UNIVERSIDADE FEDERAL DE LAVRAS

FÁBIO MINEO SUZUKI

ESTUDO DO COMPORTAMENTO DE PEIXES NO CANAL DE FUGA DA USINA HIDRELÉTRICA DE TRÊS MARIAS UTILIZANDO TELEMETRIA ACÚSTICA

LAVRAS - MG

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Orientador

Dr. Paulo Santos Pompeu

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Ficha Catalográfica Elaborada pela Coordenadoria de Produtos e Serviços da Biblioteca Universitária da UFLA

Suzuki, Fábio Mineo.
Estudo do comportamento de peixes no canal de fuga da usina hidrelétrica de Três Marias utilizando telemetria acústica / Fábio Mineo Suzuki. – Lavras : UFLA, 2014.
97 p. : il.

Tese (doutorado) – Universidade Federal de Lavras, 2014.
Orientador: Paulo Santos Pompeu.
Bibliografia.

1. Ictiofauna - Estratégias de conservação. 2. Peixe - Mortandade. 3. Peixe - Padrões de movimentos. 4. Peixes migradores. 5. Turbinas. I. Universidade Federal de Lavras. II. Título.

CDD – 574.52632

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APROVADA em 12 de fevereiro de 2014

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Dedico este trabalho à minha mãe, Sofia (in memoriam), com quem aprendi muito nessa vida. Guerreira, batalhadora e exemplo de amor incondicional aos filhos. Agradeço pelo seu apoio e incentivo transmitidos em todos os momentos de minha vida. Saudades eternas!

AGRADECIMENTOS

A realização deste trabalho não teria sido possível sem a ajuda e colaboração de muitas pessoas e instituições. Por diferentes razões e sem ordem de importância, eu gostaria de **agradecer**:

Ao meu orientador, Paulo Santos Pompeu, que além de um grande amigo é um exemplo de profissionalismo, professor e orientador. Pessoa sempre de bom humor e disposto a fazer o melhor pelos seus alunos. Sou eternamente grato por todo o seu ensinamento durante todos esses anos de orientação. Sua paciência, ajuda e o grande apoio foram fundamentais para vencer todas as inseguranças deste processo e alcançar os objetivos com este trabalho. Agradeço por toda a sua manifestação de dedicação e disponibilidade na ajuda para o desenvolvimento do trabalho. Depois de todos esses anos sob sua orientação e os ótimos momentos de convivência, não tenho dúvidas que fiz a melhor escolha para o meu crescimento profissional. Por fim, devo concordar o que você sempre fala aos seus orientados: "*você é muito melhor pra mim do que eu sou pra você*".;

Ao professor e pesquisador, Jason B. Dunham, que me orientou durante o meu programa de sanduíche realizado na Oregon State University em Corvallis, OR-USA. Agradeço os seus ensinamentos, a sua paciência, o acolhimento e toda a preocupação e esforços dispensados (cervejas, cocktails, bate-papo e pescarias), para que eu pudesse me sentir em casa em terras norte americana;

Ao pesquisador, Robert Hughes, que também me acolheu e me auxiliou durante a minha chegada em Corvallis, e com quem tive o prazer de ter ótimos momentos de convivência (cervejas, bate-papo e momentos de aventura nas terras oregonianas);

Sou muito grato aos pesquisadores Luiz G. M. da Silva e ao Carlos B. M. Alves pela colaboração e ajuda ao trabalho. Ao Luiz que me passou os primeiros ensinamentos sobre a telemetria acústica e foi importante para a realização de muitas etapas deste estudo e ao Carlos, com quem tive os ensinamentos de organização relacionados as coleta de dados em campo, marcação de peixes, e que também foi fundamental para o desenvolvimento deste trabalho;

Agradeço especialmente a minha esposa, Ludimilla, pelo qual tenho grande amor e admiração. Sou imensamente grato as suas preciosas contribuições a este trabalho, além de todo o seu carinho, companheirismo, apoio, compreensão e muita paciência durante a minha jornada de doutorado. Também agradeço toda a sua ajuda nas minhas coletas de dados em campo;

Sou imensamente grato ao Ivo Gavião Prado (biólogo - Peixe Vivo), grande amigo e parceiro de trabalhos, que não mediu esforços para ajudar e esteve sempre disposto a resolver qualquer imprevisto durante a realização deste estudo;

À equipe do programa Peixe Vivo da Cemig, em especial ao Ivo Gavião, Raquel Loures e Ricardo Silva pela assistência, colaboração e ajuda ao trabalho;

Ao Marcelo e ao Raphael, comunicadores sociais que fizeram parte do Programa Peixe Vivo e nos ajudaram a elaborar os materiais informativos (Folder, cartazes, camisetas, bonés) e a divulgar o estudo junto à comunidade de ribeirinhos do rio São Francisco na região de Três Marias e Pirapora;

Agradeço a todos os meus amigos do laboratório de ictiologia da UFLA, em especial ao Marcos e ao Alexandre que me ajudaram nas cansativas atividades de retirada e desmobilização dos equipamentos acústicos, e a Mírian, Sarah, Ruanny e ao Lucas que me auxiliaram nas atividades de amostragem de dados em campo no rio São Francisco.

À toda equipe de operação da Usina Hidrelétrica de Três Marias por toda assistência e ajuda prestadas durante o desenvolvimento deste estudo. Com certeza, a realização deste trabalho não teria sido possível sem o auxílio dessa equipe.

À empresa Hydroacustic technology Inc. (em especial ao Samuel Johnston e Colleen Sulllivan), fabricantes dos equipamentos acústicos, por toda assistência prestada durante a realização deste trabalho;

Também agradeço ao Marcos e sua equipe de mergulhadores (Escafandro). Equipe competente e de confiança que mesmo com todas as dificuldades e imprevistos, realizaram um ótimo trabalho de instalação e retiradas dos hidrofones na área do canal de fuga;

Agradeço aos meus amigos da ecologia (Thaís, Vanesca, Vitinho, Cotô, Giu, Grá, Lisiane, Lívia, Leopoldo, Amanda, Henrique, Mariana etc.), pelos ótimos momentos de convivência;

Também agradeço aos meus amigos de Corvallis (Piero, Cassia, Cleuzir, Adriana, Mariana, Clarice, Rodrigo, Danielle, Thaís, Ive, Fábio, Mousa, Ali, Russ, Mary, Nancy, Daryl), pelos ótimos momentos de convivência e que fizeram dessa experiência internacional verdadeiramente inesquecível;

Aos professores da ecologia, pelos ensinamentos e conhecimentos transmitidos em aulas e conversas do dia a dia durante esses anos;

Aos membros da banca, Prof. Dr. Angelo A. Agostinho (UEM), Prof. Dr. Luis D. S. Murgas (UFLA), Prof. Dr. Marcelo Passamani (UFLA) e o Prof. Dr. Júlio N. C. Louzada (UFLA), pelas valiosas sugestões e críticas que somaram importantes contribuições ao trabalho;

Aos irmãos Alves dos Santos (Waldir, Deir, Valdeci e Walmir), grandes pescadores e ótimos conhecedores do rio São Francisco, que foram importantes nas coletas de dados em campo;

Ao Paulo, Magali, Grá, Fá, Léo e Helinho, que hoje me acolhem como parte da família;

Ao inventor das fitas Hellerman (abraçadeiras) que foi a solução de vários problemas e imprevistos encontrados durante diversas etapas da pesquisa para este trabalho em campo;

À Polícia Militar do meio Ambiente e ao Promotor de Justiça de Três Marias, José Antônio F. D. Leite, pelo apoio ao trabalho;

Agradeço à CEMIG, pelo financiamento do trabalho por meio do projeto "Comportamento de peixes a jusante de barragens: subsídios a sua conservação";

À FAPEMIG pela concessão da bolsa de doutorado e a CAPES, pela bolsa de sanduíche;

Agradeço ao programa de pós-graduação em Ecologia Aplicada e a Universidade Federal de Lavras, pelo apoio institucional e logístico;

Meus infinitos e eternos agradecimentos aos meus pais, Sofia (in memoriam) e Joaquim, e aos meus irmãos, Rogério e Patrícia. Agradeço todo o carinho, apoio e incentivo que sempre transmitiram em todos os momentos de minha vida. Obrigado por existirem em minha vida;

Em especial, a Deus, pela saúde, proteção nas emocionantes viagens de coleta de campo e por mais esta vitória em minha vida.

RESUMO GERAL

Na tentativa de realizarem migrações ascendentes, os peixes podem ser aprisionados e mortos nos tubos de sucção durante uma manobra operacional de uma Usina Hidrelétrica (parada e partida de máquina). A compreensão dos padrões de movimento dos peixes em áreas de influência direta da operação das turbinas pode fornecer subsídios para reduzir os impactos à ictiofauna. Nesse sentido, os padrões de movimentos de duas espécies migradoras foram avaliados na área do canal de fuga da usina hidrelétrica de Três Marias, localizada no alto rio São Francisco, Minas Gerais, Brasil. Movimentos de 90 peixes (50 *P. argenteus* e 40 *P. maculatus*) foram rastreados através da técnica de telemetria acústica durante o período de 31 de Outubro de 2011 a 16 de Fevereiro de 2012. Foram avaliados temporalmente os movimentos de entrada e saída do canal de fuga e a distribuição espacial dos indivíduos imediatamente a jusante das turbinas (definida arbitrariamente até 30 metros a jusante da barragem). Além disso, foi analisada a influência de fatores ambientais (transparência e variação nictmeral) e operativos (vazão vertida e turbinada) nos padrões encontrados. A maioria dos peixes marcados deixou o canal de fuga em um curto intervalo de tempo, no entanto, visitas foram realizadas pelos indivíduos ao longo do período de estudo. Diferenças no comportamento entre as espécies foram evidentes nesse trabalho. As taxas de visita ao canal de fuga foram predominantemente realizadas pela *P. argenteus* durante o dia, enquanto o *P. maculatus* apresentou hábitos (visitas no canal de fuga e tempo permanência na área de risco) noturnos. Diferenças na preferência de profundidade também foram observadas entre as espécies, no qual *P. maculatus* permaneceu mais próximo ao fundo e a *P. argenteus* mais próximas à superfície. As taxas de visitas ao canal de fuga foram influenciadas pela abertura do vertedouro e pela vazão turbinada, com maior atividade durante o período em que o vertedouro esteve aberto e as turbinas na geração máxima. Embora o aumento da vazão turbinada possa atrair os peixes para o canal de fuga, a maior permanência do *P. maculatus* na área imediatamente a jusante das turbinas ocorreu na vazão mínima. Nesse sentido, regimes de operação máxima (vazão turbinada e vertimento) seguida por geração mínima pode representar uma situação de alto risco de ocorrência de eventos de mortalidade de peixes. Embora a tentativa de conciliar manobras operacionais com um mínimo de impacto possível à ictiofauna seja ainda um grande desafio, resultados da pesquisa com esse trabalho fornecem informações úteis para a elaboração de estratégias de ação no intuito de minimizar morte de peixes nas turbinas.

Palavra-chave: Estratégias de conservação. Morte de peixes. Padrões de movimentos. Peixes migradores e turbinas.

ABSTRACT

"Study of fish behavior in the tail race of Três Marias Dam using acoustic telemetry" - In attempt to perform migrations toward to upstream areas, the fish can be trapped and killed in the draft tube during an operational maneuver (turbine stop/startup procedures) in a Hydropower plant. The comprehension of fish movement and distribution patterns in an area under hydropower plant operational conditions can be an important key to provide useful insights as to how to manage dam operations in order to minimize the impacts on the ichthyofauna. In this sense, the movements patterns of two migratory species were evaluated in the tail race of Três Marias Dam, located on the upper São Francisco River, Minas Gerais, Brazil. We tracked the movements of 90 fish, being 50 *Prochilodus argenteus* and 40 *Pimelodus maculatus*, using acoustic telemetry from October 31st 2011 to February 16th 2012. We evaluated the temporal variations of the inward and outward movements to the tail race and the spatial distribution immediately downstream from the dam (arbitrarily defined up to 30 meters downstream from the dam). Moreover, the influence of water transparency, time scale and hydropower operation (turbine and spill discharge) were evaluated on the found patterns. The majority of tagged fish left the tail race in a short period of time, however, visits to the tail race were performed by some fish (35 individuals) over the study period. Differences in the behavior between the two species were observed in this study. The rate of visits to the tail race was predominantly performed by *P. argenteus* during diurnal period, while *P. maculatus* showed nocturnal behavior (visits to the tail race and the permanence time in the area immediately downstream from the dam). Differences in depth preferences also were observed between the two species, in which *P. argenteus* remained closer to the surface and *P. maculatus* closer to the bottom. Besides, we were able to observe the influence of spillway and turbine discharge on the rate of visits to the tail race, with greater activity during the presence of spillway discharge and the turbine operation in maximum generation. Although the increase of turbine discharge can attract the fish to the tail race, the greater permanence of *P. maculatus* in area immediately downstream from the dam was during the minimum discharge. In this sense, the maximum generation followed by minimum generation can represent a risky situation to happen an event of fish mortality. Despite the attempt to conciliate operational maneuvers with a minimum impact on the ichthyofauna is still a big challenge, our results can provide useful information to elaborate action strategies in order to minimize the fish kill in the turbines.

Keywords: Conservation strategies. Fish kill. Migratory fish. Movements patterns and turbines.

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SUMARIO

PRIMEIRA PARTE

1 INTRODUÇÃO

No Brasil, eventos como o acúmulo de peixes imediatamente a jusante dos empreendimentos hidrelétricos é um fator frequente e de grande preocupação. A presença destes cardumes próximos a barragem frequentemente leva a entrada de peixes nos tubos de sucção durante a parada de máquina para manutenção, podendo causar grandes episódios de mortandade. A preocupação em conciliar a operação com o mínimo de impacto possível à ictiofauna levou a criação do projeto intitulado “Comportamento de peixes à jusante de barragens: subsídios à conservação da ictiofauna”. Financiado pela Companhia Energética de Minas Gerais (CEMIG), este projeto foi desenvolvido em parceria com a Universidade Federal de Lavras e o CEFET-MG. Neste projeto utilizaram-se tecnologias como a Ecossonda e a Telemetria acústica no intuito de atingir os seguintes objetivos principal de criar subsídios para propor medidas de estratégias de operação que visem a diminuição de mortes de peixes nas turbinas.

A presente tese de doutorado, parte deste projeto, teve como objetivo geral avaliar o comportamento de duas espécies migradoras, *Prochilodus argenteus* e *Pimelodus maculatus*, na área do canal de fuga da Usina Hidrelétrica de Três Marias, utilizando a técnica de telemetria acústica. Este empreendimento hidrelétrico, localizado no alto rio São Francisco, é uma das principais usinas da CEMIG, e que apresenta alto risco de impacto aos peixes. Devido à sua grande abundância na área do canal de fuga, *P. argenteus* e *P. maculatus* são as espécies frequentemente mais afetadas pela operação das turbinas da UHE Três Marias.

Com os recentes avanços das técnicas de telemetria acústica, tem sido possível registrar os movimentos de peixes de forma precisa, tanto em 2D quanto em 3D. Embora esta tecnologia esteja difundida na América do Norte, no Brasil ela é inédita. Esta técnica consiste na implantação de um transmissor acústico na cavidade celomática do peixe e posteriormente o rastreamento do sinal acústico por meio de receptores (hidrofones) instalados submersamente. O tempo que se leva para o sinal alcançar cada hidrofone permite determinar a posição do peixe por triangulação, mesmo princípio utilizado pelo GPS (Sistema de posicionamento global).

Os resultados obtidos com este trabalho são apresentados em dois artigos que foram escritos na língua inglesa e estruturados nas normas da revista “River Research and Applications”. No primeiro artigo intitulado “Influences of species, time, dam operations, and time scale on fish movement patterns in the tailrace of Três Marias Dam, São Francisco River, Minas Gerais State, Brasil”, foram avaliados temporalmente os movimentos de entrada e saída dos peixes na área do canal de fuga e a influência da operação nos padrões encontrados. O segundo artigo intitulado “Assessment of hydroelectric operation on the spatial distribution patterns of two migratory fish in the tail race of Três Marias Dam, upper São Francisco river, Minas Gerais, Brasil” teve como objetivo geral avaliar temporalmente a distribuição espacial dos peixes marcados na área do canal de fuga, especificamente na área imediatamente a jusante das turbinas e a influência da geração da usina nessa distribuição.

2 REFERENCIAL TEÓRICO

Pela abrangência espacial que apresentam, as barragens estão entre as atividades antropogênicas de maior impacto à comunidade de peixes. A mudança da qualidade da água e do hábitat e o bloqueio dos movimentos migratórios dos peixes destacam-se como os principais impactos à ictiofauna (AGOSTINHO; PELICICE; GOMES, 2008). O bloqueio da migração não só impede os peixes migradores de completarem o seu ciclo de vida como também levam ao acúmulo de peixes nos ambientes imediatamente a jusante da barragem. A presença desses cardumes no canal de fuga, por exemplo, frequentemente leva ao aprisionamento de peixes dentro dos tubos de sucção durante a parada de máquinas para manutenção das turbinas. Uma vez dentro dessas estruturas, a falta de oxigênio no interior dos tubos; e a descompressão e o choque contra as estruturas físicas das turbinas durante a partida de máquinas podem levar a morte massiva de peixes (ANDRADE et al., 2012).

Na Usina Hidrelétrica de Três Marias, localizada no alto rio São Francisco, no município de Três Marias, Minas Gerais Brasil, grandes agregações de peixes são vistas com frequência à jusante da barragem, especialmente na área do canal de fuga. Em função de sua abundância, duas espécies são comumente mais afetadas durante as manobras operacionais, *Prochilodus argenteus* Spix & Agassiz, 1829 e *Pimelodus maculatus* Lacepède, 1803 (ANDRADE et al., 2012). Ambas são espécies migradoras e consideradas de importância comercial à pesca profissional (SATO; FENERICH-VERANI; GODINHO, 2003). Popularmente conhecida como Curimba, *P. argenteus* é endêmica do rio São Francisco e pertence à família Prochilodontidae (Characiformes), podendo chegar até 71 cm de comprimento. Já o mandi-amarelo, *P. maculatus*, pertencente a família Pimelodidae (Siluriformes), apresenta um comprimento total máximo de 45 cm. Esta espécie está amplamente distribuída nos rios da América do Sul.

Segundo Pientka e Parrish (2002), padrões espaciais de indivíduos são dirigidos por fatores ambientais. No Brasil, diversos estudos têm corroborado esta observação, mostrando que alguns fatores ambientais são determinantes na atração e ascensão de peixes por meio dos mecanismos de transposição. Na escada experimental de Itaipu, constatou-se uma influência significativa da temperatura da água e da vazão turbinada sobre a intensidade de ascensão dos peixes (FERNANDEZ; AGOSTINHO; BINI, 2004). Na UHE Santa Clara, a abundância dos peixes teve relação significativa com a vazão do rio (POMPEU; MARTINEZ, 2006). Já em UHE Lajeado, variações temporais no nível da água influenciaram a riqueza e a abundância de peixes que se concentravam na entrada e dentro da escada. Além disso, a velocidade mostrou-se como importante fator na seletividade dos indivíduos que ascendem as escadas (AGOSTINHO et al., 2007). Embora a velocidade e a vazão, tenham sido observadas como importantes fatores que afetam o movimento das espécies, e que de uma maneira geral também estão relacionadas com o acúmulo de peixes próximo a barragem, pouco se sabem como a operação da usina hidrelétrica afeta os movimentos e a distribuição espacial dos indivíduos nas imediações da barragem. Recentes trabalhos observaram uma maior proximidade dos peixes às turbinas durante os períodos de maior vazão turbinada (LINNIK et al., 1998; RIVINOJA; MCKINNELL; LUNDQVIST, 2001; SCRUTON et al., 2007; SILVA et al., 2012; THORSTAD et al., 2003). A compreensão dos padrões de movimentos e distribuição dos peixes na área do canal de fuga sob os diferentes regimes de operação pode ser uma chave importante para definir estratégias de operação com um mínimo de impacto possível à ictiofauna durante as manobras operativas. Estudos recentes desenvolvidos na área do canal de fuga da Usina Hidrelétrica de Três Marias têm obtido informações importantes nesse sentido.

Andrade et al. (2012) observaram uma relação negativa entre a vazão turbinada e a biomassa de peixes aprisionados nos tubos de sucção, considerando a geração mínima antes de uma manobra operativa uma situação de risco a morte de peixes nas turbinas. Além disso, Loures e Pompeu (2012) ressaltam que as manobras nas turbinas durante meses de período chuvoso pode ser uma atividade de maior risco aos peixes, em função da maior abundância de indivíduos no canal de fuga. Fica evidente a importância de estudos científicos como subsídios à proposição de estratégias de operação com menor risco de morte aos peixes.

Estudos utilizando técnicas de telemetria acústica têm aumentado constantemente nos últimos anos e, na América do Norte, já representam uma poderosa ferramenta para avaliar o comportamento de peixes. A grande preocupação com o sucesso do movimento descendente dos juvenis de salmões na América do Norte levaram os pesquisadores a desenvolver passagem de peixes eficientes baseados no comportamento dos emigrantes utilizando a telemetria acústica (GOODWIN et al., 2006). Com os avanços desta tecnologia, tem sido possível também avaliar a seleção e o uso de hábitat (HERRALA et al., 2014), padrões de movimentos migratórios (CHAPMAN et al., 2013; KURTH, 2013), influência de fatores ambientais no comportamento de peixes (MICHEL et al., 2013) e as taxas de crescimento e sobrevivência (AMMANN; MICHEL; MACFARLANE, 2013).

3 CONCLUSÃO

Resultados deste trabalho demonstram que a técnica de telemetria acústica representa uma poderosa ferramenta para obter dados precisos de movimentos e localização de peixes e que a compreensão do comportamento e os fatores que governam esses padrões revelam-se como importante subsídio para a proposição de estratégias de conservação à ictiofauna. Nesse sentido, vale destacar que as manobras operacionais realizadas durante a noite pode reduzir o impacto à *P. argenteus*. Por outro lado, sincronizar essas atividades durante o dia e nos períodos de maior transparência pode ser uma medida para reduzir o impacto ao *P. maculatus*. Considerando que, historicamente, os grandes acidentes em Três Marias tenham ocorrido com esta espécie, essa manobra pode ser uma estratégia mais apropriada para evitar episódios de mortandade. Além disso, embora o aumento da vazão turbinada e a abertura do vertedouro possam atrair os peixes para o canal de fuga, a maior permanência do *P. maculatus* na área de risco ocorre na vazão mínima, possivelmente devido a proximidade desta área com a saída da água turbinada. Nesse sentido, regimes de operação máxima (vazão vertida e turbinada) seguida de geração mínima antes de uma manobra operacional representam-se como atividades de alto risco de impacto à espécie. Por fim, adaptações de manobras operacionais de acordo com a situação de risco, associadas ao uso de grades e ao monitoramento de peixes a jusante da barragem, mencionadas anteriormente, são medidas fundamentais para conciliar manobras operacionais com um mínimo de impacto possível à ictiofauna.

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SEGUNDA PARTE - ARTIGOS

ARTIGO 1

INFLUENCE OF SPECIES, TEMPORAL SCALE AND HYDROPOWER PLANT OPERATION ON FISH MOVEMENT WITHIN THE TAILRACE OF TRÊS MARIAS DAM, SÃO FRANCISCO RIVER, SOUTHEASTERN BRAZIL

"Artigo formatado nas normas da revista River Research and Applications"

Influence of species, temporal scale and hydropower plant operation on fish movement within the tailrace of Três Marias Dam, São Francisco River, Southeastern Brazil.

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Abstract

Fish attempting to move upstream can be trapped and killed in turbines. Understanding fish movement patterns can provide useful insights for how to manage dam operations to minimize fish kill in turbines. To this end, we tracked movement of two migratory fish (n=90 individuals total; 50 *Prochilodus argenteus* and 40 *Pimelodus maculatus*) using acoustic telemetry in the tailrace of Três Marias Dam on the São Francisco River, Brazil, from 31 October 2011 to 16 February 2012. We evaluated the movements of visit and residence time in the tail race and the influence of temporal scale and discharge (turbine and spillway) on these patterns of movement. The majority of tagged fish left the tailrace in less than one week, however some individuals performed visits to the tailrace. *P. maculatus* remained longer in the tail race than *P. argenteus*. Patterns in the ratio of visits (outward/inward movements) were influenced by temporal scale, with higher variability in this ratio at higher temporal resolutions (e.g., weekly to diurnal and nocturnal scales). This pattern can be explained by differences on the movement patterns performed by the two tagged species between diurnal and nocturnal periods. It was possible to observe an increase of *P. maculatus* movements during spillway and maximum turbine discharge. *P. maculatus* movement was also influenced by river transparency, with increase of their diurnal movements in low transparency periods. We discuss the implications of these results for the understanding fish movements in the Três Marias Dam tailrace and their potential implications for adapting hydroelectric operations to minimize fish kills.

Keywords: Conservation strategies, Fish mortality, Migratory species, Movement patterns, Turbines.

Introduction

In the last decade, the growth of the Brazilian economy has increased the electric energy demand, production of which is about 80% hydropower. Currently, the majority of Brazilian largest rivers are impounded, with more than 956 hydropower plants in operation throughout the country (Castro *et al.*, 2012). Although they are important for economic growth, the dams represent one of main impacts on aquatic biodiversity due to their spatial coverage and the magnitude of alterations that they promote (Agostinho *et al.*, 2004). For the migratory fish species, the dams represent insurmountable obstacles, both to upstream movement of adults to spawning areas, as well as the downstream movement of their offspring toward development areas (Agostinho *et al.*, 2002; Suzuki *et al.*, 2011). The physical barrier prevents fish movement and frequently causes large aggregations of fish immediately below the dam, placing the ichthyofauna at risk during the operational maneuvers, specially related to turbine maintenance.

There is a lack of knowledge about the fish behavior immediately downstream from hydropower plants and which factors can drive their distribution and movements in the tailrace. However, studies attempting to evaluate upstream movements through Brazilian fish passages have detected the influence of hydrodynamic variables on the attraction of fish to the passage entrance, generally located at the tailrace. The velocity and discharge have been indicated as the main hydrodynamic factors driving the movements to the fish passage (Fernandez *et al.*, 2004; Pompeu and Martinez, 2006; Agostinho *et al.*, 2007b). Silva *et al*. (2012) have detected higher abundance of fish in the tailrace or spilbay at the Baguari Dam related to higher turbine and spillway discharges, suggesting that these variables probably play an important role attracting fish to these areas. Trapping and mortality events of fish in the draft tubes of hydropower plants mainly during turbine startup or dewatering for maintenance have been recorded in Brazil (Agostinho *et al.*, 2007a) and the magnitude of the event was directly related to the abundance of fish in the tailrace (Andrade *et al.*, 2012a; Loures and Pompeu, 2012). In this sense, understanding fish movement and aggregation patterns in an area under the influence of hydropower operational rules can provide useful insights for managing dam in order to minimize the risks for the fish fauna.

At the Três Marias Dam (TMD), located on the upper São Francisco River Basin, large fish aggregations are frequently observed in the tailrace, representing a risk of fish entry into the draft tubes during the turbines maneuvers. Two species are most commonly affected *Prochilodus argenteus* Spix & Agassiz, 1829 and, *Pimelodus maculatus* Lacepède, 1803 (Andrade *et al.*, 2012a). Both are migratory fish, abundant and considered an important species for professional fisheries (Sato *et al.*, 2003). *P. argenteus*, popularly known as Curimba, belongs to the Prochilodontidae family (Characiform), with a total length up to 71 cm. It is an endemic specie in the São Francisco River. *P. maculatus*, popularly known as *P. maculatus*, is a catfish belonging to the Pimelodidae family (Siluriform) with a total lenght up to 45 cm and it is widely distributed in South American Rivers.

The telemetry techniques have been widely employed in fish studies, especially in the Northern hemisphere, providing great results for species conservation (Goodwin *et al.*, 2006; Monnot *et al.*, 2008; Chapman *et al.*, 2013; Chase *et al.*, 2013) and it is considered a powerful tool to provide fish movement data (Adams *et al.*, 2012). The recent advances in acoustic telemetry technology have improved the study of fine-scale movement dynamics (Klimley *et al.*, 2013), enabling the understanding of migration, behavior and survival patterns of several species. Although this technique can provide high resolution data of fish movements, its use to track fish in the tailrace of hydropower plants is still restricted to a few technical studies in the North hemisphere (Scruton *et al.*, 2007) and it was never reported to tropical areas. Nevertheless, successful use of the technique in tailraces may provide fine-scale about fish behavior at risk areas that could be applied to avoid mortality at several dams worldwide.

In this study we tracked the movements of *P. argenteus* and *P. maculatus* in the tailrace of Três Marias Dam using acoustic telemetry to determine: (1) the residence time of tagged fish in the tailrace; 2) the number of visits and the tailrace residency to the tailrace; (3) the influence of species and individual size on inferred movement patterns; (4) the influence of temporal scale on the visits ratio; (5) the influence of Três Marias Dam operational discharges (turbine and spillway discharge) on the number of visits during the diurnal and nocturnal periods and (6) the influence of water transparency on diurnal movements of the fish.

Methods

Study area

The study was conducted at Tres Marias Dam, which is located on the upper stretch of the São Francisco River, close to the town of Três Marias, Minas Gerais State, Southeastern Brazil (Figure 1), and has been in operation since 1962. The dam is 2,700m long and has 65m in height with a reservoir flooding a maximum area of 1,040 km^2. The powerhouse operates with six Kaplan units (GU) with maximum capacity and discharge of 65 MW and 150 $m^3.s^{-1}$ per turbine, respectively. The draft tube for each turbine is about 15m long with two sections of 6x4m. The tailrace has about 155 m in length and 182 m of width with an area of approximately 19,870 m^2. No fish passage is located at the dam, therefore fish migrating upstream are likely to aggregate in the tailrace.

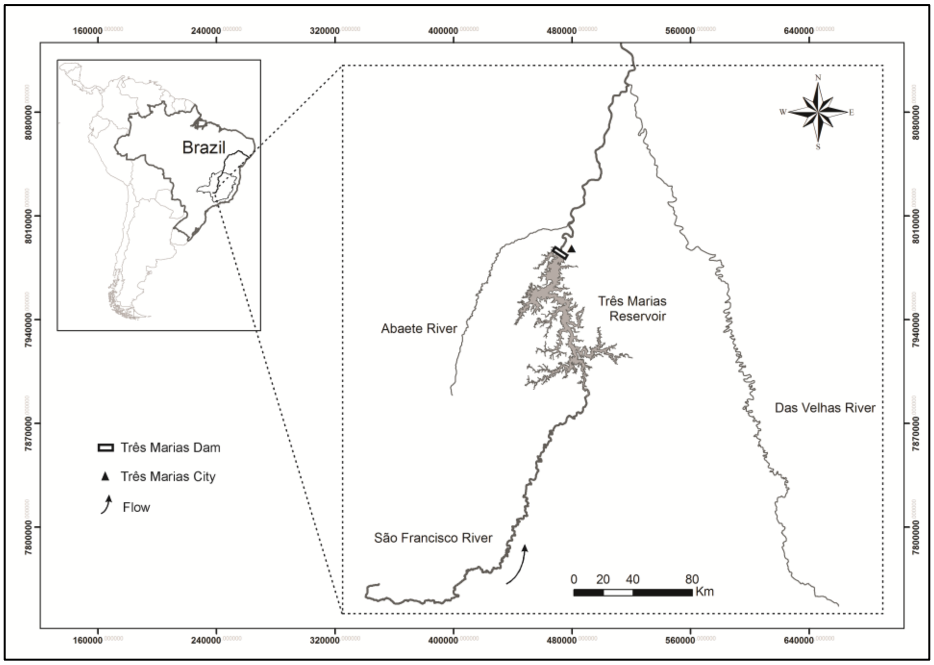

Figure 1 – Location of Três Marias Dam on São Francisco River, Minas Gerais State, Brazil.

Fish sampling and tagging procedures

Fish were captured in the tailrace and in the river downstream using cast nets from October 31st to November 4th 2011 and acoustic tags were surgically inserted in the body cavity. Each fish was weighed and measured before tagging. The surgical procedure was conducted in a rectangular plastic tank (0.57m length x 0.50m width x 0.17m height) filled with river water renewed after every three procedures. Water aeration was maintained using an external aquarium pump and temperature was checked using a regular thermometer. Eugenol (clove oil) diluted in 1ml:40L of water proportion (Hahn *et al.*, 2007) was used to anesthetize the fish prior to immobilization and surgery procedures, and Labcon Protect Plus® (Alcon pet®) to aid fish recovery (Godinho *et al.*, 2007). For the surgery, fish were immobilized using electronarcosis (Henyey *et al.*, 2002) with a non-pulsed DC current with 30 V for both species (Godinho and Kynard, 2006). After immobilization the voltage was dropped down to 26 V and 25 V for *P. argenteus* and *P. maculatu*s, respectively to allow the fish to breath normally during surgery procedure. The sterilized acoustic transmitter was inserted into the body cavity through a small incision (1.5–2.5 cm) made on the middle ventral line (*P. maculatus*) and lateral body above the anal fin (*P. argenteus*). The incision area, surgical instruments and acoustic transmitters were disinfected with an iodine solution. After the tag implantation, the incision was closed using non-absorbable sutures with 3-5 stitches. Then, the tagged fish were placed in a large tank (1.5m length x 1.2m width x 0.9 m height) filled with river water in constant renewal to recover from the anesthetic and surgery stress for at least 4-6 hours prior to release. The maximum number of tagged fish in the tank per time was 15 individuals. No mortalities were observed during this period.

A total of 90 fish were tagged, being 50 *P. argenteus* and 40 *P. maculatus*. The mean size of *P. argenteus* was 31.8 cm, ranging from 24 to 45cm, whereas the mean size of *P. maculatus* was 21.8 cm, with values ranging from 19cm to 26cm. *P. argenteus* were tagged with 795 LG acoustic transmitters (4.5cm height x 1.55 cm diameter and weighing 12g in air), while model 795 LX (3.0cm height x 0.90cm diameter and weighing 4.3g in air) were used for *P. maculatus*, both manufactured by HTI®. The acoustic transmitters represented a tag burden of a maximum 2.8% and 3.5% for *P. argenteus* and *P. maculatus*, respectively (tag weight to fish weight ratio).

Fish release

After recover, tagged fish that showed regular opercula and swimming movements were selected for release. Fish were released in the tailrace in batches of 5-6 individuals. For the release, fish were hand netted in the recovery tank and immediately placed into a smaller tank (0.78m length x 0.56 width x 0.41m height) transferred to a boat. Therefore, the tank was gently poured in the river releasing the fish in the left shore of the tailrace. This area was selected due to the low flows there, trying to reduce the chance of recently tagged fish encountering high flows immediately after release.

Fish tracking

Movements of tagged fish were tracked using a data logger connected to 11 hydrophones deployed in the tailrace (Figure 2). Positioning of the hydrophones was defined based on data gathered from previous tests conducted in the tailrace, which indicated a detection range of 100m. To accomplish that tags were set to operate at one ping every 3.2-5.3 sec and with a transmit pulse width of 5.0 msec. This setting would allow tags to have battery lives ranging from 350-500 days (LX) and 220-400 days (LG).

The tracking of fish movements in the tailrace was done from 31 October 2011 to 16 February 2012, completing a total of approximately 81 tracking days. All hydrophones were georeferenced and connected to the data logger (Model 290 Acoustic Tag Tracking System*)* using hydrophone cables (Model 690). This acoustic system operates at 307 kHz and it continuously receives and stores all tag transmission pulses for each hydrophone simultaneously. The acoustic telemetry system operated 24h per day in this study. The tagged fish positions were calculated by the same principle used by Global Position Satellites (GPS) (Ransom *et al.*, 2008).

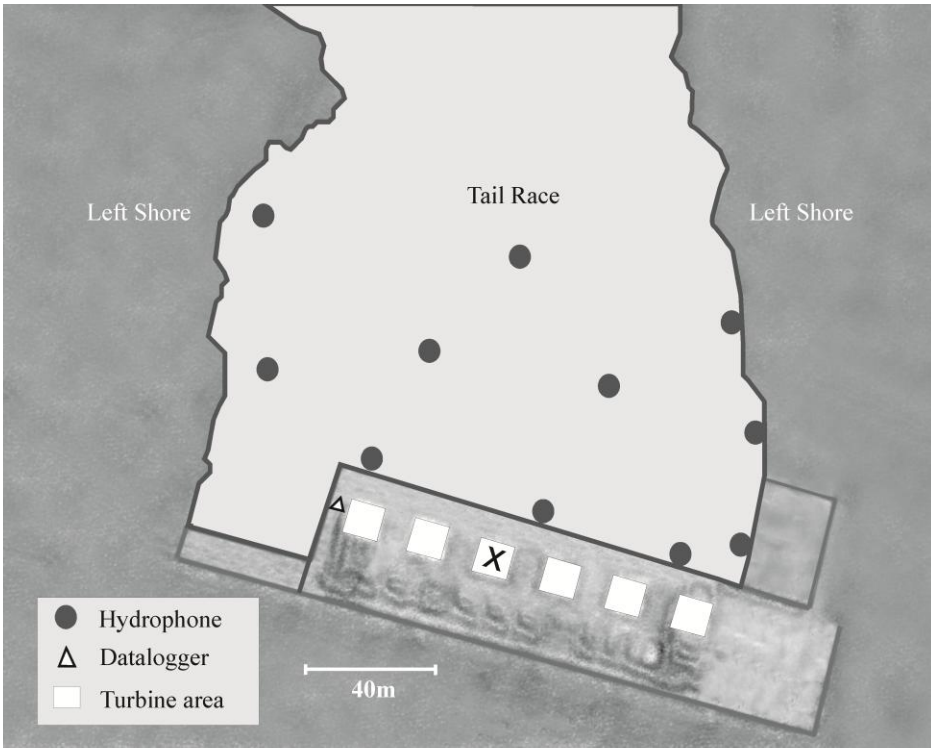

Figure 2 – Location of hydrophones, data logger and turbine area in the tailrace of Três Marias Dam, São Francisco River, Minas Gerais, Brazil. (The letter X shows the turbine that did not operated during the whole study period)

Data Analyses

Three variables were chosen to describe fish movements in the tailrace, residence time, number of visits and tailrace residency. The residence time for each tagged species was determined considering the elapsed period between release and first exit of the tracking area. The number of visits was calculated counting the number of times an individual fish was registered entering the tailrace. Lastly, the tailrace residency was considered as the elapsed time spent by an individual fish in the tracking area after moving into the tailrace. Mann-

Whitney U-test was used to verify differences for these movement variables among *P. maculatus* and *P. argenteus* (significant differences were considered for $p<0.05$). Also, the influence of individual size for each species on the number of visits was inferred using the Spearman's Rank Correlation Coefficient. The non-parametric tests were used, because the data did not show normal distribution and homogeneous variance (Kolmogorov-Smirnov test).

Moreover, the influence of temporal scale on the fish movements was evaluated using the ratio of visits (RV) in the tailrace. The RV was calculated per hour using the expression:

$RV = \frac{InM}{OutM}$, whereas:

InM = Total number of inward movements to the tailrace performed by tagged individuals;

OutM = Total number of outward movements from the tailrace performed by tagged individuals.

The influence of temporal scale on the RV was evaluated using the mean values among three temporal scales: i) weekly; ii) daily and iii) diurnal/nocturnal. For this analysis, the number of movements of *P. argenteus* and *P. maculatus* were grouped. The residuals from linear regression were utilized to examine the variability of RV related to the temporal scale. Then, we accessed the statistic differences among the scales using the Kruskal-Wallis test (significant difference: $p<0.05$).

In order to analyze differences on the movements of fish between the periods of the day, the number of visits was calculated for two categories: i) diurnal (from 6am to 6pm) and ii) nocturnal (from 7pm to 5am). Comparisons between the number of visits among periods of the day for *P. argenteus* and *P.*

maculatus were conducted with Mann-Whitney U test. Also, the same information was used to verify the influence of Três Marias Dam operational discharges on the movements of *P. argenteus* and *P. maculatus* in the tailrace. In this case, differences on the number of visits were evaluated separately for diurnal and nocturnal periods among the three scenarios of total turbine discharge using Kruskal-Wallis test. Scenario A corresponded to the minimum operational condition, with discharges varying from 385-462 m^3s^{-1}. On the other hand, Scenario B was defined as the maximum operational condition, with discharges varying from 660-715 m^3s^{-1}. In both cases, all the turbines worked with the same generation, avoiding any difference of influence among the turbines on the fish movements. Lastly, Scenario C corresponded to periods of variable discharges that promoted any change above 10 MW in power generation for any turbine and that did not remain constant for at least 2 hours (Figura 3). These scenarios were chosen because they were displayed for longer periods along the study. It is noteworthy that out of six turbines, only one turbine was not operating due to maintenance during the whole study period (Figure 2). The number of hours observed for each scenario varied between 769, 783 and 398 hours for Scenario A, B and C, respectively.

Moreover, the influence of water transparency and spill events on the movement of tagged fish in the tailrace was tested using Mann-Whitney U test. For this purpose, we defined two categories: i) high (> 2 meters) and ii) low (< 1 meter) transparency and presence/absence of spillway discharges downstream from the tailrace. The temperature values were not used in statistical analysis due the low variability during the study period (means of 23,77ºC; amplitude lower than 1°C). The water transparency (obtained with Secchi disk) and temperature were randomly measured in the tailrace at least once every 10 days. The spillway remained opened for 45 consecutive days from December 23rd to February 6th with the discharge ranging from 130 to 2604 m^3/s (Figure 3).

Turbine and spillway discharges data were provided by CEMIG (Companhia Energética de Minas Gerais) which operates Três Marias Dam.

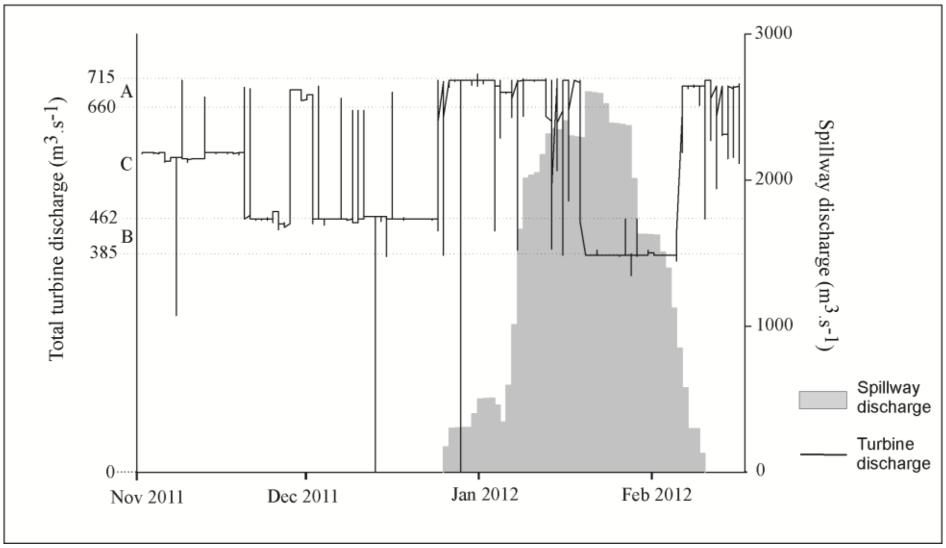

Figure 3 - Hourly variation of total turbine and spillway discharges ($m^3.s^{-1}$) at Três Marias Dam, from 31 October 2011 to 16 February 2012 (Source: Companhia Energética de Minas Gerais). The dotted lines represent the range of total turbine discharge scenarios: Minimum (A), Maximum (B) and Variation (C).

Results

From a total of 2616 hours, it was possible to work with 1933 hours of fish movements. The remainder of the time, there was no tracking of the fish movement, due to technical problems in the acoustic tag receiver or in the energy supply. Among the tagged fish, we identified nine immobile tags (acoustic signals always in the same place) after release, being 7 (14%) *P.*

argenteus and 2 (5%) *P. maculatus*. In this case, they were removed from the analyses. The remainder of tagged fish left the tailrace before the end of study period (16 February 2012). The majority (more than 75%) did it in less than one week (Figura 4). The residence time was greater for *P. maculatus* when compared to *P. argenteus* (Mann-Whitney test, U=432.50, p<0.01).

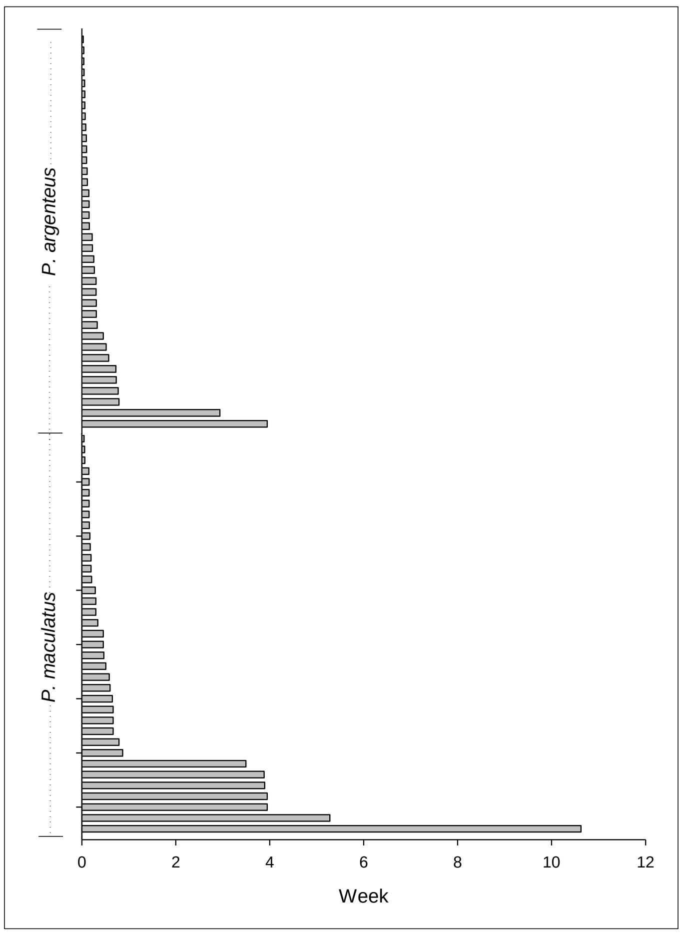

Figure 4 - The residence time of tagged *Prochilodus argenteus* and *Pimelodus maculatus* in the tailrace of Tres Marias Dam, from 31 October 2011 to 16 February 2012

Although all the tagged fish left the tailrace, 35 individuals (19 *P. maculatus* and 16 *P. argenteus*) returned, in most cases, performing visits more than twice (ranging 1-38 times) per individual. Despite the median of the number of visits having been higher for *P. maculatus*, there was no significant difference between the two species (Mann-Whitney U test, $p > 0.1$) (Figure 5). Nevertheless, there was significant negative correlation between the number of visits and individual size for *P. maculatus* ($r = -0.59$, $p < 0.05$), whereas the correlation between these two variables was not observed for *P. argenteus* ($p > 0.05$).

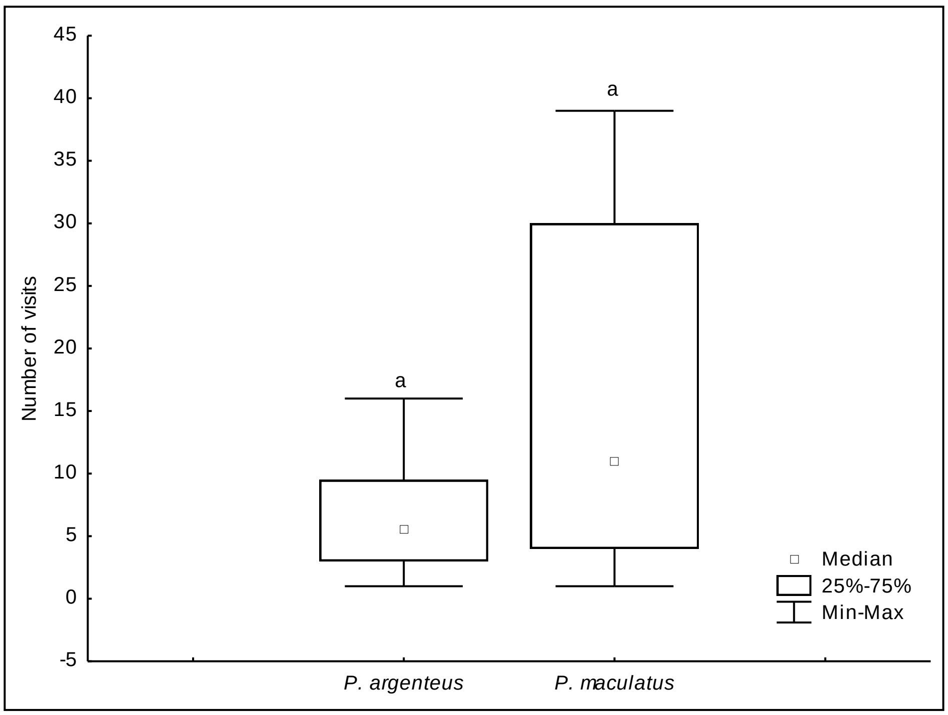

Figure 5 - Number of visits of *Prochilodus argenteus* and *Pimelodus maculatus* in the tailrace of Três Marias dam from 31 October 2011 to 16 February 2012.

The tailrace residency was also significantly longer for *P. maculatus* (median of 28,76 hours) than for *P. argenteus* (median of 5,88 hours) (Mann-Whitney test, U=33, $p<0.01$). However, there was no correlation between the tailrace residency and size of individuals for both species (Spearman correlation, $p>0.05$).

According to the ratio of visit (RV), a prevalence of outward movements from the tailrace was observed during the first fortnight. Nevertheless, after this period, the RV was 1:1 (Figure 6). Also, the RV was influenced by the temporal scale. The higher the resolution for the temporal scale (i.e. diurnal/nocturnal scale) the more variability was observed for the RV (Kruskal-Wallis test, H=94.32, $p<0.001$) (Figure 7).

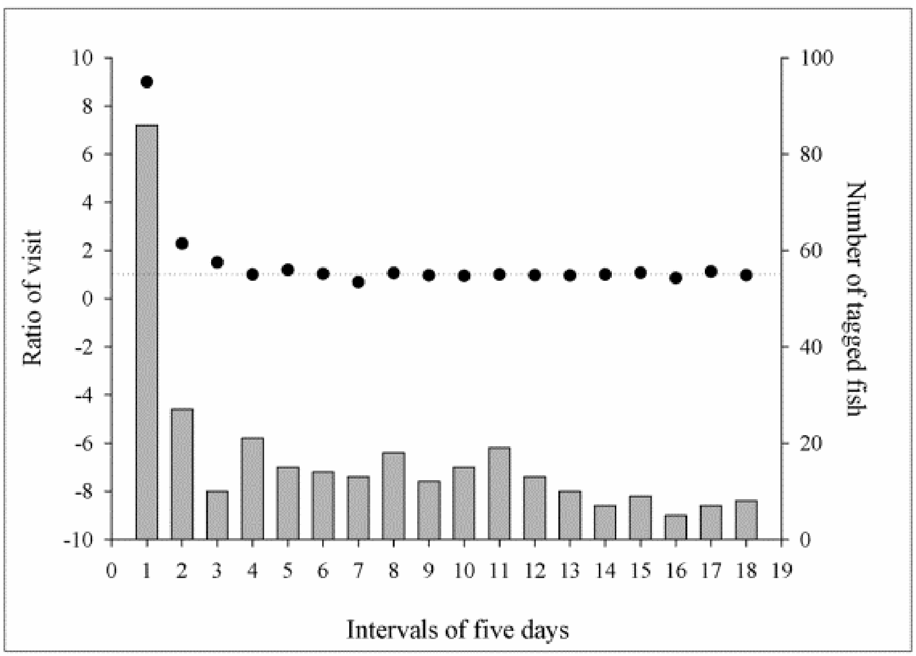

Figure 6 - Variation of the mean ratio of visit (RV – black dots) and number of tagged fish among five days interval in the tailrace of Três Marias Dam from 31 October 2011 to 16 February 2012.

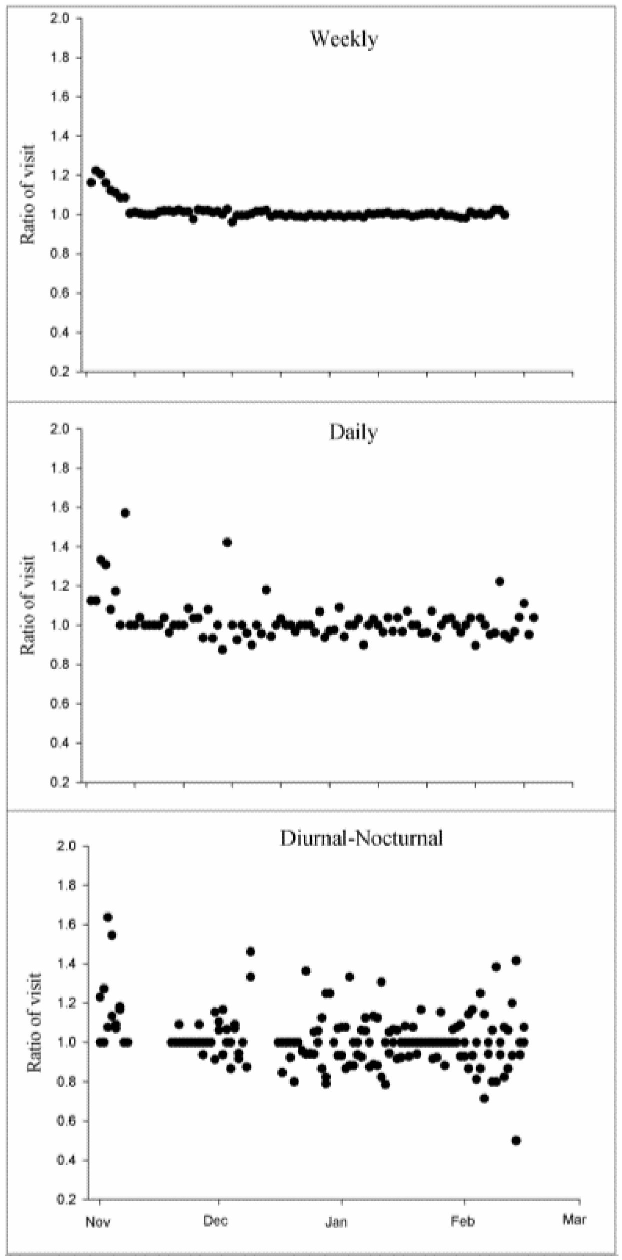

Figure 7 - Mean ratio of visit (RV) of tagged fish among temporal scales in the tailrace of Três Marias Dam during the period from 31 October 2011 to 16 February 2012.

The analysis of fish movements, based on the number of visits to the tailrace for the diurnal/nocturnal scale, revealed differences among the two species. *P. maculatus* were more active at nocturnal periods, whereas *P. argenteus* were strongly diurnal (Figure 8). Nevertheless, the influence of Três Marias Dam operational discharges on the diurnal/nocturnal movements was not observed, except for Scenario B, where fish were exposed to maximum turbine discharges. In this case, *P. maculatus* showed significant movement increase for the diurnal and nocturnal periods (Figure 8).

The transparency values ranged from 3.7 to 0.25 meters during the study period. The number of visits for *P. maculatus* was influenced by the variation of this factor, with significant increase of their movements at daylight during the high transparency periods (M-W test, $U=16.5$, $p<0.05$). *P. maculatus* number of visits was also influenced by spillway discharge, with higher values observed during spill events (Mann-Whitney test, $U=354.30$, $p<0.001$). Neither the transparency nor the spillway discharges had influenced the number of visits for *P. argenteus* (Mann-Whitney test, $U=817$, $p>0.1$).

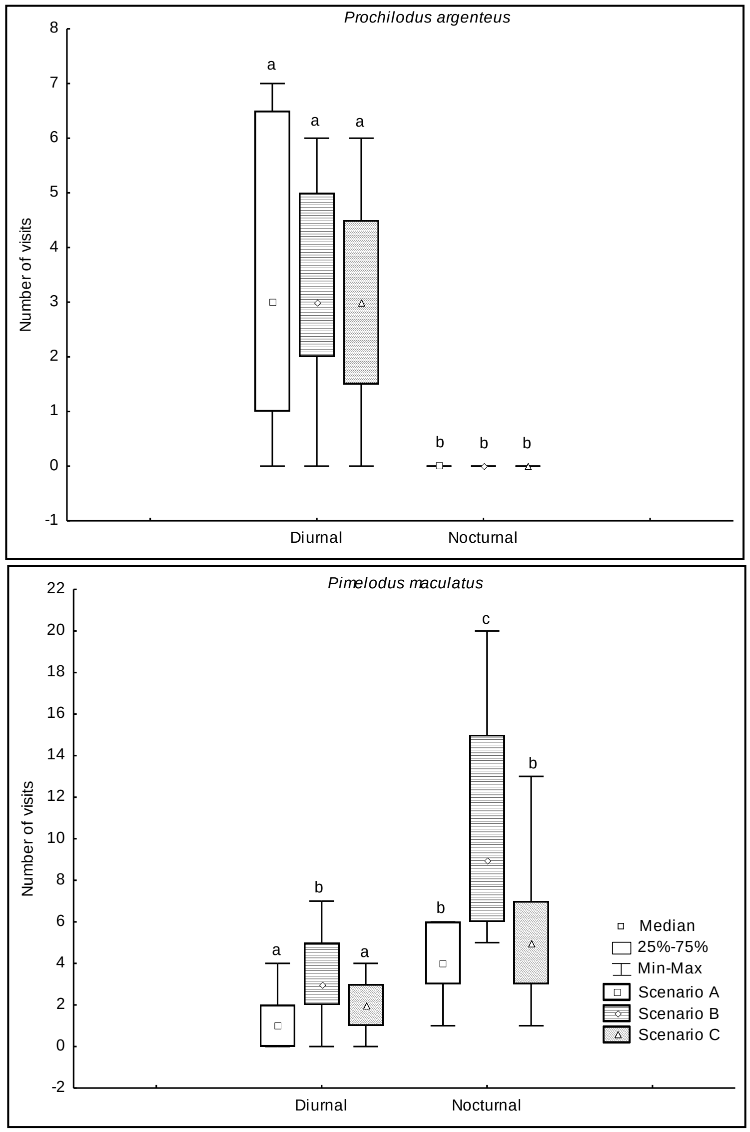

Figure 8 – Influence of the diurnal/nocturnal periods on the number of visits to the tailrace for *Prochilodus argenteus* and *Pimelodus maculatus* considering three scenarios for Três Marias Dam operational discharges from 31 October 2011 to 16 February 2012. Scenario A = 385-462 $m^3.s^{-1}$; Scenario B = 660-715 $m^3.s^{-1}$ and Scenario C = variable discharges.

Discussion

In recent years, fish tagging techniques have become a powerful tool for fisheries research in Brazil. Most of them have been directed towards solving one of the biggest concerns in fish conservation, the efficacy of fish passages for migratory species (Fernandez *et al.*, 2004; Pompeu and Martinez, 2006; Agostinho *et al.*, 2007b; Fontes Júnior *et al.*, 2012; Wagner *et al.*, 2012). Some studies have been done to understand the migratory behavior of a few neotropical species (Godinho and Kynard, 2006; Godinho *et al.*, 2007; Hahn *et al.*, 2011). However, there are no fish tagging studies that have addressed the understanding of fish behavior immediately downstream from the dam to understand fish movements in this area with high risk for the fish fauna. The major risk is associated with high mortality rates observed for several hydropower plants in Brazil due to fish entering and getting trapped inside the draft tube of turbines, representing a big concern for fish conservation (Agostinho *et al.*, 2007a). Although the knowledge of fish movement patterns in the tailrace can be an essential step for elaboration of strategies to minimize this impact, the use of telemetry techniques for this purpose is scarce, especially for acoustic telemetry. The reason for that relies on the fact that the tailrace environment imposes several unsuitable conditions for the use of acoustics, such as high turbulence, high flows, bubbles and electric interference (Steig *et al.*, 2013). Despite these unsuitable conditions, this study showed the possibility of tracking movements of tagged individuals of *P. argenteus* and *P. maculatus* in the tailrace of Três Marias Dam.

One important variable that can determine the success of a telemetry study is the effectiveness of the surgery procedure to allow the fish to recover, reducing mortality and bias to the behavior. For this study, nine tags were detected immobile in the tail race. This result can be due to either the death of the tagged fish or the tag being expelled. Individuals can respond in different ways and some have higher sensibility and susceptibility to infection after the surgery, leading to the loss and expulsion of the transmitter or even death (Bridger and Booth, 2003; Ammann *et al.*, 2013). Considering the death of some tagged fish, it was not possible to determine the mortality rates, since hydrophones coverage was limited to the tailrace only and fish that moved downstream was not detected.

The residence time for both studied species in the tailrace after release was short with the majority of the fish leaving the tailrace in less than one week. This quick outward movements from the tail race likely occurred in order to search for shelter and/or a safe area after the stressful conditions of the capture-tagging-release process. Exiting from the tailrace might be an attempt by tagged fish to avoid high turbulence and flow conditions and also predator attacks by fish and birds. These predators are often seen in high concentration in the tailrace feeding on *P. argenteus* and *P. maculatus*. Comparing this time between the two tagged species, *P. maculatus* remained significantly longer than *P. argenteus*. The bottom swimming behavior of *P. maculatus* may give them an advantage over *P. argenteus* in finding some place to hide, since the river bed in the tailrace is covered by large rocks, according to reports made by divers during the hydrophones deployment.

The variability in the number of visits to the tailrace performed by *P. argenteus* and *P. maculatus* indicates that these species are in constant displacement between the tailrace and the areas downstream from the dam. Scruton *et al.* (2007) detected shorter range of tailrace entrances for Atlantic Salmon (1-21 entrances) when compared to this study. Also, for another Curimba species – *Prochilodus lineatus* – Silva (2004) detected a single entrance of radio tagged fish into the tailrace of Igarapava and Jaguara Dams. Unsuccessful attempt to migrate upstream can lead the fish to seek out other migratory routes and consequently undertake a new attempts through the tail race (Scruton *et al.*, 2007) or moving out of the tailrace toward tributaries (Antonio *et al.*, 2007). Nevertheless, the outward movement of fish from the tailrace can also be due to unfavorable conditions within the area, such as noise, vibration and dissolved gas (Scruton *et al.*, 2007). The tailrace residency was also significantly greater for *P. maculatus*, indicating that this species remains longer periods within the area when compared to *P. argenteus*. Although the both species are considered migratory fish, *P. argenteus* are known as long distance migrants, while *P. maculatus* perform short distance movements (Sato and Godinho, 2003). The smaller home range for *P. maculatus* can explain the greater the number of visits and the tailrace residency for this specie. The greater permanence in the tail race, the more likely it is to suffer injuries and/or mortality depending on physical and operating characteristics of the plant, as well as the swimming ability of the species (Scruton *et al*., 2007). Therefore, the higher number of visits made by smaller *P. maculatus* can explain the major presence of smaller individuals (average size of 22 cm) in the draft tubes during the operational maneuvers (CEMIG unpublished data).

The prevalence of outward movements from the tailrace was already expected in the first days after release. The lower number of inward movements to the tailrace performed by the tagged individuals can be explained by a few reasons: (1) stressed fish after the surgery moved downstream looking for shelter; (2) fish were captured by fisherman or predator and (3) died fish due to the tagging procedures. Silva (2004) had also registered downstream movements of Curimba (*P. lineatus*) in the first days after tagging/releasing procedure. Moreover, Hahn *et al*. (2007) described clear downstream movements of *Pterodoras granulosus* and *Schizodon borellii* at the Lateral Canal at Itaipu Dam immediately after release, probably caused by post-surgical stress. Only after fifteen days there was a balance between outward and inward movements. This equilibrium only after a fortnight can be an evidence of the time that tagged individuals have taken to recover from the stress and surgery. It is known that the fish swimming performance can be affected in the first days after tagging and some tagged fish can take a few days to recover totally from the surgery (Mellas and Haynes, 1985; Moore *et al.*, 1990).

Another finding of this study was the influence of the temporal scale on the analysis of fine-scale movements, with major difference on the observed ratio of visits (outward and inward movements) at higher resolution scale (weekly to diurnal/nocturnal scales). The higher variation in this ratio was explained by the diurnal/nocturnal difference between the behavior on each species, with major movements for *P. argenteus* during the day and at night for *P. maculatus*. Analyses of the ratio of visits at the weekly and daily scale did not allow good observations of the variations among diurnal and nocturnal periods. Silva (2004) also described that most of the migratory movements of Curimba (*P. lineatus*) at the fish ladder of the Igarapava Dam occurred during the day while *P. maculatus* is expected to have predominantly nocturnal habits, remaining hidden during the daylight (Santos *et al.*, 1984). Moreover, this result agree with that found by Loures & Pompeu (2012) in the same study site, where captures of Characiforms and Siluriforms were predominant in the diurnal and nocturnal periods, respectively. However it is noteworthy that the *P. maculatus* behavior at daylight was influenced by water transparency, since movements for this species were greater at low transparency period, indicating that water clarity is likely to promote changes in the fish movements. This pattern was also observed for Chinook salmon, where the increase of activity during the day was related to the water turbidity (Chapman *et al.*, 2013; Michel *et al.*, 2013). The lower *P. maculatus* movements during the daylight in periods with high water transparency can be a response to avoid predation. The higher water transparency increases the predators visibility, increasing the encounter rate with the prey and favoring attack success (Gregory and Levings, 1998).

There is little information in the scientific literature about the influence of hydropower plant operation on the fish movement immediately downstream, especially in the tailrace. On the other hand, it is known that the fish can respond to the hydrodynamics stimulus, like velocity and discharge (Goodwin *et al.*, 2006; Martignac *et al.*, 2013). Studies evaluating the efficiency of fish passage have showed that discharge has an important influence on the ascension of migratory species, with positive correlation with the abundance of fish in the facility (Fernandez *et al.*, 2004; Pompeu and Martinez, 2006). Silva *et al*. (2012) showed that the spillway and turbine discharges increased the abundance of fish downstream from Baguari Dam, with significant higher values for migratory allochthonous and non-migratory species in the spillbay during spill events. In addition, the water velocity represents an important variable on the selectivity of fish that ascend through the fish ladder (Agostinho *et al.*, 2007b). The results gathered with the analysis of the number of visits related to the different operational scenarios at Três Marias Dam were consistent with these general observations. Although the *P. argenteus* movements did not show relation with the turbine discharge scenarios, higher *P. maculatus* movements was observed mainly during the maximum discharge scenario (660-715 m^3s^{-1}). The high swimming performance and bottom swimming preference of *P. maculatus* (Santos *et al.*, 2008) may facilitate its movement into the tailrace, even during the maximum discharge. Hahn (2007) describes variability in the abundance of radio tagged dourado – *Salminus brasiliensis* due to total discharge of Itá Dam. High discharges promoted reduction in the number of fish within the tailrace, however, low discharges increased the variability on the number of fish below Itá Dam.

Specific information about the influence of hydropower plants operation on the movements of fish was discussed by Linnik *et al.* (1998), Rivinoja *et al*. (2001), Thorstad *et al.* (2003) and Scruton *et al*. (2007). Linnik et al. (1998) observed a greater proximity of sea trout (*Salmo trutta*) to the turbines during higher water discharge at Włocławek hydropower on the Vistula River, Poland. Rivinoja *et al*. (2001) found that Atlantic salmon (*Salmo salar*) had their migration affected by the flow regime regulated by the Stornorrfors hydropower development with higher discharges (mean of 150 m^3s^{-1}) leading the fish to upstream migration toward the turbine. Also, for Atlantic salmon, Thorstad *et al*. (2003) registered fish migrating upstream toward the power station outlet during high discharges (150-300 m^3s^{-1}). Scruton found the same pattern for the same species at a power plant on the Exploits River, Canada, as well as the pattern observed for *P. maculatus* for this study. These results clearly indicate the increase in the likelihood of have fish attracted to the tailrace during high flow regimes at the dams.

Furthermore, the higher number of visits during opened spillway periods observed in this study suggests that the spill events also influence on *P. maculatus* movements within the tailrace, probably because it increases the total discharge to the river downstream. The hypothesis that the spill can attract fish to the tailrace was already mentioned and evaluated in the same site by Andrade *et al*. (2012a), but the data were inconclusive to confirm it.

The results found in this paper, like the longer tailrace residency, higher median of the number of visits and the influence of discharge (turbine and spillway discharges) on inward movements to the tailrace indicate the higher vulnerability of *P. maculatus* than *P. argenteus* to entry into the draft tube. This vulnerability plus the high swimming performance and the bottom swimming preference of *P. maculatus* can facilitate their entry into the draft tubes, explaining why *P. maculatus* is the species most affected by turbine operation (Santos *et al.*, 2008; Andrade *et al.*, 2012a).

Some preventive measures adopted in order to minimize the impact on fish at Três Marias Dam have led to positive results. The use of fish screens, for example, during turbine stop/startup procedures has reduced the entry of fish into the draft tubes and avoided fish mortality events. Furthermore, fish monitoring conducted regularly immediately downstream from the dam by Peixe Vivo (CEMIG´s environmental program) has proportioned subsides for operational areas to perform turbines maneuvers with lower impact (Andrade *et al.*, 2012a). Nevertheless, to conciliate these preventive measures with scientific results can lead to even more efficient results. Loures & Pompeu (2012) recommend that activities more risky to the fish are undertaken in months of low precipitation, periods of lowest abundance in the tailrace. Considering our results, we also recommend that operational maneuvers are conducted in periods of low precipitation, since this corresponds to periods of higher water transparency. The lower *P. maculatus* movements during the diurnal periods can reduce the probability of fish entrance into the draft tube in case of an operational maneuver. Furthermore, our results indicate that these maneuvers during maximum generation and opened spillway periods can represent higher risk of *P. maculatus* injuries/kills events. However, it is worth mentioning that this result reflects the situation of visitations movements to the tail race, and the fish response in areas closer to the turbines may be different from our results, due the higher turbulence and water velocity. This would explains the results found by Andrade et al. (2012b), in which observed a greater number of trapped fish inside the draft tube during minimum discharge. In this sense, although the maximum generation can attract fish to the tail race, the higher water discharge can keep fish away from the areas too close to the turbines, reflecting a lower number of trapped fish inside the draft tube. In this context, we believe that the maximum operation (spillway and turbine discharge) followed by minimum generation before some risky operational maneuvers can represent a situation of high impact to the species.

In summary, the results elucidated in this paper show the importance of studies addressed to the understanding of fish behavior in an area under the influence of hydropower plant operation. Certainly, fish movement data can provide hydropower plants managers with good information about the likelihood of occurrence of a fish injuries/kills events since these impacts can occur in combination with fish attraction to the tailrace (Scruton *et al.*, 2007). The knowledge of fish movement and aggregation patterns provides useful insights on how to manage hydropower plants operation to minimize these undesirable impacts worldwide. Finally, the results also encourage the use of telemetry techniques for several sites to provide the necessary data to subsidy managers decision to take action related to hydropower plants operational maneuvers.

Acknowledgement

This work could not have been completed without the efforts of the ichthyology laboratory team from UFLA and Peixe Vivo program (special thanks for Ivo Prado, Raquel Loures and Ricardo Silva). We thank the Alves dos Santos brothers (Waldir, Deir, Walmir and Valdeci), fishermen from Tres Marias city for the help in this work. We also owe thanks to the Três Marias Dam operational and maintenance team, Marcos and his diver team and Hydroacustic Technology Inc (special thanks for Samuel Johnston and Colleen Sullivan) for their assistance for the development of this study. We are grateful to the Federal University of Lavras for logistical help, CEMIG for funding this study and Fundação de Amparo à Pesquisa do estado de Minas Gerais (FAPEMIG) for the PhD scholarship.

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ARTIGO 2

ASSESSMENT OF HYDROPOWER PLANT ON THE SPATIAL DISTRIBUTION PATTERNS OF TWO MIGRATORY FISH IN THE TAIL RACE OF TRÊS MARIAS DAM, UPPER SÃO FRANCISCO RIVER, MINAS GERAIS, BRAZIL

“Artigo formatado nas normas da revista River Research and Applications”

Assessment of Hydropower plant operation on the spatial distribution patterns of two migratory fish in the tail race of Três Marias Dam, upper São Francisco River, Minas Gerais, Brazil

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Abstract

The understanding of fish movements and how these patterns are influenced by the hydropower plant operations may be an important key to define operational strategies with less risk of fish kill in the turbines. From October 31st 2011 to February 16th 2012, we used acoustic telemetry to access the spatial distribution of two migratory fish (n=90 individuals total; 50 *Prochilodus argenteus* and 40 *Pimelodus maculatus*) in the tail race of Três Marias Dam on the São Francisco River, Minas Gerais State, Brazil. We evaluated the spatial distribution of tagged fish in relation two areas: outside and inside the area immediately downstream from the dam in the tail race (arbitrarily delimited up to 30m downstream from the dam). We considered the closer to the dam, the higher is the risk of fish entrance in the draft tube. Differences in the detection number inside of this area in two periods seem to indicate the influence of tag implantation on their swimming behavior. Moreover, evident differences were found in the behavior between the two tagged species. The *P. argenteus* remained longer in the area immediately downstream from the dam and closer to the surface during diurnal period. On the other hand, we observed a greater permanence of *P. maculatus* in the same area and closer to the bottom at nocturnal period. The spatial distribution of both species was influenced by the hydropower plant operation, with greater permanence in the area immediately downstream from the dam during minimum turbine discharge. The findings in this study provide useful insights for the better understanding of fish behavior in an area under influence of hydropower operation and for the adapting of these operations in order to minimize fish kill.

Keywords: Fish kill, migratory species, movement patterns, operation strategies, turbines.

Introduction

Although the hydroelectric power is important for economic growth, it is widely recognized that river impoundment causes several impacts, especially on the aquatic community. Dam construction changes the water and environment quality in both downstream and upstream areas, representing loss of habitat for many fish species. For migratory fishes, the habitat fragmentation by dams prevents these fish from reaching spawning areas and interrupts their reproductive cycle (Agostinho *et al.*, 2008). Furthermore, the frustrated attempt to move upstream during the reproductive season causes fish accumulation downstream from the dam, whose aggregation frequently leads to the entrance of many fish into draft tubes. In general, the entrance of fish into these generator units occurs during the operational maneuvers, like stop and start up procedure of the turbines. From this point on, depending on the amount of fish inside the draft tube, the level of dissolved oxygen can decrease drastically in a short time, leading to the death of many fish in the turbines. Moreover, the decompression and mechanical shock during the startup procedure represent other events that can promote fish kill (Andrade *et al.*, 2012).

Although it is known that migratory and reofilic behavior is closely linked with the reasons of fish accumulation downstream from the dam and the hydrodynamic conditions may attract fish toward the tailrace, little is known about how the hydropower plants operation might influence the fish behavior. As noted by Goodwin *et al.* (2006), fish respond to different hydrodynamic cues; and in general the spatial pattern of individuals is driven by environmental factors (Pientka and Parrish, 2002). In north America, the comprehension of fish behavior and their response to different hydrodynamic conditions has helped design efficient downstream passages for out-migrating juvenile salmon around hydropower dams (Baigún *et al.*, 2007). In this sense, the understanding of fish movement and distribution patterns in an area under hydropower plant operational conditions can be an important key to provide useful insights as to how to manage dam operations to minimize these kinds of impacts. The telemetry techniques have been a powerful tool to evaluate the fish behavior (Klimley *et al.*, 2013). The acoustic telemetry, in particular, has provided 3D position data with high resolution (sub metric precision), enabling the understanding of fish movements patterns in different environments (Ransom *et al.*, 2008). Although the fish studies with the acoustic telemetry is increase constantly in North Hemisphere, there is no register of this technique in South America.

At Três Marias Dam, located in the upper São Francisco River, large aggregations of fish are seen frequently at the tail race. Since 2007, when there was an accident that resulted in a large fish kill episode (Cemig, 2012), operational maneuvers have been done with precaution to avoid other fish kill events and some preventive measures and studies have been developed in this area (Andrade *et al.*, 2012; Loures and Pompeu, 2012). Two fish species are commonly the most affected: *Pimelodus maculatus* and *Prochilodus lineatus* (Andrade *et al.*, 2012). *P. maculatus*, popularly known as Mandi, is a catfish belonging to the Pimelodidae family (Siluriform) with total length up to 45 cm and it is widely distributed at South American Rivers. *P. argenteus*, popularly known as Curimba, belongs to Prochilodontidae family (Characiform), with total length up to 71 cm, and is endemic to the Francisco River. Although the both species are considered migratory fish, *P. argenteus* are known as long distance migrants, while *P. maculatus* perform short distance movements (Sato and Godinho, 2003). Moreover, both are abundant considered important for professional fisheries (Sato *et al.*, 2003).

In order to evaluate the fish movements patterns in an area under direct influence of hydropower operation, we tracked the movements of *P. argenteus* and *P. maculatus* through acoustic telemetry in the tail race of Três Marias Dam located in the upper São Francisco River, Minas Gerais State, Brazil. More specifically, we evaluated: (1) the daily variation and between diurnal and nocturnal period of spatial distribution patterns, (3) depth preference between the two tagged species and (3) the influence of turbine discharge on the spatial distribution of tagged fish in the tail race. All analyses were done taking into account two delimited areas in the tail race: outside and inside the area immediately downstream from the dam (arbitrarily delimited up to 30m downstream from the dam). This area was defined as a place with high probability of fish entrance into the draft tube, due its greater proximity to the accesses to these structures.

Methods

Study area

The Três Marias Dam is located on the upper stretch of the São Francisco River, in the Três Marias municipality. It represents the biggest river in Brazil with approximately 2863 km of extension, with mean annual discharge of 2846 $m^3.s^{-1}$. This hydropower has been in operation since 1962 (Figure 1). The dam has an extension of 2700m and height of 65m and the reservoir has a maximum flooded area of 1040 km^2. There are six Kaplan generation units (GU) with maximum generation and water discharge of 65 MW and 150 $m^3.s^{-1}$ per turbine, respectively. Each turbine has a draft tube with two sections with 15m long and an aperture (exit) of 6x4 m. The tail race has about 155 m of maximum extension and 182 m of width with approximately 19870 m^2 of area. There is a backwater area in the tail race, whose space is destined for future generator units. This area is accessible for fish and represents the place with lowest water velocity in the tail race (Figure 2). It should be mentioned that there is no fish passage in this Dam.

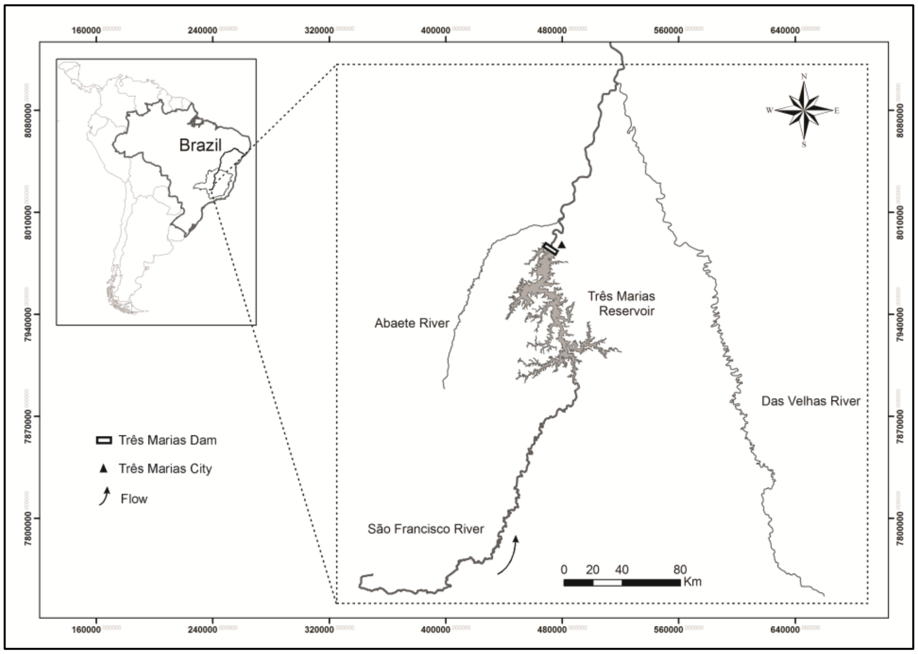

Figure 1 – Location of Três Marias dam on the upper São Francisco River, Minas Gerais State, Brazil.

Fish capture and tagging

The fish sampling and tagging were done from October 31st to November 4th 2011. The fish were captured in the tailrace and in the river downstream using cast nets. Each fish was weighed and measured before starting tag implantation. The surgical procedure was done in a rectangular plastic tank (0.57m length x 0.50m width x 0.17m height) filled with river water and renewed every three procedures. In each surgical procedure, the eugenol (clove oil) was diluted in a proportion of 1ml/40L of water (Hahn *et al.*, 2007) as fish anaesthetic and Labcon Protect Plus® (Alcon pet®) were used to aid fish recovery (Godinho *et al.*, 2007). An aquarium air pump and thermometer were used to aerate the water and to measure the water temperature in the tank, respectively. The fish immobilization was done by electronarcosis technique that consists of a constant low voltage direct current in water (Henyey *et al.*, 2002). For this study, we used a non-pulsed DC current with 26 V and 25 V for *P. argenteus* and *P. maculatu*s, respectively, to allow the breath movements as normal as possible. The sterilized acoustic transmitter was inserted into the peritoneal cavity through a small incision (2.0–3.0 cm) made on the middle ventral line (*P. argenteus*) and lateral body above the anal fin (*P. maculatu*s). The incision area, surgical instruments and acoustic transmitters was disinfected with an iodine solution. A total of 90 fish were tagged, being 50 *P. argenteus* and 40 *P. maculatus*. The mean size of *P. argenteus* was 31.8 cm, ranging from 24 to 45cm, whereas the mean size of *P. maculatus* was 21.8 cm, with values ranging from 19cm to 26cm. Two acoustic transmitters were deployed in this study: Model 795 LX (4.5cm height x 1.55 cm diameter and weighing 12g in air) for *P. argenteus* and Model 795 LG (3.0cm height x 0.90cm diameter and weighing 4.3g in air) for *P. maculatus*, both models are developed by Hydroacustic Technology Inc. (HTI). The acoustic transmitters represented a tag burden of a maximum 2.8% and 3.5% for *P. argenteus* and *P. maculatus*, respectively (tag weight to fish weight ratio).

After the tag implantation, the incision was closed using non-absorbable sutures with 3-5 stitches. Then, the tagged fish were placed in a large tank (1.5m length x 1.2m width x 0.9 m height) filled with river water in constant renewal to recover from the anesthetic and surgery stress for at least 4-6 hours prior to release. The maximum number of tagged fish in the tank per time was 15 individuals. No mortalities were observed during this period.

Telemetry system

The acoustic tags was set with transmission rate at one ping every 3.2-5.3sec and pulse width of 5.0 msec. According to the manufactures, this setting would allow tags to have battery lives ranging from 350-500 days (LX) and 220-400 days (LG). The tracking of fish movements in the tail race was done from October 31st 2011 to February 16th 2012 using 11 Hydrophones (acoustic receivers) installed underwater and positioned to cover the entire tail race area (Figure 2). Positioning of the hydrophones was defined based on data gathered from previous tests conducted in the tailrace, which indicated a detection range of 100m. In order to obtain 3D tracking of tagged fish with sub-metric precision, the hydrophones were installed at different depths (approximately half near the bottom and half near the surface) and positions according to the manufacturers (HTI). All hydrophones were georeferenced and linked to the Data logger (Model 290 Acoustic Tag Tracking System*)* by hydrophone cables (Model 690). This acoustic system operates at 307 kHz and continuously receives and stores all tag transmission pulses for each hydrophone simultaneously. The tagged fish positions are calculated by the same principle used by Global Position Satellites (GPS) (Ransom *et al.*, 2008). The acoustic telemetry system was operated 24h per day in this study.

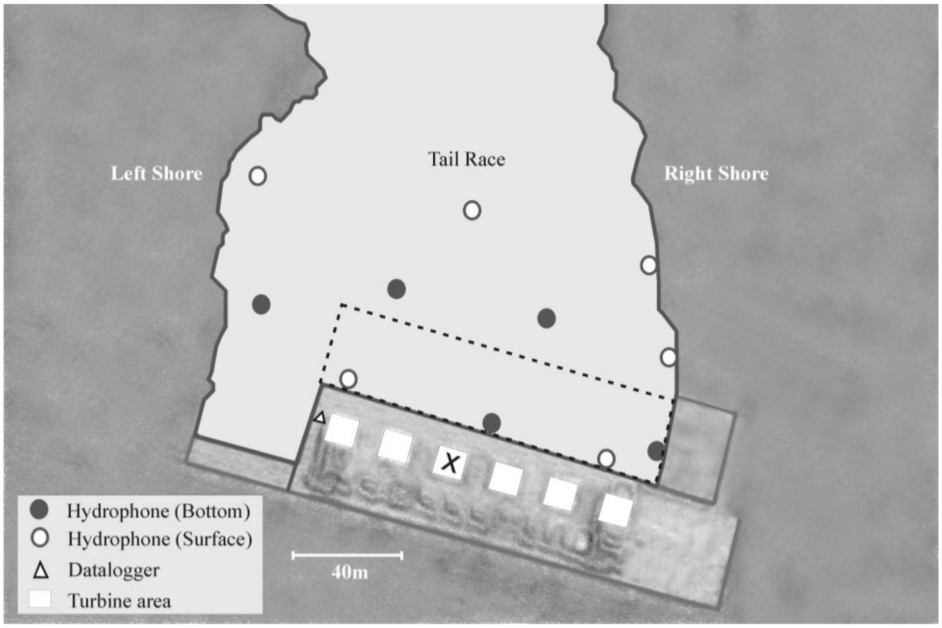

Figure 2 – Location of hydrophones, data logger and turbine area in the tailrace of Três Marias Dam, São Francisco River, Minas Gerais, Brazil. (The letter X shows the turbine that did not operated during the whole study period and the dotted line shows the delimited area (135m x 30m) immediately downstream from the dam)

Data analyses

There are two slots in each turbine that are accessible for fish to reach the draft tube: the stoplog slot and the exit of the turbine water (outflow) (Figure 3). We considered the greater the proximity to these accesses, the greater are the chances to the fish reach the draft tube. In this sense, we delimited arbitrarily an area immediately downstream from the dam (Area IDD) with approximately 30m length x 135m width and with a total area of 3,896.5 m^2 (Figure 2). For the development of statistical analyses, we took into account the detection number of tagged fish inside and outside the area IDD. We used ARCGIS 9.3.1 to delimit this area in the tail race and to calculate the number of detections inside and outside the area IDD.

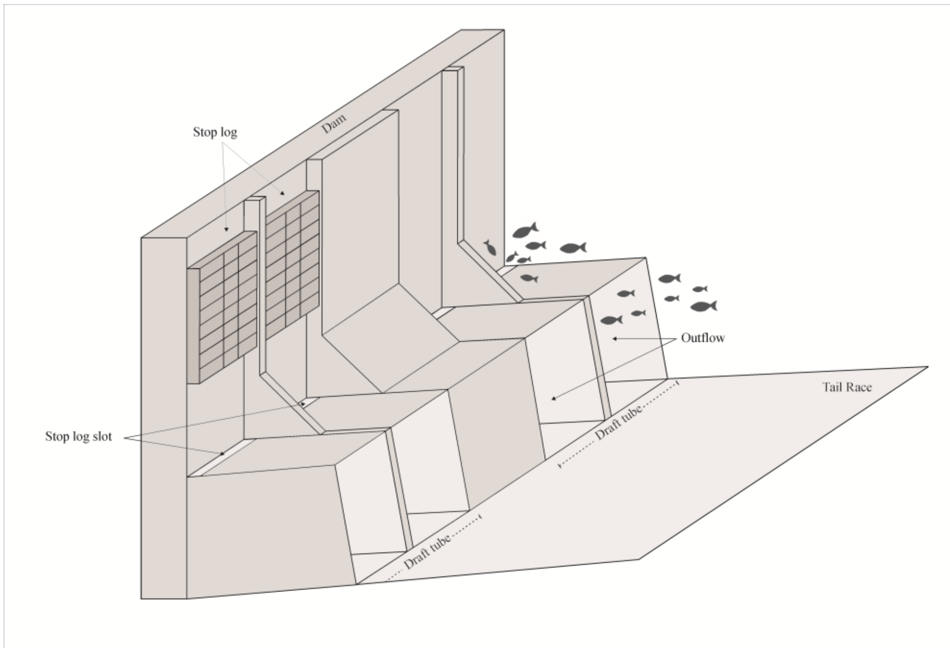

Figure 3 - 3D schematic drawing of a section of Três Marias Dam and the location of the accesses (Stoplog slot and Outflow) for the fish to reach the draft tube. Map not to scale.

Along study period we calculated the daily mean of detection number percentage inside the area IDD in order to evaluate temporal differences on the spatial distribution in the tail race between the two tagged species and a possible effect of tag implantation on the fish behavior. We standardized the data calculating the percentage of total detections number inside and outside the area IDD for each tagged fish per day. Differences in the daily percentage of detection number inside the area IDD before and after the 30th day after the release of tagged fish were tested using Mann-Withney U-test (significant difference: $p<0.05$) for each species. The non-parametric test was chosen, because the data did not show normal distribution and homogeneous variance (Kolmogorov-Smirnov test).

To avoid a possible influence of tag implantantion on the following analyzes, we used only the data after the 30th day from the release time in the tail race. In order to examine the variation along of day period of the spatial distribution, we established two periods: diurnal (from 6am to 6pm) and nocturnal (from 7pm to 5am). We standardized the data calculating the total detection number percentage outside and inside the area IDD per day and per tagged individual. Differences of median values between diurnal and nocturnal periods for each species were tested using Mann-Withney U-test.

Differences in depth preference, between *P. argenteus* and *P. maculatus*, inside the area IDD were tested using Student´s t-test. In this case, the parametric test was used, because the data show normal distribution and homogeneous variance (Kolmogorov-Smirnov test). Due to the water level variations in the tail race that depend on the water discharge scenario, we used the values of distance from the bottom. In this analysis, we grouped all the registered values from the same species and day period.

To access the influence of turbine discharge on the spatial distribution of *P. argenteus* and *P. maculatus* in the tail race, we established two discharge scenarios: minimum (385-462 $m^3.s^{-1}$) and maximum (660-715 $m^3.s^{-1}$). The minimum and maximum discharge scenarios were chosen because they were displayed for longer time, 769 and 783 hours, respectively (Figure 4). Besides, in both cases, all the turbines worked with the same generation, avoiding any difference of influence among the turbines, except one turbine that was stopped for maintenance during whole study period (Figure 2). The turbine discharges data were provided by CEMIG (Companhia Energética de Minas Gerais) which operates Três Marias Dam. We evaluated the influence of turbine discharge using density maps (detection number/m^2) elaborated for each discharge scenario in the diurnal and nocturnal periods and for each species. In this case, we grouped the data from the individuals of the same species. These maps were generated using point density by ARCGIS 9.3.1. Then, we used Kruskal Wallis-test to verify statistical differences on the median of detection number values inside the area IDD for each discharge scenario during the diurnal and nocturnal periods. In this test, we standardized the data calculating the total detection number outside and inside the area IDD per day and individual for each day period, discharge scenario and species. Furthermore, we calculated the median of the distance from the backwater (BW) and left shore for each discharge scenario during diurnal period for *P. argenteus* and both diurnal and nocturnal periods for *P. maculatus*. These values were tested using Mann-Whitney test between minimum and maximum discharge scenario.

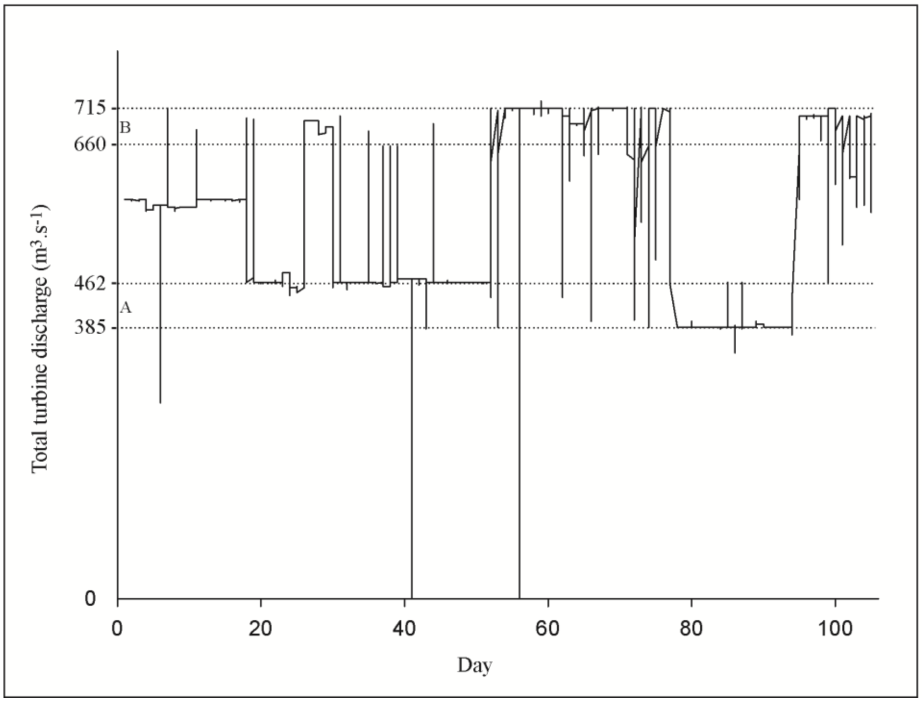

Figure 4 – Hourly variation of total turbine discharge ($m^3.s^{-1}$) of Três Marias Dam, during the period from October 31st 2011 to February 16th 2012. (Source: Companhia Energética de Minas Gerais – CEMIG). The dotted lines represent the range of total turbine discharge scenarios: Minimum (A) and Maximum (B).

Results

From a total of 2616 hours, it was possible to work with 1933 hours of fish movements. The remainder of the time, there was no tracking of the fish movement due to some technical problems in the acoustic tag receiver or in the energy supply.

Of 90 tagged fish, we were able to obtain the 3D tracking of 74 individuals: 39 *P. argenteus* and 35 *P. maculatus*. The remainder of tagged fish (16 individuals) were excluded from the statistical analyses, because either they were considered dead after their release (immobile tags) or it was not possible to obtain the 3D tracking, due to the lack of acoustic signal reception from at least 4 hydrophones. The remainder of tagged fish left the tail race before the end of study period (February 2012), however 35 individuals (19 *P. maculatus* and 16 *P. argenteus*) returned to the tail race, in most cases, performing visits more than two times (ranging from 1-38 times) per individual (Figure 5).

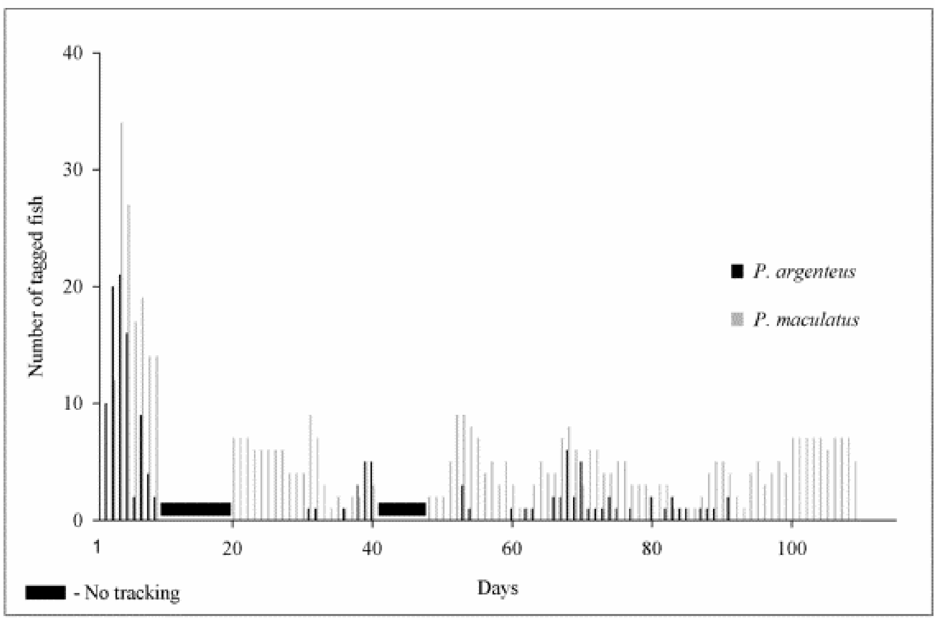

Figure 5 – Number of tagged fish (*P. argenteus* and *P. maculatus*) per day in the tail race of Três Marias Dam from October 31st 2011 (1st day) to February 16th 2012 (108th day).

We observed an evident difference of the daily mean of detection number per individual inside the area IDD for *P. argenteus* and *P. maculatus* between two periods (Figure 6). From the release time to the 30th day, we registered a low detection number inside the area IDD (median of 5.89% and 6.21% for *P. argenteus* and *P. maculatus*, respectively). However after the 30th day, there was a significant increase in this number (median of 40.71% and 46.41% for *P. argenteus* and *P. maculatus*, respectively) (Mann Whitney U test, *P. argenteus*: $U=13.5$ and $p<0.01$, *P. maculatus*: $U=88.5$ and $p<0.01$) (Figure 7).

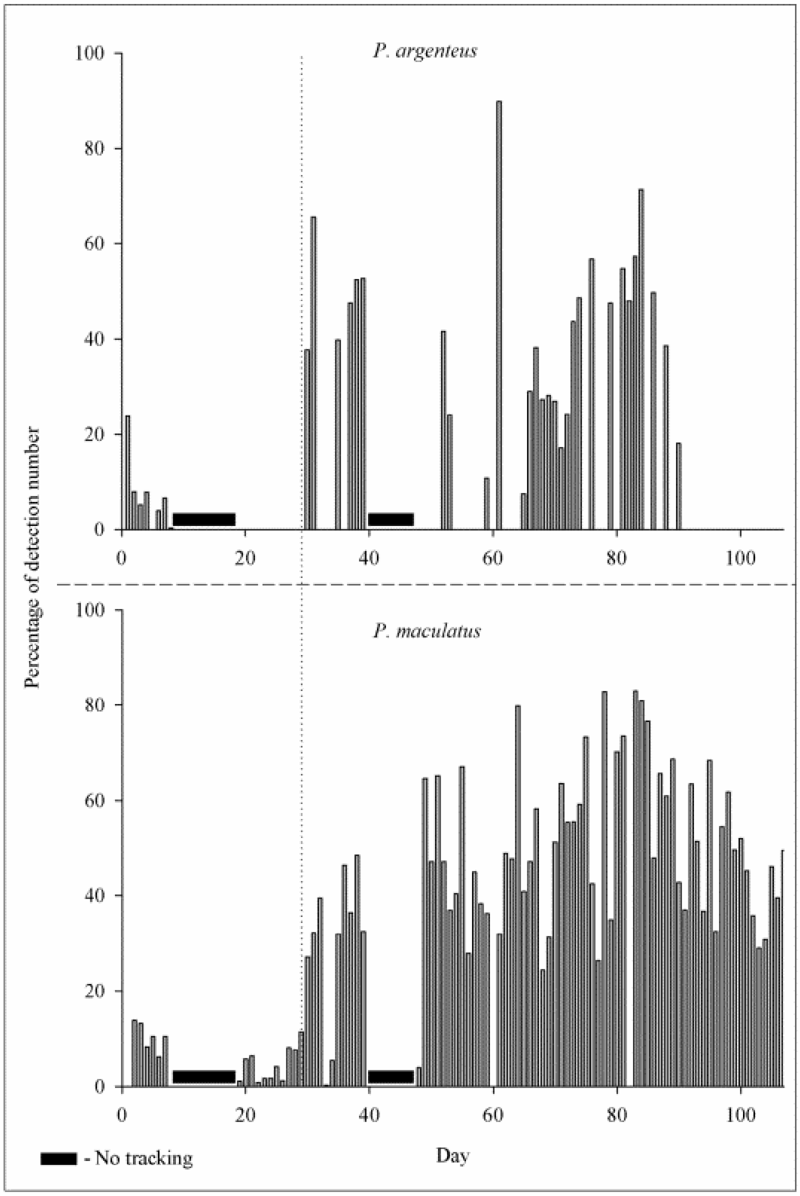

Figure 6 – Mean of detection number per individual inside the area IDD for *P. argenteus* and *P. maculatus* during the study period in the tail race of Três Marias Dam from October 31st 2011 (1st day) to February 16th 2012 (108th day). The dotted line delimits the before (left) and after (right) of the 30th day.

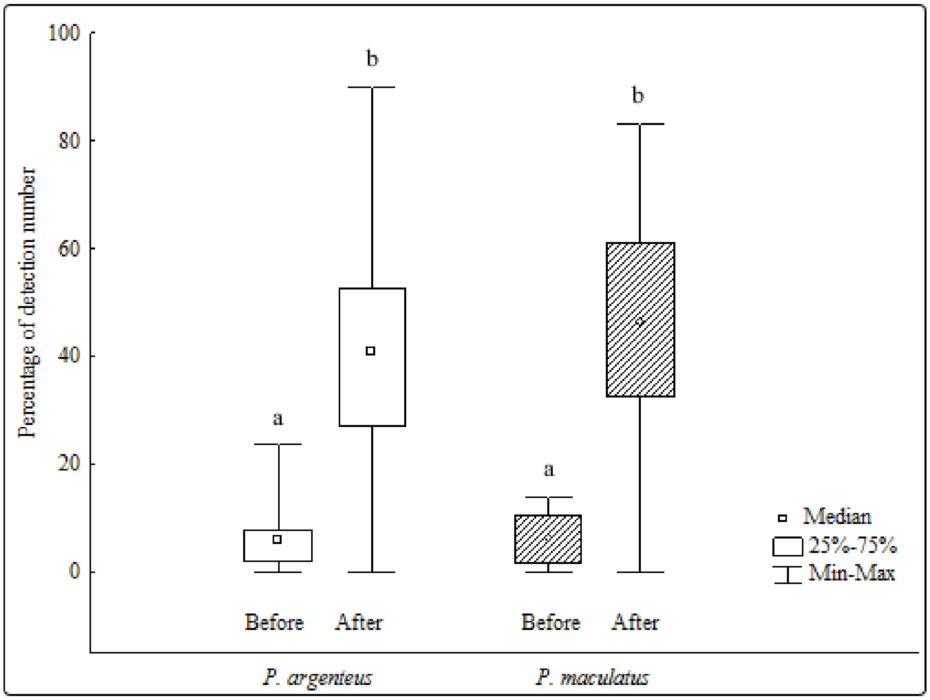

Figure 7 – Percentage of detection number inside the area IDD, for *P. maculatus* and *P. argenteus*, before and after the 30th day from the release time in the tail race of Três Marias dam, from November 11st 2011 to February 16th 2012.

Considering only the movement data after the 30th day, we noticed significant difference of the detection number of *P. maculatus* inside the area IDD between the diurnal and nocturnal period. The detection numbers registered inside the area IDD were higher during the nocturnal period than diurnal period (M-W test, $U=362$, $p<0.05$) (Figure 8). Unlike *P. maculatus*, we were not able to analyze the diel activity for *P. argenteus* due to the lack of movement data during the nocturnal period.

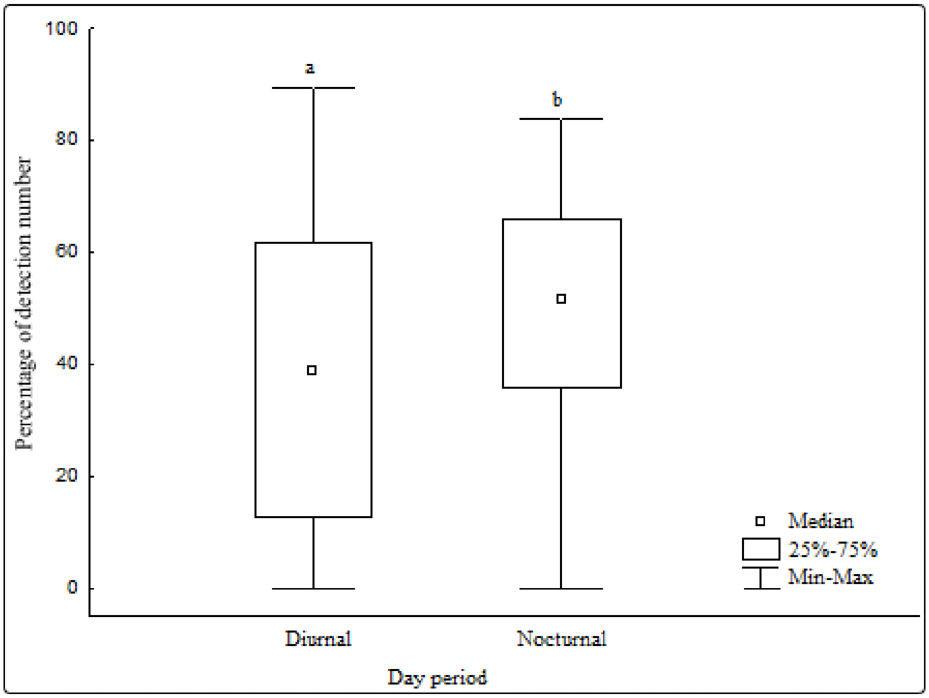

Figure 8 – Percentage of detection number inside the area IDD between diurnal and nocturnal period for *P. maculatus* in tail race of Três Marias dam, from November 11st 2011 to February 16th 2012.

Comparing the distance from the bottom to evaluate the depth preference between *P. argenteus* and *P. maculatus* inside the area IDD, we verified a displacement of the depth value distribution curve towards lower values (0-8 m) for *P. maculatus*, whereas the *P. argenteus* distribution curve showed the values toward the higher values (8-16 m) (Figure 9). This difference was confirmed by the significant difference of the median between *P. argenteus* and *P. maculatus* (M-W test, U= 32483.00, $p<0.01$).

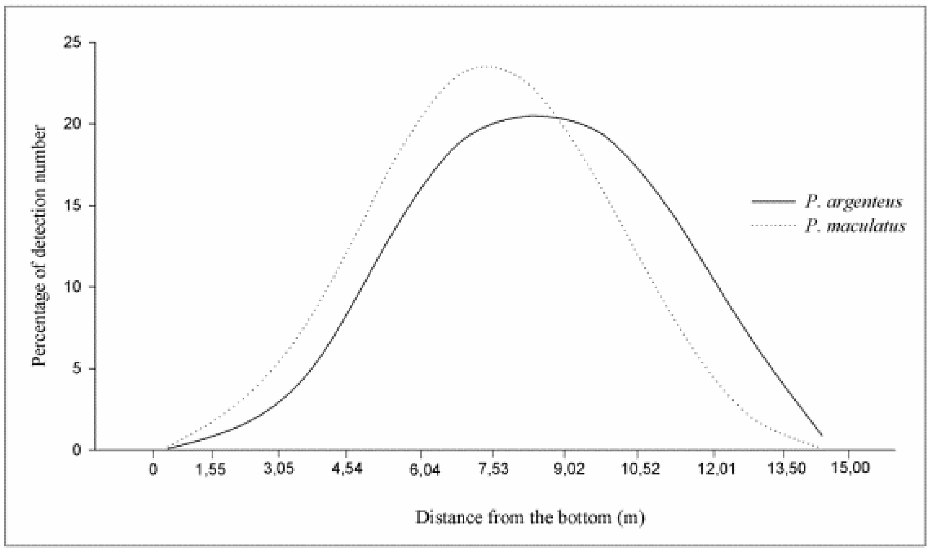

Figure 9 – Percentage of distance from the bottom values registered for *P. argenteus* and *P. maculatus* inside the area IDD in the tail race of Três Marias Dam, from November 11st 2011 to February 16th 2012.

Evident difference was found in the spatial distribution patterns of *P. argenteus* detection on the density maps between minimum and maximum discharge scenarios in the diurnal period (Figure 10), with greater values during minimum discharge (K-W test: $H = 36.35$, $p < 0.01$ - Figure 11). The analyses of the distance from the backwater and left shore between the two discharge scenarios also showed greater values at minimum discharge, but there was no significant difference ($p>0.05$). The same pattern was observed for *P. maculatus*. On the detection density map elaborated for this species, we observed an evident difference between the minimum and maximum discharge scenarios for both periods. At minimum discharge there was a concentration of fish inside the area IDD, while during maximum discharge the highest density regions were not limited only to the area IDD, we were able to observe a dispersion of these points in the tail race (Figure 12). These differences were consistent with the results found by median analyses. The median of detection number percentage inside the area IDD was higher at minimum discharge for both day periods (M-W test: $U=45.00$, $p<0.05$) (Figure 13). Besides, the median distance from the backwater and left shore also showed similar results. During the minimum discharge the distances from the backwater were higher significant in the diurnal (M-W test: $U = 46.00$, $p < 0.05$) and nocturnal period (M-W test: $U=47.00$, $p<0.05$). The median distance from the leftshore was higher, but it was not significantly different for both periods ($p>0.05$).

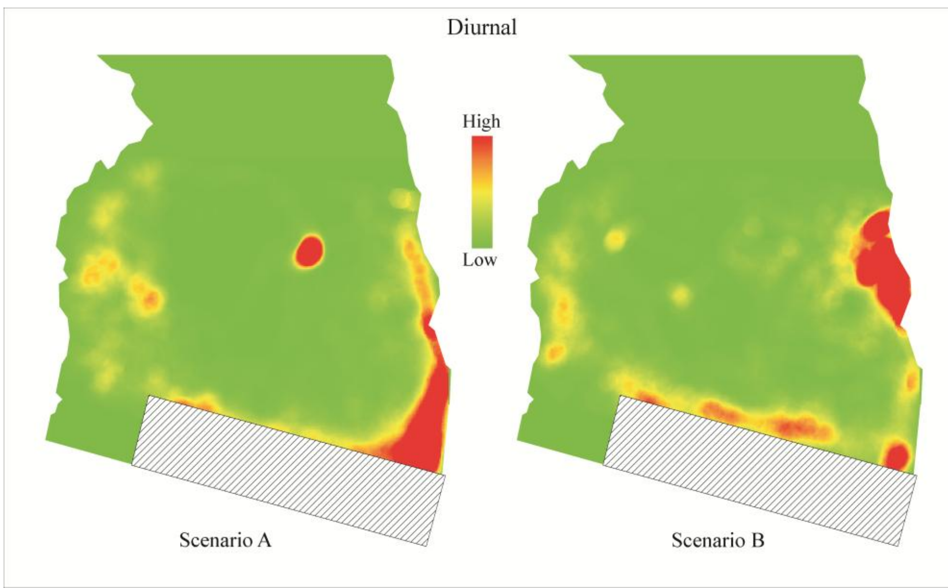

Figure 10 – Density of detection points for *P. argenteus* inside the area IDD at minimum (Scenario A) and maximum (Scenario B) discharge scenarios in the diurnal period in the tail race of Três Marias dam from November 11st 2011 to February 16th 2012.

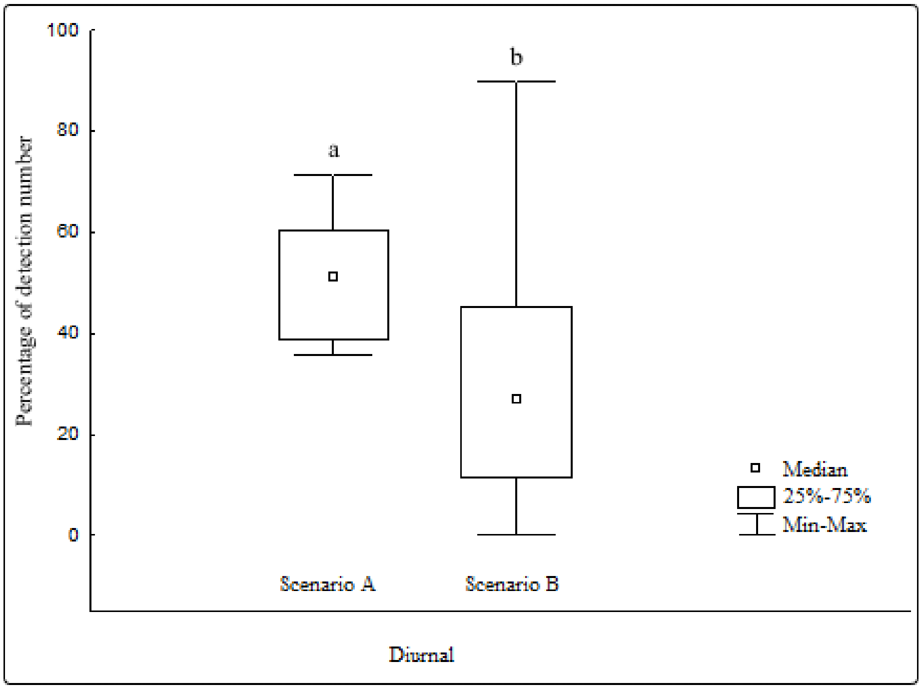

Figure 11 - Percentage of detection number of *P. argenteus* at minimum (Scenario A) and maximum (Scenario B) discharge scenarios in the diurnal period in the tail race of Três Marias Dam, from November 11st 2011 to February 16th 2012.

Figure 12 - Density of detection points for *P. maculatus* inside the area IDD at minimum (Scenario A) and maximum (Scenario B) discharge scenarios in the diurnal and nocturnal period in the tail race of Três Marias dam from November 11st 2011 to February 16th 2012.

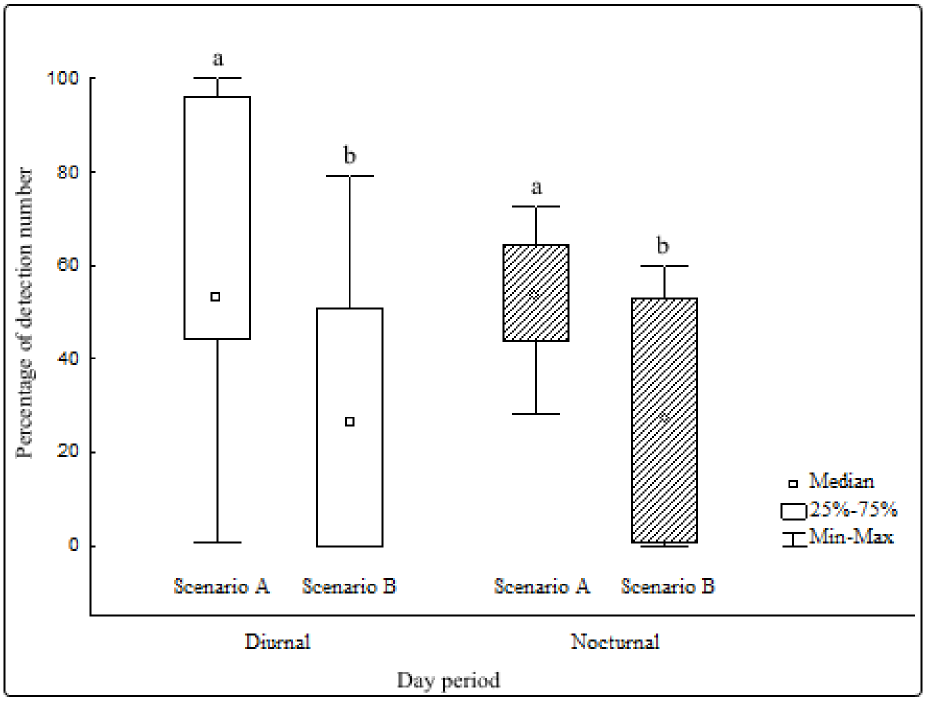

Figure 13 - Percentage of detection number of *P. maculatus* inside the area IDD at minimum (Scenario A) and maximum (Scenario B) discharge scenarios in the diurnal and nocturnal period in the tail race of Três Marias Dam, from November 11st 2011 to February 16th 2012.

Discussion

The occurrence of trapped fish in the draft tube and fish kill episodes as consequence of fish aggregation downstream from the dam (tail race) in Três Marias Dam has led to the adoption of some preventive measures to minimize the impact on fish communities, such as the use of fish screens to isolate the draft tube area and fish monitoring immediately below the dam. The use of fish screens during operational maneuvers has reduced the fish entrance into the draft tubes during the turbine stop/startup procedures (Andrade *et al.*, 2012), whereas the fish monitoring done by fishery biologists from Peixe Vivo program has provided useful information on the fish aggregation situation in the tail race before some risky operational maneuvers (Loures, 2012). This program was begun in 2007 in order to minimize the impact of hydroelectric plants on fish communities, to define management plans for the ichthyofauna conservation and to produce scientific knowledge (Cemig, 2012). In the latter case, to conciliate these measures with the understanding of fish community ecology in the tail race, it is essential to obtain even more efficient results. With the advances of telemetry techniques, for example, it has been possible to describe fine scale 2D and 3D fish movement patterns in order to understand their behavior (Goodwin *et al.*, 2006; Monnot *et al.*, 2008; Chapman *et al.*, 2013; Herrala *et al.*, 2014). Although the number of telemetry studies to understand the fish behavior in North America has increased constantly, this is the first study in Brazil in the tail race of a hydroelectric power plant. In our study, the acoustic telemetry techniques allowed the 3D tracking of two migratory fish, *P. argenteus* and *P. maculatus*.

We identified nine immobile tags in the tail race over this study period. Even when taking all necessary precautions, we cannot discard fish deaths due to the tag inplantation surgery. Individuals can respond in different ways and have higher sensibility and susceptibility to infection after the surgery, leading to the loss and expulsion of the transmitter or even death (Bridger and Booth, 2003; Ammann *et al.*, 2013). Despite the death of some tagged fish, it was not possible to determine the survival rates, since outside the tail race there was no reception by the hydrophones, whose coverage was limited to only the tail race.

We believe that closer to the Dam, the greater the turbulence, water velocity and the risk of fish entrance into the draft tubes, due to the proximity to the stoplog slot and the turbine water exit. In this sense, considering the delimited area immediately downstream from the dam as the area with higher turbulence and water velocity in the tail race, we observed a significant increase of permanence for *P. argenteus* inside the area IDD after the 30th day. Coincidently, this pattern was the same for *P. maculatus*. We believe that one of the explanations for the lower detection number inside the area IDD for both species in the first 30 days may be attributed to the influence of the surgery and tag implantation. It is known that the fish swimming performance can be affected in the first days after tagging and some tagged fish can take some days to totally recover from the surgery (Mellas and Haynes, 1985; Moore *et al.*, 1990). In this sense, the lower detection number inside the area IDD in the first 30 days seems to indicate the influence of tag implantation on the swimming behavior of *P. argenteus* and *P. maculatus*. Possibly, the fish avoid the areas with higher turbulence and water velocity while they recover from the tagging. In this case, in order to avoid any influence of the surgery, we decided to utilize the fish movement data only from the 30th day onward, for both species.

It is known that Neotropical fish exhibit differences in diel activity. Representatives of Characiformes tend to perform their activities during the diurnal period, whereas Siluriformes, in general, show nocturnal behavior

(Lowe-Mcconnell, 1987). Results of studies about the efficiency of fish passage in Brazilian rivers are consistent with this observation, with greater upstream movements during the diurnal and nocturnal period for Characiformes and Siluriformes, respectively (Pompeu and Martinez, 2006; Fernandez *et al.*, 2007). This variation pattern between the species likely explains the diel difference on the detection number inside the area IDD between the diurnal and nocturnal period found for *P. maculatus*. The lower values of this ratio were observed in the period when they are considered more active (i.e. in the nocturnal period for *P. maculatus*). Hence, this result seems to indicate that *P. maculatus* tends to face the area IDD in the nocturnal period, avoiding the turbulence area in a period when they are less active, probably remaining hidden most of the time during this period (Santos *et al.*, 1984). Although we were not able to analyze the variation in the diel activity of *P. argenteus* due the lack of nocturnal data, the detection predominantly in the diurnal period in the tail race may indicate that this species remains in other downstream areas in the nocturnal period, possibly avoiding the high water velocity and flow in the tail race in this period. Loures & Pompeu (2012) found similar results in which they evaluated the temporal variation in a fish community in the same place. The capture of Characiformes and Siluriformes in the tail race were greater in the diurnal and nocturnal period, respectively.

We were able to observe another difference in the behavior between the two species. There was a significant difference in the distribution pattern through the water column between *P. argenteus* and *P. maculatus*. The distribution curves through the water column indicate that *P. maculatus* tend to be closer to the bottom, while *P. argenteus* stay closer to the surface. This difference is in agreement with the information found in the literature, in which *P. argenteus* is a water column swimmer, whereas *P. maculatus* show a bottom swimming preference (Santos *et al.*, 2008). The swimming closer to the bottom and walls of the dam structures, as well as its expressive swimming performance, may facilitate the entry of *P. maculatus* into the draft tube, this being one of the reasons why *P. maculatus* represents the species most affected by dams (Santos *et al.*, 2008).

Several recent studies have been addressed to understand the fish movement patterns for different purposes, for example: (1) to clarify the migration patterns and subsidize management actions focused on fish conservation (Alves *et al.*, 2007; Godinho *et al.*, 2007; Hahn *et al.*, 2011); (2) to improve the efficiency of upstream fish passage for the neotropical migratory fish (Pompeu and Martinez, 2006; Fernandez *et al.*, 2007) and (3) to design efficient downstream passage for out-migrating juvenile salmon around hydropower dams (Goodwin *et al.*, 2006; Baigún *et al.*, 2007). In general, these studies have demonstrated that the spatial pattern of fish individuals is driven by environmental factors. According to Baigún et al. (2007), improvements to bypass design depend on a better understanding of the influence of hydrodynamic conditions on fish movements . In this context, we believe that the understanding of the spatial distribution pattern of *P. argenteus* and *P. maculatus* in different hydroelectric generation scenarios can be an important key to minimize fish kill in the turbines. Although the presence of *P. argenteus* and *P. maculatus* in the tail race is closely linked with the migratory and reofilic behavior of these species, this work demonstrates that the spatial distribution pattern of fish in the tail race may be influenced by turbine operation. The higher concentration of density points inside the area IDD confirmed by significant difference of detection number between the discharge scenarios (i.e. greater at minimum discharge) is strong evidence of the influence of this factor on spatial distribution patterns of these species. These results are consistent with those found by Andrade et al. (2012). They observed a negative correlation between the turbine discharge and trapped fish in the draft tube. The lower water velocity and flow at minimum discharge enable the fish to reach the area IDD and to enter into the draft tube more easily during operational maneuvers. On the other hand, although the critical and maximum prolonged speeds of neotropical species are superior to those of temperate area species (Santos *et al.*, 2012), the higher water velocity and flow at maximum discharge must keep the fish away from the area IDD for the most of the time.

To conciliate operational maneuvers with a minimum possible impact on ichthyofauna is still a big challenge for the hydroelectric companies. Despite this difficulty, the adoption of some preventive measures as mentioned previously, is important for the hydroelectric companies in order to improve their operation with less risk of fish mortality (Andrade *et al.*, 2012; Loures, 2012). Furthermore, the knowledge about fish community dynamics immediately downstream from the dam can be one of the keys to adapting the energy operation and ichthyofauna conservation. A temporal variation study on the fish community in the tail race of Três Marias dam, for example, demonstrated that operational maneuvers synchronized with periods of low abundance in the tailrace (*i.e.*, during months of low precipitation), may be a measure to reduce the impact of the operation on the downstream fish community (Loures and Pompeu, 2012). Moreover, our results show that the synchronization of operational maneuvers in the diurnal period (from 6am to 6pm) can also represent a higher mortality risk for *P. argenteus*, due to their greater proximity to the dam during this period. On the other hand, considering that *P. maculatus* is the species historically most affected by turbines (Andrade *et al.*, 2012), maneuvers in the nocturnal period (from 7pm to 5am) can represent an activity in which there is a higher chance some fish mortality episodes to occur. The higher number of detections inside the area IDD in this period increases the probability of fish entrance into the draft tube, making the operational maneuvers more dangerous. Moreover, we emphasized that risky operational maneuvers in the turbines immediately after a minimum discharge period can increase the chance of fish entrance into generators units, and consequently, fish mortality events even more. As already mentioned by Andrade et al. (2012), we also believe that the operation in maximum discharge before some risky operational maneuvers can be one of strategies to minimize the amount of trapped fish in the draft tube and avoid fish kill.

This study shows that the ability to obtain detailed information on fish behavior using telemetry techniques is very important to understand fish movements and the processes that influence these patterns in an environment under influence of hydropower plants operations. Furthermore, the findings of this work can be useful information for future studies. The indicative of tagging influence on the fish behavior during the first days after the implantation is important information for future fish studies in order to avoid any incorrect conclusion based on the results about these species. Future works could address this issue in more detail in order to confirm this possibility and how long the fish take to recover from the surgery. In a management context, our results provide useful insights for definition of operational strategies in order to minimize fish kill in the turbines. The adaptation and synchronization of the hydropower operation in according to the risk situation may be an important strategy to minimize the impact on fish community.

Acknowledgement

This work could not have been completed without the efforts of the ichthyology laboratory team from UFLA and Peixe vivo program (special thanks for Ivo Prado, Raquel Loures and Ricardo Silva). We thank the Alves dos Santos brothers, fishermen from Três Marias city for the help in this work. We also owe thanks to the Três Marias Dam operational and maintenance team, Marcos and his diver team and Hydroacustic Technology Inc (special thanks for Samuel Johnston and Colleen Sullivan) for their assistance for the development of this study. We are grateful to the Federal University of Lavras for logistical help, CEMIG for funding this study and Fundação de Amparo à Pesquisa do estado de Minas Gerais (FAPEMIG) for the PhD scholarship.

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