat available that was or could be blocked by artificial dams (Supplementary Material - Fig. S1). We used two rates of dam construction, in the current scenario considering the location of the 36 hydroelectric plants in operation, and in the future scenario considering the location of all planned (104) and current operation, summing 140, in the UPRB. These combinations were done using maps of current time and future (2030) generated in ENMs. We choose 2030 because it is the climate change future scenario with minor loss of habitat suitable for fish species being possible to evaluate the dam effect in the species potential range under climate change.

3. Results

The consensus model for the selected species had a good accuracy (mean ± SD, AUC 0.8 ± 0.03, TSS 0.6 ± 0.06; Table S3). The species *Myloplus levis* had the best predictive fit (AUC = 0.84; TSS = 0.64), while *Brycon hilarii* showed the worst fit (AUC = 0.73; TSS = 0.44). According to relative importance, the suitability of this fish subset in the UPRB was driven by the elevation, precipitation of coldest quarter (BIO 19), temperature annual range (BIO 7) and precipitation of warmest quarter (BIO 18; Supplementary Material - Fig. S2). The occurrence probability of the species follows the optimal response curve for elevation, precipitation of coldest quarter and temperature annual range, with the highest probability occurrence in sites with elevation below 250 m, precipitation between about 50 mm and 150 mm and air temperature varying from 17 °C to 18 °C (Fig. S3).

3.1. Climate change scenarios

The current local richness of migratory fish inhabiting the UPRB is concentrated in the sub-basins of the Pantanal, Paraguay, and Cuiabá rivers. The sub-basins of the São Lourenço, Itiquira, Taquari and Miranda show some richer sites (dark blue pixels; Fig. 2). The fish species *Mylossoma duriventre*, *Salminus brasiliensis* and *Myloplus levis* show greater potential range in current time, occupying more 4500 pixels (Fig. 3). In 2030, spatial patterns are predicted to drastically change due to the expected reduction in local diversity and the few richer sites should maintain roughly 85% of current fish species (Fig. 2). In addition, we expect an expressive retraction of the fish potential range in 2030 of between 48% and 100% compared to the current time in the UPRB (Table S4). For species *Megaleporinus macrocephalus* is predicted to lose its entire potential range in 2030 (Fig. 3). In 2050, the spatial pattern will change again, as there will be a decrease of richness and suitable habitats for fish in relation to the estimated values in 2030 (Fig. 2). The local richness in the UPRB decreasing 29% in 2050 (Fig. 2), with loss of entire range of the species *M. obtusidens* and *P. corruscans* (Fig. 3). The forecast to 2070 is that the fish richness reduces 86% (Fig. 2) and 78% of the migratory fish loss entire potential range (Fig. 3). In 2090, richer sites will maintain only 14% of current richness in few areas of UPRB at the sub-basin of the northern Pantanal and Paraguay (Fig. 2). The species of *Myloplus levis*, *Mylossoma duriventre*, and *Pseudoplatystoma reticulatum*, will be the only fish with suitable habitat in 2070 and 2090 (Table S4). However, most fish species (78,6%, 11 species) such as *Piaractus mesopotamicus*, *Pseudoplatystoma corruscans* and *Brycon hilarii* will have had their entire potential range lost in the UPRB in the coming years (Fig. 3; Table S4). Overall, future climate projections reveal a progressive reduction in the suitable area over time, with a richness of migratory fishes decreasing 86% until the end-of-century (2090; Fig. 2), together with the expressive reduction of potential range of species fish (Fig. 3).

3.2. Climate change and river fragmentation by dam scenarios

The outputs of overlap among the species range and barrier raster showed that operating hydropower facilities block up to 4% of the potential distribution of all migratory fish in current scenario, except for *Megaleporinus macrocephalus and Metynnis mola* which their potential range were not impacted by artificial dams in any scenario (Fig. 4A). The catfishes (order Siluriformes) *Zungaro jahu*, *Pseudoplastysoma corruscans*, *P. reticulatum*, and *Hemisorubim platyrhynchos* have between 2% to 4% of their potential range interrupted by artificial dams in operation (Fig. 4A). The highest proportion of suitable habitat available which are blocked by artificial barriers occurs in the sub-basins of the Cuiabá, São Lourenço and Paraguay, estimated loss in current scenario of up to about 10%, 7% and 6% respectively (Fig. 4B). Future scenario considering both operating and proposed dams may be more critical. Many species will have their potential range about 45% strongly reduce by dams in the near future, as *Megaleporinus obtusidens* (Fig. 4A). However, *Brycon hilarii*, an agile fish

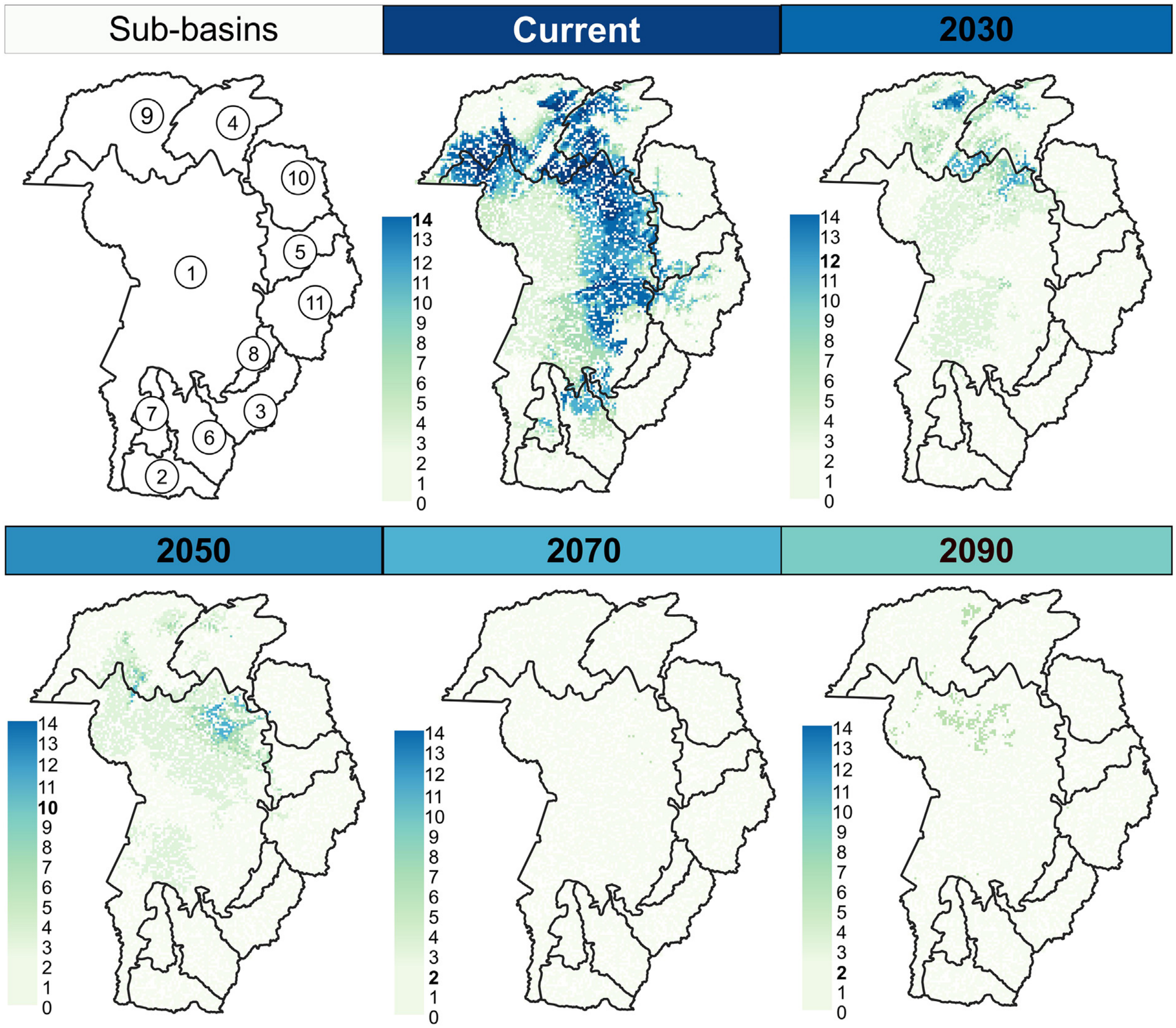

Fig. 2. Spatial patterns of the richness of migratory fish in the Upper Paraguay River Basin, Brazil. Observed the sub-basins: ① Pantanal, ② APA, ③ Aquidauana, ④ Cuiabá, ⑤ Itiquira, ⑥ Miranda, ⑦ Nabileque, ⑧ Negro, ⑨ Paraguay, □ São Lourenço, □ Taquari and richness pattern predicted considering the migratory fish at current time, 2030, 2050, 2070 and 2090 under climate change SSP3-7.0 scenario. The richness of each time period is indicated in bold.

with ability for jumping, may have about 27% of potential range blocked by hydropower. In sub-basins scale, commercial fisheries may face reduction due to loss suitable habitat available for migratory fish of until 85% of the Taquari, 67% of the Cuiabá, 12%of the Negro and 10% of the Paraguay (Fig. 4B). Therefore, habitat loss by artificial dams is concentrated mainly in the Planalto region where the hydropower plants currently exist or will be installed (Fig. S4).

4. Discussion

Climate change and river fragmentation by dams will reduce the areas climatically suitable for the occurrence of migratory fish and reshuffle the species distribution across the Upper Paraguay River Basin under future conditions. The potential range retraction predicted for the future reveals the vulnerability of these fishes to climate change progressive loss of suitable areas for species occurrence from 2030, which tends to boost extinction processes in the river basin. Only four migratory fishes would have suitable habitat until the end-of-century. Because there is the need for upstream migration to reproduce, migratory fish would be potentially impacted by dams that block most suitable habitats for spawning and initial development in high areas of the Planalto region. Therefore, fish stocks and food security are threatened by climate change and the future deployment of hydroelectric plants in the UPRB.

Temperature increases are the primary driver of temporal species richness (Buisson et al., 2008), but precipitation indicator as in the warmest and coldest quarter (BIO 18 and BIO 19, respectively) are critically important to freshwater fishes in the tropical areas (Morrongiello et al., 2011; Manjarrés-Hernández et al., 2021). Although many other variables influence fish species distribution, temperature and precipitation can appropriately characterize climatic niches because they are directly related to hydrological aspects. In the UPRB, the fish reproductive period occurs between October and March, which coincides with the onset of rain and the highest annual temperatures (Carolsfeld et al., 2003; Bailly et al., 2008; Costa and Mateus, 2009; Tondato et al., 2010; Ziober et al., 2012). However, precipitation of the coldest quarter (between June to August) was a driver to habitat suitability for migratory fish indicating the importance of rain volume at large scale for reproduction period preceded by gonadal maturation (Barzotto et al., 2017; Barzotto and Mateus, 2017). Locally, migratory fishes have their biological events synchronized with climate patterns (Bailly et al., 2008) and our results emphasize the importance of the cyclical periods of flood and drought for fish life cycle from the species distribution perspective in the UPRB. Global warming has altered both thermal regime and rainfall frequency and directly impacts freshwater ecosystems (Nickus et al., 2010). Intense or moderate flood duration could benefit fish reproductive activity (Bailly et al., 2008), while frequent drought could raise the loss of suitable habitat for fish (Matthews and

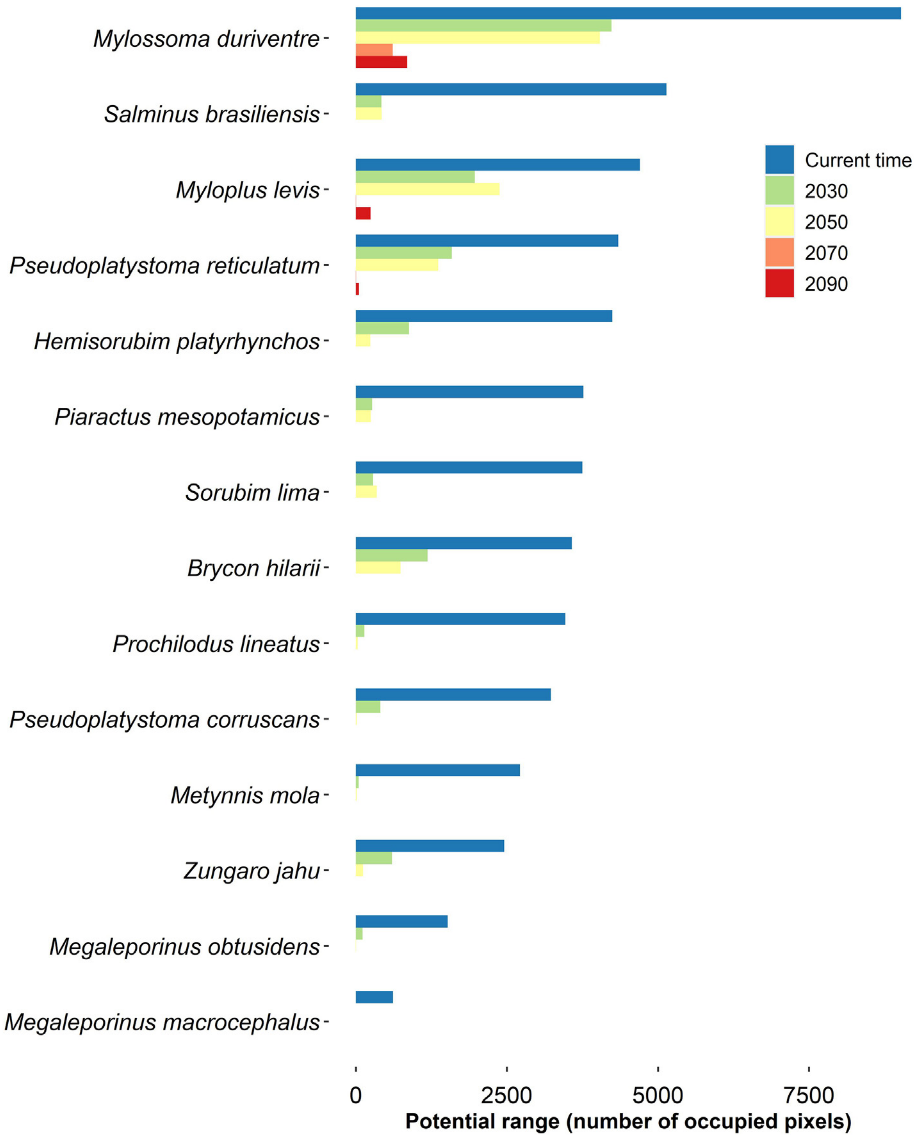

Fig. 3. Potential range of migratory fish to current time and predicted until end-the-century at the Upper Paraguay River Basin, Brazil. The potential range is estimated based on suitable gradients generated by the consensus model and converted into modeled presence and absence values and corresponds to the number of occupied pixels in each time period.

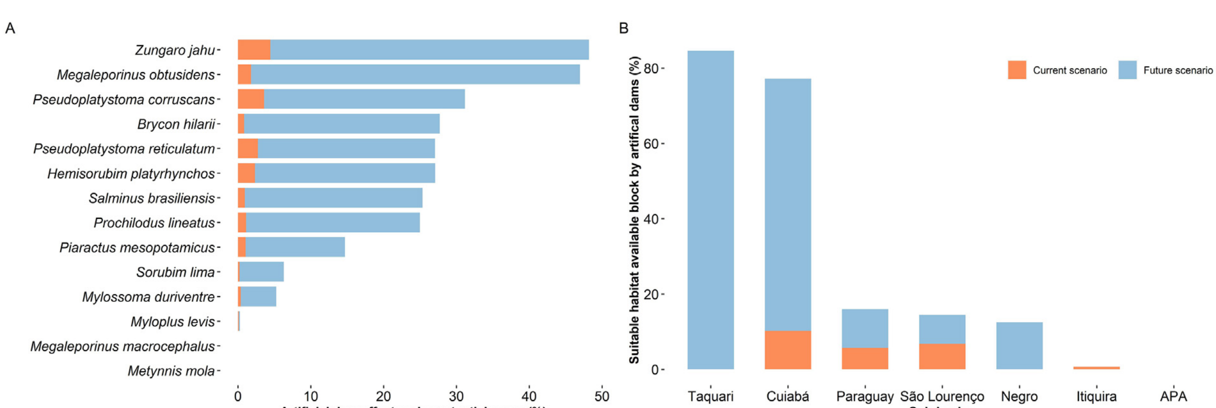

Fig. 4. Artificial dam effect under A) Potential range of the migratory fish, and B) Sub-basins in the Upper Paraguay River Basin, Brazil. In current scenario corresponds to the effect of the 36 operating hydroelectric plants, while the future scenario considering the effect of all planned (104) and operating, summing 140 hydroelectric plants in the UPRB. The species *Megaleporinus macrocephalus* and *Metynnis mola* which their potential range were not impacted by artificial dams in any scenario. The sub-basins of Pantanal, Aquidauana, Miranda and Nabileque not have any hydroelectric plants in operating or planned.

Marsh-Matthews, 2003; Penha et al., 2015; Frederico et al., 2016; Röpke et al., 2017).

Freshwater conservation implies safeguarding of the connectivity between main channel river and headwaters (McIntyre et al., 2016) to maintain fish migration and development (Carolsfeld et al., 2003; Silvano et al., 2009) and long-term population persistence. Our results alert to possible future negative consequences caused by both climate change and hydroelectric plants that should modify the spatial pattern of fishery resources in the UPRB. Tropical species tend to be close to their upper tolerance limits of warmer conditions (Deutsch et al., 2008), and the presence of dams should prevent fishes from track their climate niche, limiting their populations to small areas (Comte and Grenouillet, 2013; Myers et al., 2017; Kano et al., 2016). Moreover, future hydroelectric plants in the UPRB will impose barriers for suitable habitats by preventing species access to breeding areas and, consequently, decreasing long-term persistence of the fish stocks. Large-bodied catfish are the most harmed by dam effect (Fearnside, 2014) including both upstream and downstream impacts which have been already observed in the Tocantins River (Ribeiro et al., 1995) and the Madeira River (Santos et al., 2018; Damme et al., 2019). There are many direct effects of river fragmentation by dams such as species abundance decrease, local extinction, and mortality increase which have been observed in freshwater fishes around the world (e.g., Gehrke et al., 2002; Agostinho et al., 2008; Pelicice et al., 2015; Mueller et al., 2020). The loss of frugivorous fishes (*P. mesopotamicus*, *B. hilari*; Araújo et al., 2021) or relevant species in top-down community regulation (*P. corruscans*, *P. reticulatum*, *S. brasilensis*; Barthem and Goulding, 1997; Hahn et al., 2011) will likely affect entire aquatic taxonomic groups (Estes et al., 2011; Bauer and Hoye, 2014) altering biotic interactions and creating imbalance in the ecosystem (Comte et al., 2013).

Besides ecological importance, freshwater fish conservation has a social importance for income and food security (Lynch et al., 2016). It is predicted that if all the planned dams are constructed in the UPRB, there will be twice the current number of potential migration routes blocked, which may directly impact fishing productivity (Medinas de Campos et al., 2020). Contracting or change in the species ranges caused by climate change exposition (Rogers et al., 2019) or by implementation of new hydroelectric plants (Agostinho et al., 2008; Monaghan et al., 2020) could reduce fishing grounds, which will be necessary the displacement of fishermen to caught of the target species. Here, the sub-basins of the Cuiabá, Paraguay, and Taquari would be more exposed to food insecurity and economic loss but the consequences of hydroelectric development in the UPRB would reach the entire fishery chain. The social impacts include a decrease or loss of fishermen income that depend on fishing for their subsistence and will impact many riverine families. Secondary fishing economic sectors such as bait trade, ice factories, fishing equipment suppliers, restaurants, boats, hotels, and others could also been damaged (ANA, 2020). The impacts on the local economy may bring losses between US$ 86 and 139 per person per day (Shrestha et al., 2002), for example, annual economic value of the recreational fishery in a stretch of Cuiabá River was estimated at around US$ 1.8 million (Massaroli et al., 2021). The benefits of ecosystem services provided by freshwater biodiversity can increase the need to protect and conserve ecological interests in an increasingly economic era (Cowx and Portocarrero Aya, 2011; Daily, 2000). In the UPRB, the overload of fishing modalities (subsistence, commercial, and recreational) and other conflicts involving the freshwater system call for rigorous control of existing laws and implementing conservation policies as soon as possible. However, the ideal integration has not been achieved for the entire UPRB and mainly actions for freshwater conservation depends on quality water and healthy habitat (Phang et al., 2019). Unfortunately, there are many challenges for an effective management for freshwater conservation mainly due to vast areas, understaffing of management agencies responsible for fisheries and the lack of public policies in Brazil (Arlinghaus et al., 2021). For example, conservation initiatives such as creation of protected areas (PAs) predominantly focus on terrestrial biodiversity limiting to conserve freshwater groups. There is evidence that current PAs in the Paraná-Paraguay Basin have seriously failed to protect migratory fish species (Bailly et al., 2021).

Since 80's, the URPB Brazilian states have led to the loss of natural water surface, mainly in the Pantanal (MapBiomas, 2021). The implementation of hydroelectric power contributes to reducing the natural water surface, because stock water in reservoirs alters the dynamic of rivers (Castello and Macedo, 2015; Olden and Naiman, 2009). In the Pantanal, the weakening of flood pulse affects all biodiversity and the hydrological regime because it restructures and promotes changes in biotic communities due to environmental alterations during the transition from a terrestrial to aquatic area (Junk and Cunha, 2005). Sustainable economic development is urgent and necessary around the world. If the economic cost implies loss of environmental integrity and people's quality of life, this would be unfeasible in the long term. New solutions should comprise biodiversity maintenance, food security and clean energy production (Ziv et al., 2012). We used an effective tool to predict the potential distribution of freshwater fish and identified where the best strategies for tracking the ecological impacts of climate change will be most needed (Valencia-Rodríguez et al., 2021). However, the ENMs are not free from uncertainties because its estimates are based on environmental conditions disregarding important factors for the species distribution such as evolutionary factors, dispersion, and biotic interactions (Soberón, 2007; Peterson et al., 2018) and sampling biases. Therefore, due to high predictive uncertainty there must be a conservative interpretation of our results that combine climatic and ecological data at macroscale for commercial fisheries in the UPRB that expose the vulnerability of freshwater fish in the face to climate change. To face the challenge of incorporating the climate change perspectives to biodiversity conservation planning, science-based actions are needed to align the conservation measures to enhance the effectiveness of protected areas. In addition, maintaining ecological and social functions of freshwater habitats, and conserving migratory fish are important issues in the current global emergency context of the migratory fish decline. We highlighted that sustainable conservation of freshwater life is a way to provide food, drinking water, and income to the population in the future without damage to this megadiverse ecosystem.

Data accessibility

The information that supports the finding of this study are available in online Supplementary Material.

CRediT authorship contribution statement

Luiza Peluso: Data curation, Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. **Priscila Lemes**: Conceptualization, Methodology, Supervision, Writing – Reviewing and Editing. **Lúcia Mateus**: Data curation, Investigation, Supervision, Writing – Reviewing and Editing. **Jerry Penha**: Data curation, Investigation, Writing – Reviewing and Editing. **Dayani Bailly**: Data curation, Writing – Reviewing and Editing. **Ibrahim Fantin-Cruz**: Data curation, Resources. **Fernanda Cassemiro**: Visualization, Writing – Reviewing and Editing. **Yzel Suárez**: Data curation, Resources, Writing – Reviewing and Editing. **Elaine Kashiwaqui**: Resources. All author contributed critically with the manuscript and gave final approval for publication.

Declaration of competing interest

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.

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Appendix A. Supplementary data

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