MARINA OLIVEIRA LOUZADA

MIGRATORY FISH HABITAT FRAGMENTATION BY HYDROPOWER DAMS: HISTORY AND TRENDS FOR THE SÃO FRANCISCO AND PARAÍBA DO SUL RIVER BASINS

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Orientador
Prof. Dr. Paulo dos Santos Pompeu

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FRAGMENTAÇÃO DE HABITAT DE PEIXES MIGRATÓRIOS POR USINAS HIDRELÉTRICAS: HISTÓRICO E TENDÊNCIAS PARA AS BACIAS DO SÃO FRANCISCO E PARAÍBA DO SUL

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Aprovada em 11 de Agosto de 2017

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RESUMO GERAL

A manutenção da conectividade longitudinal e dos fluxos naturais dos rios é crucial para a preservar a abundância e a diversidade dos peixes migratórios de longa distância. Usando uma análise quantitativa baseada em mapas, analisamos o processo de fragmentação dos rios da Bacia do rio São Francisco (SFRB) e da Bacia do rio Paraíba do Sul (PSRB), no Brasil. Neste trabalho, desenhamos diferentes cenários para a fragmentação, quantificando esse processo em uma perspectiva histórica e potencial levando em consideração o estado atual e futuro da bacia hidrográfica. Determinamos também o provável número de espécies migratórias em todas as extensões lóticas remanescentes. Observamos a presença de um maior número de espécies migratórias em fragmentos iguais ou maiores que 100 km. No cenário futuro observamos que houve um aumento no número de fragmentos, especialmente aqueles iguais ou menores a 50 km, inadequados para manter a maior parte das espécies migratórias. Neste trabalho mostramos a história do desenvolvimento hidrelétrico nas duas bacias e comparamos como essas tendências podem afetar a sustentabilidade futura desses rios.

Palavras-chaves: Hidrelétricas. Peixes migradores. Barragem. Fragmentação. Rios. Bacia hidrográfica.

ABSTRACT

The maintenance of the longitudinal connectivity and natural flows of rivers are crucial for preserving the abundance and diversity of long distance migratory fish. Using a quantitative analysis based on maps, we analyze the fragmentation process of the rivers of the São Francisco River Basin (SFRB) and Paraíba do Sul River Basin (PSRB), in Brazil. In this work, we drew different scenarios for the fragmentation, quantifying this process in a historical and potential perspective taking into account the present and future state of the river basin. We also determined the probable number of migratory species in every reminiscent lotic extension. We observed the presence of a larger number of migratory species in fragments equal or larger than 100 km. On the future scenario, there was an increase in the number of fragments, especially the ones equal or shorter than 50 km, inadequate to hold most of the migratory species. In this work we show the history of hydroelectric development in the two basins and compare how these trends can affect the future sustainability of these rivers.

Keywords: Fragmentation. River basin. Migratory fish. Hydropower dam. Development.

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1 INTRODUÇÃO GERAL

A fragmentação causada por barramentos tem sido apontada como uma das maiores causas de perda de diversidade de peixes migratórios de água doce. Diferente dos peixes salmonídeos, os peixes migradores neotropicais são predominantemente potamódromos, passando assim grande parte de sua vida entre zonas reprodutivas em tributários e zonas de alimentação nas grandes calhas de rios de maior porte. Sendo assim, eles requerem longas extensões de rios não obstruídos para completarem seu ciclo de vida.

Com mais de 4000 espécies registradas, a América do Sul possuí uma das faunas mais ricas e diversas de peixes de água doce do mundo. A construção de barragens hidrelétricas obstruem a passagem de peixes à montante e à jusante dos rios, prejudicando o habitat e as oportunidades de migração de muitas espécies de peixes de água doce. Estudos recentes mostram que mesmo as ações de mitigação, como elevadores e escadas de peixe não são eficientes na facilitação da passagem. Sendo assim, novas alternativas devem ser estudadas e implementadas para evitar perdas dramáticas na fauna de peixes migratórios.

Este trabalho mostra, a partir de uma perspectiva histórica, como o desenvolvimento hidrelétrico vem afetando a bacia do Rio São Francisco (SFRB) e Paraíba do Sul (PSRB), e quais são as tendências à fragmentação por conta de planos de desenvolvimento de potenciais hidrelétricos na região.

2 REFERENCIAL TEÓRICO

Desde a construção das primeiras usinas hidrelétricas no séc. XIX, a porcentagem do uso da força da água como meio de geração de energia elétrica vem crescendo de forma constante e intensa. Com o crescimento da demanda de energia mundial, as usinas passaram a usar de barragens e represas para aumentar o poder de produção. Esses barramentos e seus reservatórios contribuem para outros fatores como abastecimento de água para dessedentação e irrigação, controle da vazão a jusante da barragem, estocagem de peixes, aquicultura, recreação e turismo, uso industrial e para navegação (Matsumura & Tundisi, 2008). Apesar de estar intrinsecamente conectado com as necessidades do mundo moderno e possuir diversos benefícios socioeconômicos regionais, o barramento hidrelétrico vem acompanhado de diversas dificuldades nos âmbitos ambientais e sociais. Nos aspectos ambientais, a regulação do rio e a formação da barragem inundam terras férteis, destroem a flora local, deslocam ou extinguem localmente a fauna terrestre e impactam negativamente as populações de peixes locais, nativos da região, especialmente os migratórios (Agostinho *et al*,. 2007; Carolsfeld *et al*,. *2003*).

Segundo a Agência Internacional de Energia (IEA) a energia hidrelétrica representa 16.5% da produção mundial de energia, perdendo apenas para fontes vindas de combustíveis fósseis (petróleo, carvão e gás natural). No Brasil temos 1.223 empreendimentos em funcionamento, contabilizando 68.5% da energia hidrelétrica produzida no país (IEA, 2013; ANEEL-BIG, 2016). Esses empreendimentos podem ser classificados de várias formas, segundo as orientações do Centro Nacional de Referência em Pequenas Centrais Hidrelétricas (CERPCH, 2015), sendo que a altura da queda d'água e a potência de geração de energia são os maiores determinantes da nomenclatura usada. Sendo assim, 449 dos empreendimentos construídos no Brasil são Pequenas Centrais Hidrelétricas (PCHs), que se caracterizam por ter uma altura de queda d'água entre 25 e 130m e potência de 1 a 30 MW, enquanto as Usinas Hidrelétricas (UHEs), correspondendo a 219 empreendimentos, tem potência instalada maior que 30 MW e queda d'água superior a 130m de altura. As Centrais de Geração Hidrelétrica, que somam os outros 555 empreendimentos, tem potencial inferior ou igual a 1MW, normalmente não possuem reservatórios, são barragens de desvio em rios com acidente natural (ANEEL, 2003).

Sendo uma fonte barata de produção de energia, R$100,00/MWh comparado com R$140,00/MWh das termelétricas (CEMIG, 2012), as hidrelétricas se espalharam pelos rios do país, se concentrando majoritariamente (mais de 80%) na região Sul e Sudeste (Agostinho *et al*, 2007). O crescimento da construção de reservatórios no Brasil deslanchou em 1940, quando um grande número de hidrelétricas começou a ser instalado em diversos rios, principalmente nas bacias dos rios Paraná e Paraíba do Sul. Através de incentivos governamentais e planos de aproveitamento dos cursos d'água, observou-se na década seguinte um aumento ainda mais acentuado no número de reservatórios chegando a construção de quase 50 barragens entre 1950 e 1959 (Agostinho *et al*, 2007).

Certas peculiaridades chamam à atenção quanto à caracterização das represas hidrelétricas no Brasil. Por ter rios de grande porte drenando as principais bacias do país, boa parte de suas UHEs foram construídas na calha de maior porte, formando grandes barragens e extensos reservatórios. Em um estudo de 2014, Pelicice *et al.* mostram que das 66 barragens encontradas nas calhas principais das bacias brasileiras, 78% possuem reservatórios com uma área maior que 50km², enquanto 28% possuem áreas maiores que 500km². Adicionalmente, em várias bacias os reservatórios das represas estão dispostos em cascata ao longo do eixo longitudinal do rio, criando uma série de barreiras ecológicas (Pelicice *et al.*, 2015). Estes são fatores importantes porque não só mostra a extensão da área que foi afetada pela inundação da região, mas também nos mostra o tamanho do impacto ambiental causado pelos empreendimentos.

O represamento de um rio é um processo tão intenso e dramático que resulta na criação de um novo ecossistema (Baxter, 1977). Esse impacto é especialmente intenso para os peixes migratórios por conta do efeito da barragem e do reservatório no seu ciclo de vida. Durante a estação chuvosa, os peixes adultos migram rio acima para desovar, após a qual os ovos e larvas são transportados passivamente através da corrente para berçários naturais, nas áreas produtivas das planícies de inundação a jusante. Após o evento reprodutivo os peixes adultos passam por uma migração de retorno, voltando à jusante dos rios para habitats adequados para a alimentação (Agostinho & Zalewsky, 1995; Lowe-McConnell 1999;. Pompeu *et al*. 2012). Da mesma forma, os ovos, que são livres, são carreados para jusante, em direção às planícies de inundação (Carolsfeld *et al.*, 2003). Peixes migratórios têm um alto valor social e comercial e, por requererem longos trechos de rio e regimes de cheias naturais para que consigam concluir seu ciclo de vida (Carolsfeld *et al.*, 2003), são altamente afetados pela fragmentação dos rios e pelas mudanças no regime hidrológico natural por conta das represas.

Para entendermos melhor o efeito que um empreendimento como esse tem nos peixes migratórios é necessário entender também que a construção dos barramentos modifica a entrada da matéria orgânica nas teias tróficas ao regularizar o fluxo de água no rio e pela retenção de nutrientes no reservatório (Agostinho *et al.*,2009), assim como reduz ou impede a comunicação do rio com as várzeas, restringindo as possibilidades de alimento (Agostinho *et al.*, 2008). O reservatório e a barragem servem como barreiras ecológicas, seja por apresentar condições ambientais completamente diferentes do regime fluvial original do rio, como no caso da represa, ou pelo simples impedimento físico como é o caso do barramento (Pelicice *et* al., 2015). O resultado desse conjunto de alterações físico-morfológicas do rio é o isolamento genético, a diminuição ou completa alteração das populações de peixes, dificuldade na dispersão de ovos, larvas e adultos rio abaixo, entre outros (Suzuki, 2011; Pelicice et al. 2015; Agostinho *et al*,2007; Jager *et* al., 2001).

Para mitigar os impactos ambientais das barragens sob os peixes migratórios, o licenciamento exige frequentemente a construção de estações de piscicultura ou a construção de passagens para peixes. Esses últimos visam, entre outras coisas, aumentar a conectividade longitudinal do rio, ao prover uma escada, ou outra forma de passagem, vindo de um lado da barragem ao outro. Vários estudos recentes têm mostrado que as passagens de peixes construídas na América do Sul, bem como os peixamentos, tem se mostrado ineficazes, sendo que até agora não conseguiram restabelecer populações viáveis de peixes migratórios, sendo que seus estoques continuam em franco declínio (Agostinho *et al*., 1997; Pelicice & Agostinho 2008; Pompeu *et al*., 2012). Portanto, outras medidas para evitar a perda da biodiversidade aquática se fazem necessárias.

Diversos países vem adotando o descomissionamento de barragens como maneira de restaurar a estrutura e comunidade aquática, obtendo resultados expressivos (Scully *et al.,1990*; Roni *et al.*,2002). É importante perceber também o impacto global que o barramento infringe na bacia hidrográfica. O planejamento adequado da distribuição das hidrelétricas se faz uma alternativa crucial, assim como a manutenção de grandes trechos de rios sem barramentos na forma de rios de preservação permanente (Pompeu, 2012). Somente assim seria possível manter, em cada bacia hidrográfica, uma sessão de rio suficiente para a manutenção das populações das espécies migradoras locais.

Com os planos de desenvolvimento energético de mais 28.349 MW no Brasil até o ano de 2027 (EPE, 2007), alternativas ao atual planejamento de construção de barramentos se faz imprescindível. Este trabalho visa apontar o desenvolvimento da energia elétrica numa nova direção, buscando otimizar o uso e a construção de barragens em áreas já exploradas energeticamente, mostrando que existe espaço não só para o desenvolvimento, mas também para um melhor uso do espaço disponível, no sentido de que vários dos planos de desenvolvimento focam em regiões no norte do Brasil onde temos grandes extensões de floresta e hotsposts de biodiversidade.

Apesar do enorme esforço e recursos sendo investidos na recuperação dos sistemas hídricos, pouca atenção tem sido dada ao desenvolvimento de métodos sistemáticos para priorizar decisões de remoção de barreira (Kemp & O'Hanley, 2010). O principal método usado é o de pontuação e ranking (Pess *et al*. 1998; Taylor & Love 2003). Nesse tipo de método, as barreiras são avaliadas com base em uma variedade de atributos físicos, ecológicos e econômicos e posteriormente são classificadas por ordem de pontuação decrescente. Dado um orçamento específico, a premissa básica desse tipo de procedimento é que a remoção das barragens seja feita da do topo ao fim do ranking até que o orçamento seja esgotado.

Os sistemas de pontuação e ranqueamento são relativamente simples e de fácil implementação, e praticamente não exigem esforço computacional. O seu principal ponto fraco é que as decisões de remoção são consideradas independentemente uma das outras. Ao ignorar a estrutura espacial da bacia, soluções altamente ineficazes podem ser produzidas, tendo que as remoções de algumas barreiras não necessariamente resultam em ganho de habitat para as espécies-alvo (O'Hanley & Tomberlin, 2005).

Para que seja eficaz e eficiente, métodos mais sofisticados são necessários, de preferência que sejam capazes de considerar sistematicamente todas as restrições relevantes, operacionais e de recursos, bem como a rede espacial subjacente formado pela presença de múltiplas barreiras. A consideração da estrutura espacial é particularmente importante por conta dos efeitos agregados, não aditivos que as barreiras podem ter sobre a conectividade longitudinal e dinâmica populacional à longo prazo. Neste tipo de contexto técnicas de otimização, que alguns estudos têm investigado, são uma opção ideal, direcionando de forma eficiente atividades de remoção de barreiras e de mitigação (Kemp & O'Hanley, 2010).

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SEGUNDA PARTE - ARTIGO

MIGRATORY FISH HABITAT FRAGMENTATION BY HYDROPOWER DAMS:
HISTORY AND TRENDS FOR THE SÃO FRANCISCO AND PARAÍBA DO SUL RIVER BASINS

Artigo redigido conforme a norma para publicação científica NBR 6022 (ABNT, 2003[a])

Habitat Fragmentation of Migratory Fish at the São Francisco and Paraíba do Sul River Basin

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ABSTRACT

The maintenance of the longitudinal connectivity and natural flows of rivers are crucial for preserving the abundance and diversity of long distance migratory fish. Using a quantitative analysis based on maps, we analyze the fragmentation process of the rivers of the São Francisco River Basin (SFRB) and Paraíba do Sul River Basin (PSRB), in Brazil. In this work, we drew different scenarios for the fragmentation, quantifying this process in a historical and potential perspective taking into account the present and future state of the river basin. We also determined the probable number of migratory species in every reminiscent lotic extension. We observed the presence of a larger number of migratory species in fragments equal or larger than 100 km. On the future scenario, there was an increase in the number of fragments, especially the ones equal or shorter than 50 km, inadequate to hold most of the migratory species. In this work we show the history of hydroelectric development in the two basins and compare how these trends can affect the future sustainability of these rivers.

Keywords: fragmentation, river basin, migratory fish, hydropower dam, development

1 INTRODUCTION

The growing need for cheap and clean energy has motivated developing countries to invest massively in hydropower energy (Tolmasquim et al 2012; ANEEL 2008). Brazil, a country with nearly 184 million inhabitants (IBGE 2008) had in 2008 95% of its population supplied with access to the electrical grid (ANEEL 2008). This benefit, even though economically cheaper, comes at a potentially high cost to the environment. The damming of rivers represents serious ecological issues (Nilsson et al 2005), such as the habitat loss of migratory fish due to river fragmentation (Wofford et al 2005; Jager et al 2001), the change in the local/regional hydrological cycles (Rosenberg et al. 2000), the proliferation of diseases vectors and invasive species (McCully 2001; Quintero 2003; Goldsmith & Hildyard 1984).

Brazil is a megadiverse country, with two of the world's hotspost for tropical biodiversity conservation. Specifically for freshwater fishes Brazilian ecosystems harbour more than 3000 known species (Buckup et al 2007). Many species of this megadiverse freshwater fishes are migratory but the actual number of species is unknown. Long distance migratory fish are the most important species for commercial fisheries because of their large size, abundance and market value (Northcote, 1978; Hoeinghaus et al., 2009). In riparian freshwater systems the abundance and diversity of migratory fishes are limited by the maintenance of the river's longitudinal connectivity and its natural flow regimes. Both aspects can be deeply affected by river's blocking due to the building of hydropower dams.

Dams built for electric power generation is one of the main causative agent of fragmentation of rivers, (Dynesius & Nilsson 1994;. Roni et al 2002, 2008). Dams prevents species access to breeding habitats for migratory fish and disrupt the dynamic of nutrients and sediment downstream movement. (Anderson et al, 2007;. Lehner et al, 2011.). As a result, the loss of connectivity in the rivers can increase fish populations' isolation and their consequent decline due to inbreeding, recruitment, and juvenile survival (Arthington et al, 1995;. Gehrke et al, 2002;. Penczak and Kruk, 2000 Wofford et al., 2005). Thus, rivers fragmentation assumes a central place in all approaches intend in manage or planning for management of rivers basins and environmental impact assessment of hydropower plant building.

Environmental impact assessments often only consider local scale repercussions, often lacking the analysis of cumulative impacts within the river basin that can impose to the fish communities more the local-scale threats (Grill et al 2015). This aspect turn a very relevant issue in a scenario of 846 new hydropower projects planned to the next 10 years in Brazil

(ANEEL, 2016). In 30 years, none of the biggest Brazilian River basins would be un-fragmented. Thus, it is urgent to assess and predict the impacts produced or the amount of habitat that still available for migratory fish species and offer some information for a best development planning of electric sector in Brazil. Additionally, a historical analyses can provide an overview of past development trends and gives guidance over mistakes to be avoided in future planning.

Here, we aimed to highlight the importance of a integrative development plan and the impacts associated to unplanned growth by evaluating the current and potential fragmentation of two of the most important Brazilian river basins, the São Francisco and Paraíba do Sul and discuss its potential impacts over the migratory fish distribution.

2 MATERIAL AND METHODS

2.1 STUDY AREAS

SÃO FRANCISCO RIVER BASIN

The São Francisco basin's (631,133 km^2) cover 7.4% of Brazil between 21°S and 7°S latitude (Knoppers et al. 2006). The river is the 31st longest river in the world (Welcomme 1985), and the uses of its waters include power generation, irrigation, industrial and urban water supplies, navigation, and fishing. Downstream Três Marias dam (45°15'50" E; 18° 15'12" S), its floodplain covers approximately 2,000 km^2 (Welcomme, 1990), supporting one of the most important locations for inland Brazilian fisheries (Sato & Godinho, 2004). For the last four decades, the waters of the São Francisco River have been dammed for flow control and energy generation, and recent fishery collapses have been linked to changes in flood intensity and frequency (Godinho et al. 2007; Nestler et al., 2012).

PARAÍBA DO SUL RIVER BASIN

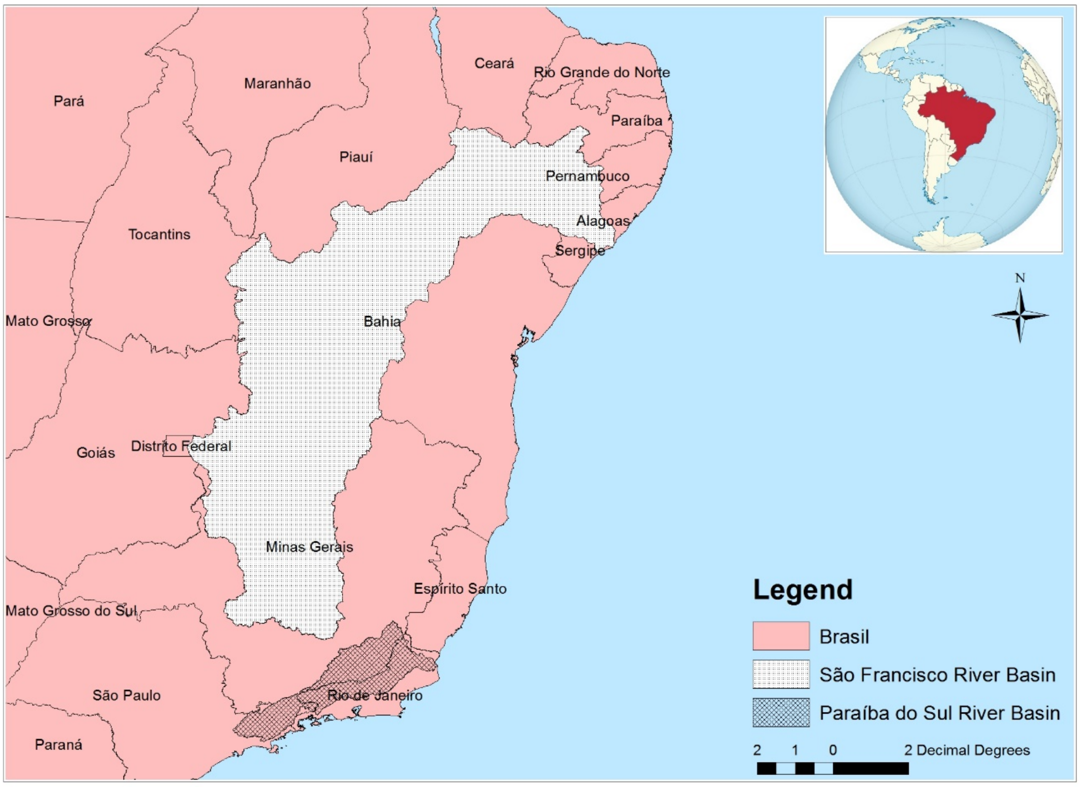
The Paraíba do Sul river basin is born with the Paraitinga River, high in the Bocaina mountain range, in the state of São Paulo. When it merges with the Paraibuna River, it becomes the Paraíba do Sul River. The river runs along the Serras do Mar and 12 Mantiqueira, enters the Paraíba Valley until it reaches the north of Rio de Janeiro, where it meets the sea near the city of São João da Barra. This entire route covers an extension of 1,150 km (Bizerril, 1999).

The waters of the Paraíba do Sul River currently supply 28 municipalities, totalling around 14 million people (IBGE, 2007). In addition to supplying water to the population, the rivers of the basin serve for irrigation, dilution of sewage and generation of electric energy. Urban settlements and agricultural and industrial activity were established early in the basin.

The first recorded process of degradation in Paraiba do Sul Basin date back to the seventeenth century when the riparian vegetation cover in certain areas of the São Paulo and Rio de Janeiro states were removed to increase sugarcane cultivation areas and, later, coffee. Its most extensive use began in the 1940s with industrial development and consequent urban sprawl in the region.

Figure 1 - Study areas

STUDY AREA



Source: From the author (2017)

2.2 HISTORICAL TRENDS OF HYDROPOWER DEVELOPMENT

To evaluate how the development of hydropower enterprises has happened throughout the history of the two basins, data from the National Registry of Dams (Cadastro Nacional de Barragens – CNB) reporting the beginning of construction and start of operation was gathered for all the PCHs (Small Hydropower Plant) and UHEs (large Hydropower Plants) built on the study areas. For the estimative of dams planned and under construction for 2017 we used all the projects approved and under construction made available by ANEEL.

2.3 HABITAT FRAGMENTATION SCENARIOS

To evaluate the fragmentation scenarios we made use of the hydrographic map, basin delimitation and geographic coordinates of the small hydropower plants (PCH) and large hydropower plants (UHE) available at the National Water Agency (ANA) and the National Agency of Electric Energy (ANEEL). In Brazil, legislation states that small hydropower dams are the ones that have a production capacity of less than 30 MW. Because migratory fishes are reported to dwell in larger rivers during most part of their life span, we restricted our research to rivers with orders above equal and above 4. The ordering of the rivers was made by the Strahler method using a spatial analysis tool in a geographic information system software. The topographical data necessary for the ordering of the rivers was acquired at the Geomorphological Data Bank of Brazil (TOPODATA).

The resulting hydrographic network obtained was overlapped with the geographic coordinates of the hydropower dams. We considered a river fragment the extension of river free of impediments to the fish migration.

For the sake of comparison between migratory fish distribution and the fragmentation of the basin, two scenarios of fragmentation were built (i) the present fragmentation scenario with all the hydropower dams built until 2016 and (ii) the prospective scenario where the fragments were the result of all the current barriers plus the foreseen hydropower developments licensed by the National Agency of Electric Energy.

To relate how migratory fish distribution is affected by fragmentation we surveyed the scientific literature for data correspondent to the capture of fish on river extents covering the years of 1990 to 2011. We found that most species only occurred in fragments equal or larger than 100 km, therefore, on the foreseen potential distribution, for the future scenario of fragmentation, we considered all fragments smaller than 100 km as unsuitable for migratory fish.

2.4 UHE RESERVOIR AREA COMPARISON

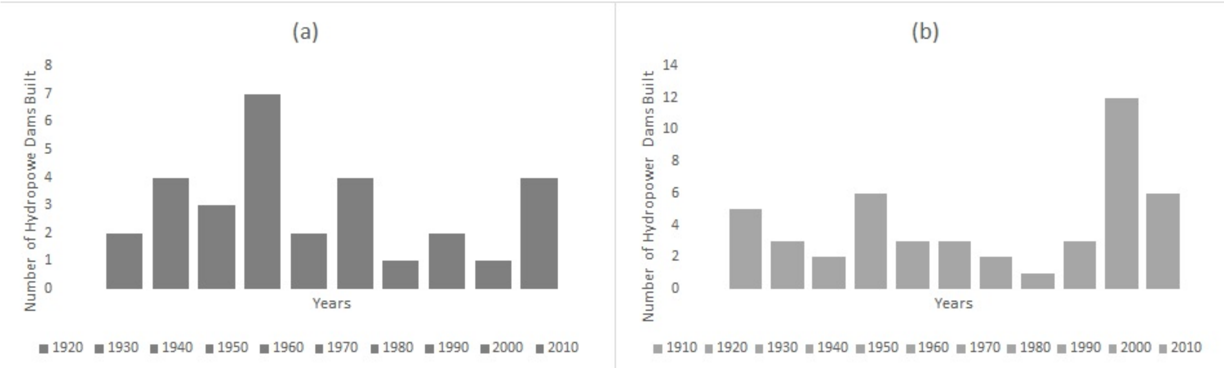
For the comparison of UHE reservoir area comparison, in a geographic information system we estimated the size of the reservoir area by using the elevation raster obtained at the Geomorphological Data Bank of Brazil (TOPODATA) and dam height to plot the flooded area.

3 RESULTS

3.1 HISTORICAL TRENDS OF HYDROPOWER DEVELOPMENT

Of the 23 PCHs in operation at the SF river basin, seven did not have information about their construction dates and start of operation, all UHEs had their information up to date. Of the 33 PCHs and 19 UHEs in operation at the PS river basin, we were not able to find construction data for four PCHs and two UHEs. During the last century, dam building for hydropower production started as early as 1912 for the PSRB and before recent years had an all-time high during the 1950s at the SFRB and 2000s for the PSRB with the conclusion and start of operation of 12 hydropower stations.

Figure 2 – Historical Development of dams on the São Francisco and Paraíba do Sul river basins.



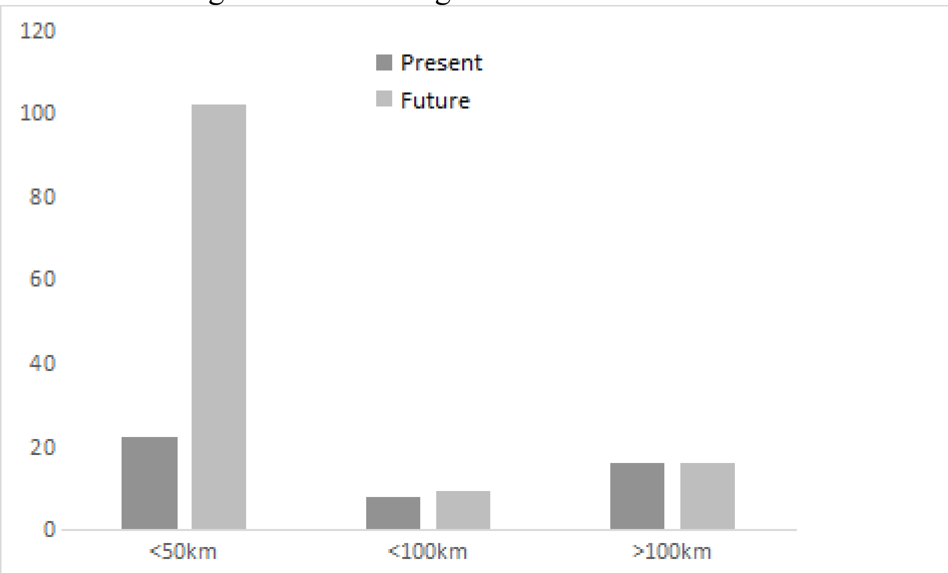
Source: From the author (2017)

According to the ANEEL, Brazil has a total of 4,694 hydropower dams in operation, totaling 153,439,212 kW of installed capacity. An additional 24,490,669 kW is planned for the next years, coming from the 256 projects currently under construction and 590 in developments with construction not yet started. When taking into consideration impoundments that are still on the phase of licensing and administrative processing the numbers go up considerably. For the whole country there are 1628 projects for PCHs and 273 for UHEs underway.

3.2 HABITAT FRAGMENTATION SCENARIOS

Nowadays the PSRB has 44 dams, that divide the river network into 22 fragments smaller than 50km, 8 fragments between 51 and 100 km and 8 fragments larger than 100 km in extension. In the future, 75 new commissions are predicted for the area, been 70 of them new small hydropower plants. This new power plants and the damming will increase the fragments with and extension smaller than 50km to 102 and will be responsible for much of the fragmentation of the basin (Figure 3).

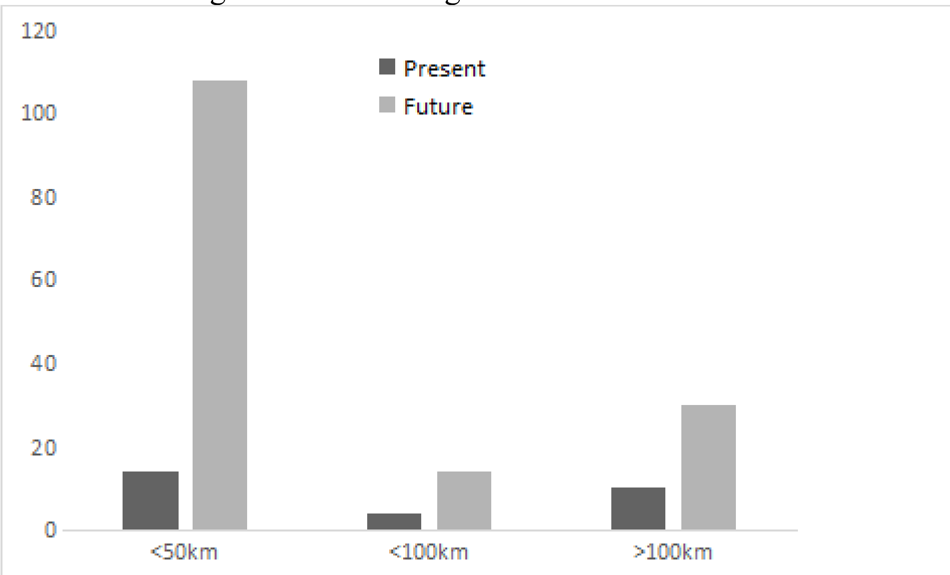
Figure 3 –River Fragment Size for the Paraíba do Sul River basin.



Source: From the author (2017)

Nowadays the SFRB has 28 dams that divide the river network into 14 fragments smaller than 50km, 4 fragments between 51 and 100 km, 10 fragments larger than 100 km in extension. In the future, 126 new commissions are predicted for the area, been 103 of them new small hydropower plants. This new power plants and the damming will increase the fragments with and extension smaller than 50km to 108 and will be responsible for much of the fragmentation of the basin (Figure 4). We noticed that in the future scenario the number of segments larger than 100 km increase, but that due to the construction of UHEs fragmenting the much larger river segments into separate ones.

Figure 4 – River Fragment Size for the São Francisco River Basin



Source: From the author (2017)

From the 12 species of migratory fish present on the SFRB, only river fragments larger than 100 km in extension were found to hold all the species. River fragments between 100km-50km hold 6 of the species, in river fragments smaller than 50km only the species *Salminus hilarii* and *Prochilodus costatus* were found.

From the eight species of migratory fish present on the PSR basin, only river fragments larger than 100 km in extension were found to hold all the species. River fragments between 100km-50km hold some of the species, however there was a lack on the knowledge on the distribution of two species. At river fragments smaller than 50km only the specie *Leporinus copelandii* was found.

Table 1.Relationship between migratory fish occurrences and the extension of lotic stretch in Rio São Francisco and Paraíba do Sul river basins in Brazil. X indicates the presence of the species on the stretch, - is stretches without the specie and ? is the absence of information on the literature about the specie on the specific stretch.

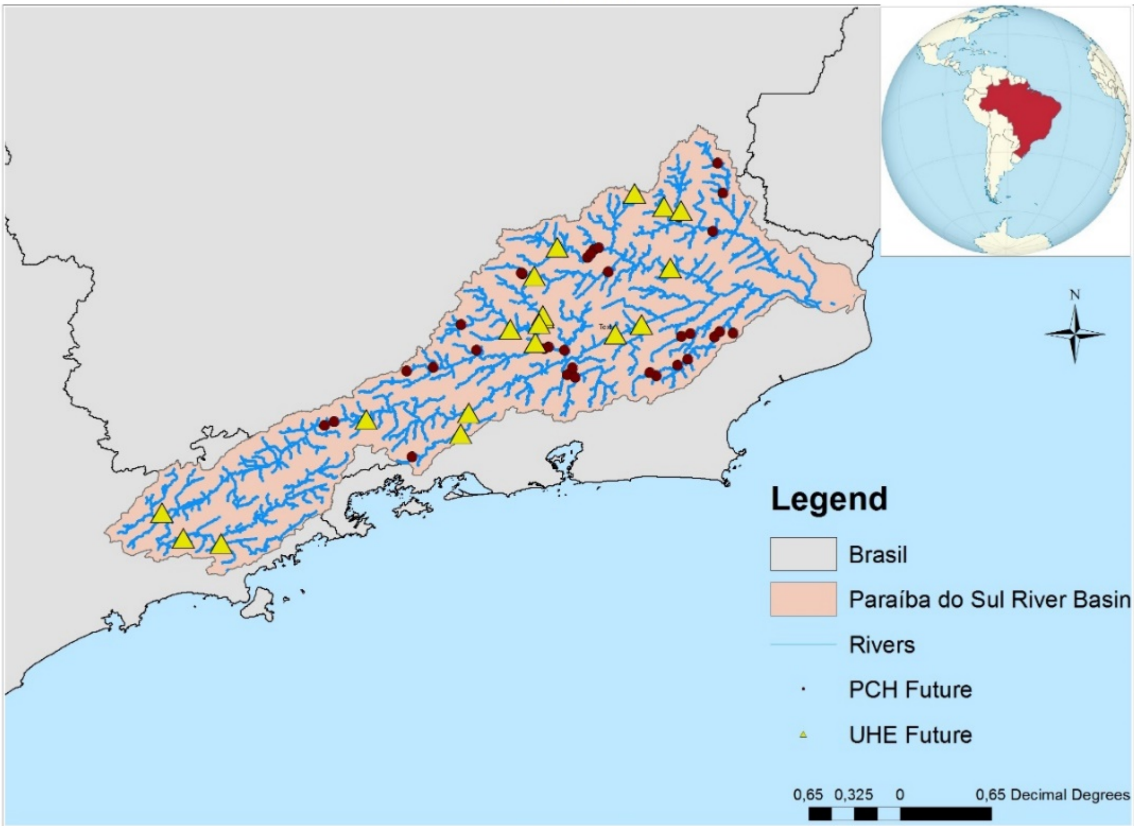
Species\River Basin	**>100km**	**<100km**	**<50km**
São Francisco River Basin			
Brycon orthotaenia	X	-	-
Conorhynchus conirostris	X	-	-
Leporinus elongatus	X	X	-
Leporinus renhardti	X	X	-

Leporinus taeniatus	X	X	-
Pimelodus maculatus	X	X	-
Prochilodus argenteus	X	-	-
Prochilodus costatus	X	X	X
Pseudopatystoma corruscans	X	-	-
Rhineleps aspera	X	-	-
Salminus franciscanus	X	-	-
Salminus shilarii	X	X	X
Paraíba do Sul River Basin			
Brycon insignis	X	X	?
Leporinus cf. steindachneri	X	X	-
Leporinus conirostris	X	X	-
Leporinus copelandii	X	X	X
Pimelodus maculatus	X	?	-
Prochilodus lineatus	X	?	-
Prochilodus vimboides	X	-	-
Salminus brasiliensis	X	-	-

Source:(Alves et al. 1998; Bizerril 1999)

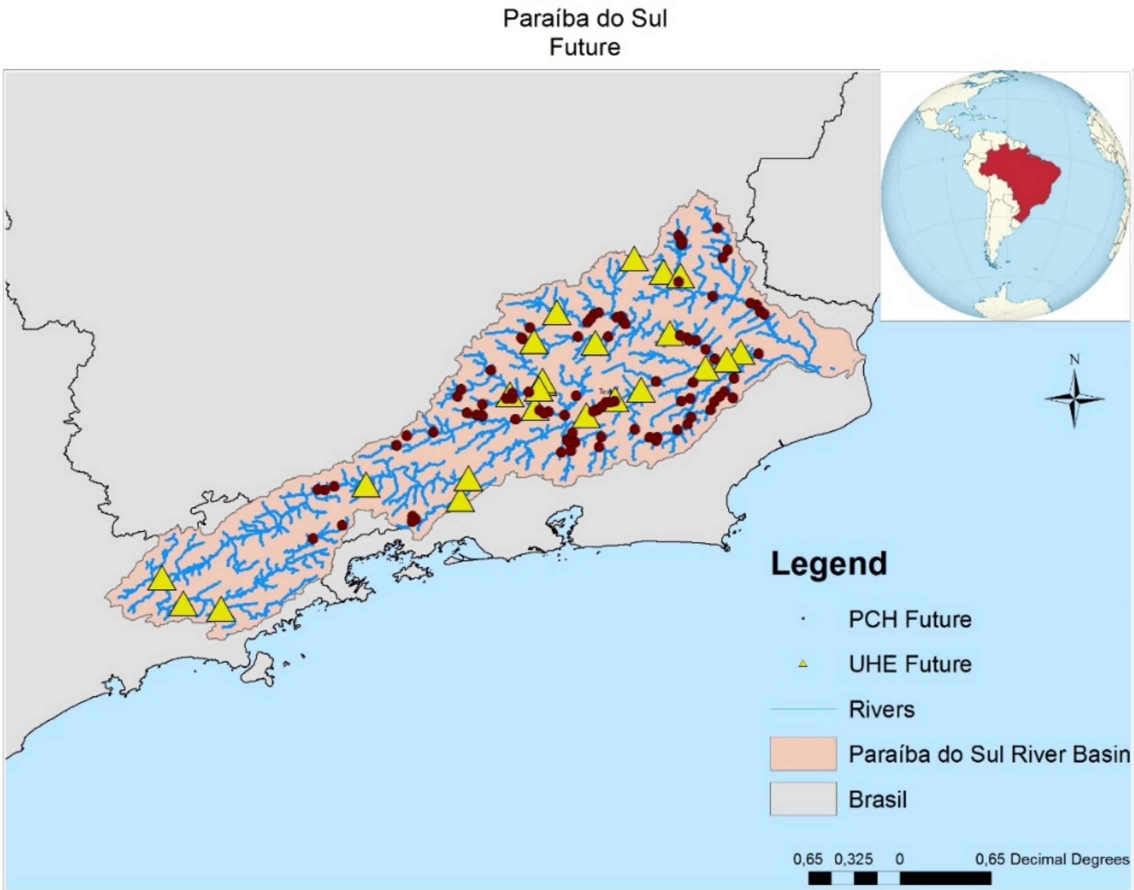
Figure 5 – Present Fragmentation Scenario of the Paraíba do Sul River Basin.

Paraíba do Sul
Present



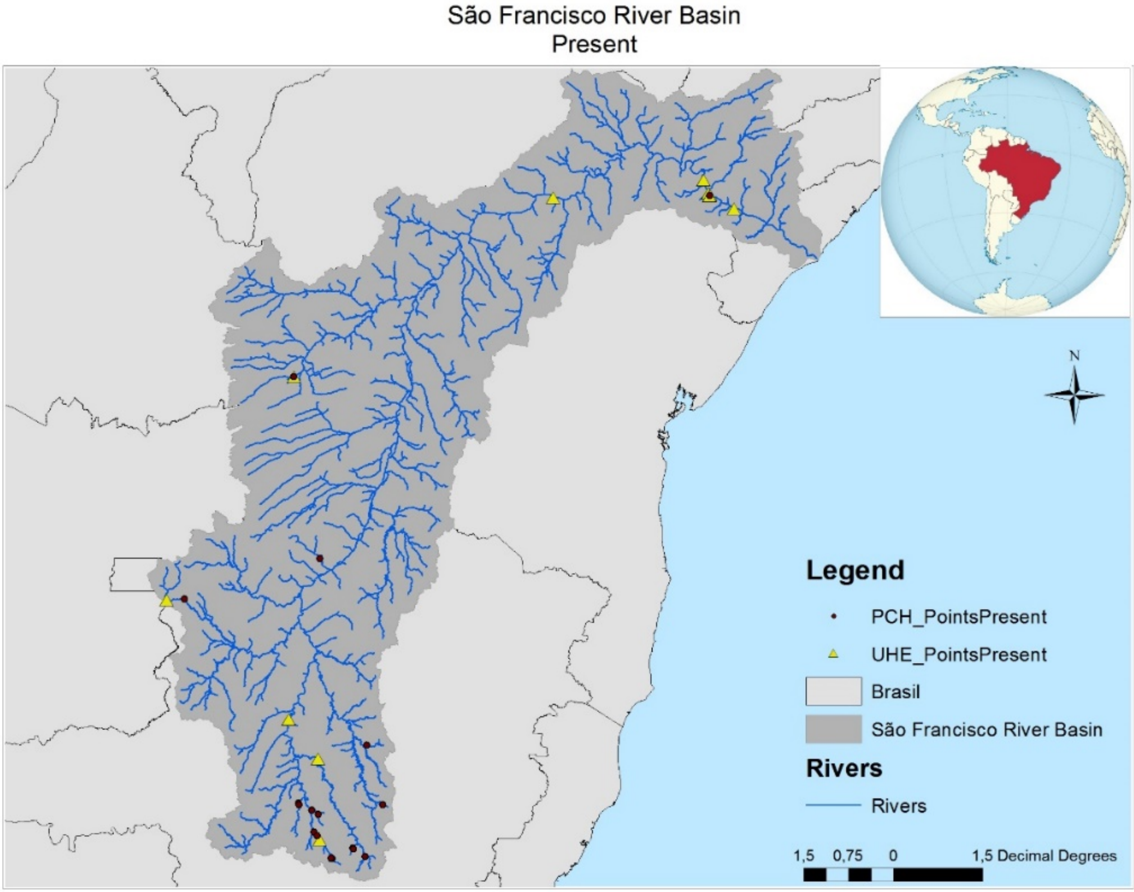
Legend: Present Fragmentation Scenario of the Paraíba do Sul River Basin. Here the yellow triangles represent Large Hydropower Dams and the purple dots represent Small Hydropower Dams. Source: From the author (2017)

Figure 6—Future Fragmentation Scenario of the Paraíba do Sul River Basin



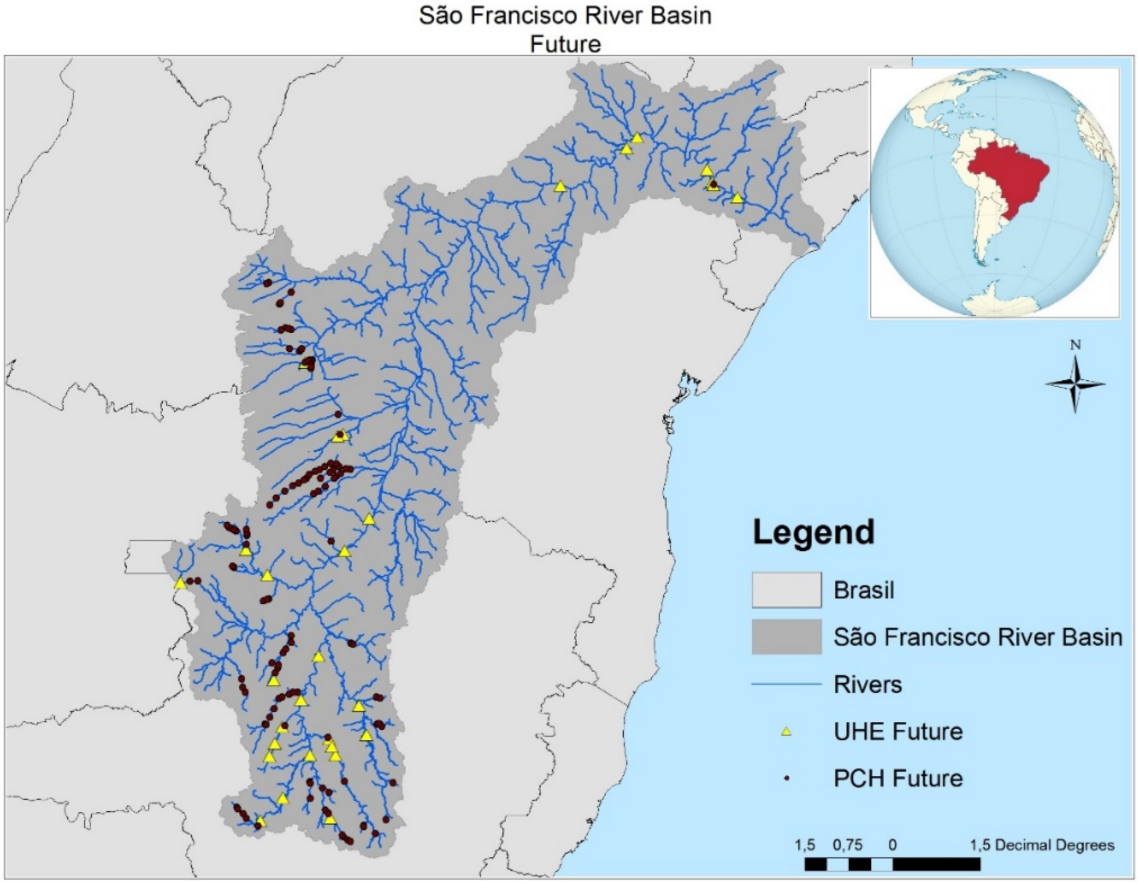
Legend: Here the yellow triangles represent Large Hydropower Dams and the purple dots represent Small Hydropower Dams. Source: From the author (2017)

Figure 7 Present Fragmentation Scenario of the São Francisco River Basin.



Legend: Here the yellow triangles represent Large Hydropower Dams and the purple dots represent Small Hydropower Dams. Source: From the author (2017)

Figure 8 Future Fragmentation Scenario of the São Francisco River Basin

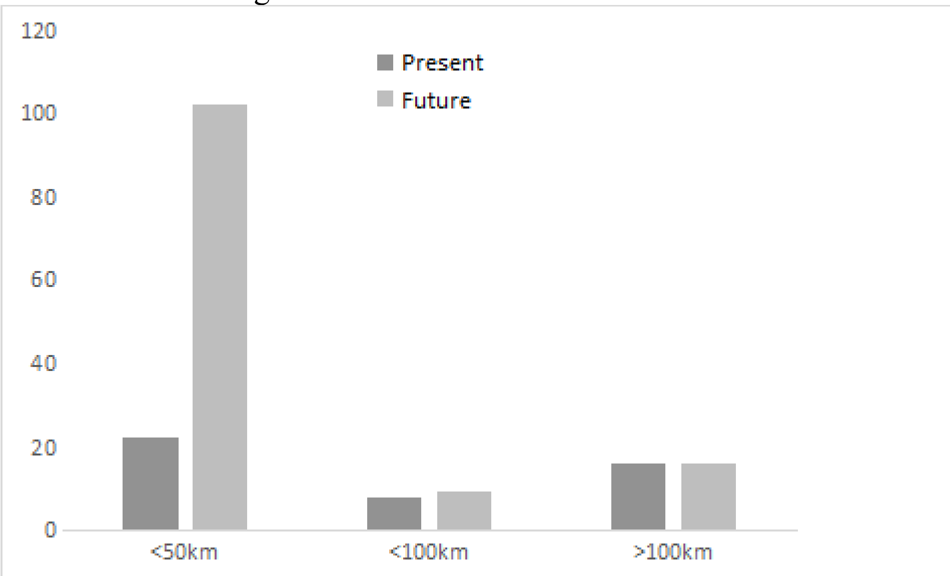


Legend: Here the yellow triangles represent Large Hydropower Dams and the purple dots represent Small Hydropower Dams. Source: From the author (2017)

3.3 UHE RESERVOIR AREA COMPARISON

When it comes to UHE reservoir area, the river basins differed greatly in size. The Paraíba do Sul river basin had smaller flooded areas, with seven of their 19 reservoirs being smaller than 3km². The largest reservoir area for the PSR basin was the Paraíbuna UHE with 177km² of reservoir area against the 4.124km² of the Sobradinho UHE for the SFR basin.

Figure 9 – UHE Reservoir area in km² for both river basins



Source: From the author (2017)

4 DISCUSSION

On the northeast region of Brazil, the constructions of dams started around 1577 (Apipucos, Recife-PE) and came at first as an attempt to aid the droughts that afflicted the area, in the southeast states the implantation of dams was mainly directed for the production of electricity starting early on the 1900s. Until the 1950s all the energy companies in Brazil were in the private sector and were mainly located in the south and southeast regions of the country. Before the organization of the electrical development sector in Brazil, decisions were made according to the individual characteristics of each impoundment and the company conducting the construction. There was no integrated planning nor exchange of information among different companies as the concessionaires worked around their particular goals (Mercedes et al 2011).

During the 1950s there was an intensification on demand for expansion and distribution of energy and state intervention was made necessary as a way to mitigate the lack of investment in the private sector in the area. At the time, state concessionaires started investing in large impoundments, deploying extensive studies on the development, construction and operation of dams. Great contributions came in the form of inventory studies that aimed to locate the best locations for hydropower dam construction, on a perspective of where more energy could be produced and not necessarily where it would be more environmentally ideal. At first, these studies were made in the southeast region of Brazil, under a project namely known as Canambra, later expanded to the south and further territories. These inventories were used to plan the implementation of new impoundments on the following years. From the 1980s onwards, previous inventories began being revised and progressively new environmental conditions were included on the project definitions of the inventories.

On the southeast of the country, including at the PSRB, many of the projects that were planned thinking solely in energy production and had huge reservoirs were altered, and new projects envisioned a larger quantity of smaller hydropower dams with smaller reservoirs. This was mainly because due to the economic development of the southeast and south of the country this older projects would require the flooding of large areas, including whole cities, industrial parks and agricultural land. Our findings regarding the reservoir area comparison of Large Hydropower Dams (UHE) on the two basins studied (Figure 5) exemplify how this planning strategy changed the present scenario of the river basins. We see that almost half of the reservoirs on the PSRB are smaller than 3km² and even the largest one is not comparable in size to the largest one of the SFRB, where large hydropower dams were built further on the timeline, at 177km² from the first against 4.124km² of the later.

On the 1990s, the organization of the electric development in Brazil began being made by the means of the Brazilian Electric Regulatory Agency – ANEEL, all the planning concerning privatizations, operational changes and tenders for concessions have been sued by this agency since then. To voice and organize the use of water and solve conflicts, the government installed, also around this time, the Hydrographic basin committees (CHB). based on the principles that it would act as a decentralized, integrated and participatory water management group, having the river basin as the territorial unit for planning and management (ANA, 2011). It is important to remark that until this point, decisions made about hydroelectric development did not take into consideration major environmental damage. Even with the committees acting as a management force, planning at the river basin level, still to this day river connectivity is not taken as a major threat on the reports.

Since the last decade of the XX century, a large number of investors have been acting on the implementation of small hydropower dams. That is arguably largely due to governmental incentives (ANEEL 2003) that sees small hydropower dams as clean and economically viable means of energy production.

We have shown the fragmentation caused by damming on the São Francisco and Paraíba do Sul river basin, correlating its extensions to the presence of migratory fish species. The occurrence of migratory species decreases in lotic lengths lower than 100 km in a way that when this extension is less than 50 km, only two species were found (*Salminus hilarii* and *Prochilodus costatus)* for SFRB and one *(Leporinus copelandii)* for the PSRB. The current situation of the basins shows that there are still large fragments, especially in the main channel of the rivers, in larger order rivers. In the future, after the construction of the planned dams, fragments with extensions inferior to 50 km will increase in quantity. The lowers reaches of the basins will have an increased quantity of successive barriers, mainly in tributaries. Most of the fragments of above 100 km extensions lying in the lower portions of the basin

During the rainy season, adult fish migrate upstream to spawn, after which eggs and larvae are passively transported through the stream to natural nurseries in the productive areas of the downstream floodplains. After the reproductive event, adult fish undergo a return migration, returning downstream from the rivers to suitable habitats for food (Agostinho & Zalewsky, 1995; Lowe-McConnell 1999; Pompeu et al., 2012). Similarly, the eggs, which are free, are carried downstream towards the flood plains (Carolsfeld et al., 2003). Migratory fishes have a high social and commercial value and, because they require long stretches of river and natural flood regimes to complete their life cycle (Carolsfeld et al., 2003), they are highly affected by river fragmentation and changes in Natural hydrological regime due to dams.

The construction of the barriers modifies the entrance of the organic matter in the trophic webs by regulating the flow of water in the river and by the retention of nutrients in the reservoir (Agostinho et al., 2008). The reservoir and the dam serve as ecological barriers, either because they present environmental conditions completely different from the river's original regime, as in the case of the dam, or by simple physical impediment such as the bus (Pelicice et al., 2015). The result of this set of physical-morphological changes of the river is the genetic isolation, the reduction or complete alteration of fish populations, difficulty in dispersing eggs, larvae and adults downstream, among (Suzuki, 2011; Pelicice et al. 2015; Agostinho et al,2007; Jager et al., 2001).

To mitigate the environmental impacts of dams under migratory fish, licensing often requires the construction of fish farming stations or the construction of fish passages. The latter aim, among other things, to increase the longitudinal connectivity of the river by providing a ladder, or other form of passage, from one side of the dam to the other. Several recent studies have shown that fish passages constructed in South America, as well as fish stocks, have proved to be ineffective and have so far been unable to re-establish viable populations of migratory fish, and their stocks continue to decline (Agostinho et al., 1997; Pelicice & Agostinho 2008; Pompeu et al., 2012).

River basin committees main concerns are about flow regulation, pollution and general degradation and how even though there is a main concern about local level environmental impact basin level, cumulative effects are rarely taken into account, if they ever are at all. The São Francisco River basin committee even advices on its later water resource plan that the use of PCHs should be increased as a sustainable, smaller impact alternative (RP1B, 2015).

Despite the enormous effort and resources being invested in the recovery of water systems, little attention has been given to the development of systematic methods to prioritize barrier removal decisions and basin level managment (Kemp & O'Hanley, 2010). To be effective and efficient, more sophisticated methods are required, preferably being able to systematically consider all relevant resource and operational constraints as well as the underlying spatial network formed by the presence of multiple barriers. Consideration of the spatial structure is particularly important because of the aggregate, non-additive effects that barriers may have on longitudinal connectivity and long-term population dynamics. In this type of context optimization techniques, which some studies have investigated, are an ideal option, effectively targeting barrier removal and mitigation activities (Kemp & O'Hanley, 2010).

It is of paramount importance that strategies of conservation and preservation include rivers of permanent preservation and decommissioning existing barriers in addition to optimization techniques. This study emphasizes the impacts of fragmentation on the longitudinal connectivity of river basins, and reinforces the importance of large lotic segments for migratory fish species. We aim to point the development of electric energy in a new direction, seeking to optimize the use and construction of dams in areas already explored energetically, and showing that there is space not only for growth but also for a better use of available space.

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