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FACTORS INFLUENCING MOVEMENTS OF TWO MIGRATORY FISHES WITHIN THE TAILRACE OF A LARGE NEOTROPICAL DAM AND THEIR IMPLICATIONS FOR HYDROPOWER IMPACTS

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ABSTRACT

Fish attempting to move upstream through hydroelectric dams 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. We evaluated the movements of two migratory fish (Curimba—Prochilodus argenteus and Mandi—Pimelodus maculatus) using acoustic telemetry in the tailrace of Três Marias Dam (São Francisco River, Brazil) from 31 October 2011 to 16 February 2012. The majority of tagged fish left the tailrace in less than one week; however, some individuals returned, performing several visits to the tailrace. Mandi remained longer in the tailrace than Curimba. The number of visits was influenced by diel period, turbine and spillway discharge. Although the diel period was the only important contributor to the visits performed by Curimba, the movements of Mandi were significantly influenced by three factors. We found that whereas Curimba was predominantly diurnal, Mandi showed nocturnal habits. Additionally, visits of Mandi were significantly greater during higher turbine and spillway discharge. We discuss the implications of these results for understanding fish movements in the Três Marias Dam tailrace and their potential implications for adapting hydroelectric operations to minimize fish kills. Copyright © 2016 John Wiley & Sons, Ltd.

KEY WORDS: acoustic telemetry; conservation strategies; fish kill; movement patterns; turbines

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INTRODUCTION

Rapid growth of the global economy in the past decade has led to an increasing demand for electricity. Efforts to meet these increasing demands have resulted in impoundment of the majority of largest rivers in the world (Nilsson et al., 2005) representing about 16% of total electricity production (International Energy Agency, 2010). Although hydropower is important for economic growth, there are concerns about its impacts on aquatic biodiversity (Agostinho et al., 2004; Goodwin et al., 2006; Winemiller et al., 2016). For migratory fishes, these dams and their reservoirs often represent insurmountable obstacles, both to upstream movement of adults to spawning areas, as well as the downstream movement of their offspring toward rearing areas (Agostinho et al., 2002; Suzuki et al., 2011; Pelicice et al., 2015). These barriers can also result in large aggregations of fish immediately below dams, placing fish at risk during dam operations, particularly in relation to maintenance of turbines (Andrade et al., 2012).

Although there are concerns about fish behaviours immediately below hydropower dams, little is known about actual patterns of movement by fish and the factors that influence them, especially in the South American rivers. Some studies of upstream movements of fish through passage facilities at dams in Brazil have identified velocity and discharge as the main hydraulic drivers of movement (Fernandez et al., 2004; Pompeu and Martinez, 2006; Agostinho et al., 2007b). Similarly, Silva et al. (2012) found that higher abundance of fish in a dam tailrace was related to higher turbine and spillway discharges, suggesting that these variables play an important role in attracting fishes. Entrainment of fishes in the draft tubes of hydropower plants, during turbine startup or dewatering, has been recorded in Brazil (Agostinho et al., 2007a). The magnitude of such events was directly related to the abundance of fish in the tailrace. Once inside the draft tubes, the level of dissolved oxygen, rapid gas decompression and mechanical shock are the main factors that can lead the death of many fishes in the turbines (Andrade et al.,
2012; Loures and Pompeu, 2012). Accordingly, understanding movement and aggregation of migratory fish in relation to hydropower operations can provide useful insights for minimizing such impacts.

At the Três Marias Dam (TMD), located on the upper São Francisco River Basin in central Brazil, large aggregations of fish are frequently observed in the tailrace of the dam, where they may be at risk of entry into the draft tubes during operation of turbines. Two of the most common species affected include Prochilodus argenteus Spix & Agassiz, 1829 and, Pimelodus maculatus Lacepède, 1803 (Andrade et al., 2012). Both are abundant migratory fish and considered important species for commercial fisheries (Sato et al., 2003). P. argenteus, known as Curimba, is a characin (Order Characiformes) that attains a total length of up to 71 cm and is endemic to the São Francisco River (Boncompagni-Júnior et al., 2013). P. maculatus, known as the Mandi-Amarelo, is a catfish (Order Siluriformes) with a total length of up to 44 cm and is widely distributed in South American rivers (Barbosa et al., 1988).

In this study, we used acoustic telemetry to track the movements of Curimba and Mandi in the tailrace of TMD to determine: (i) the post-release residency, number of visits and duration of residency of tagged fish within the tailrace; (ii) the influence of species and individual size on movement patterns; and (iii) the influence of diel period (i.e. diurnal and nocturnal) and TMD operational discharges (turbine and spillway discharge) on the number of visits to the tailrace. In addition, we discuss how our results can support future operations of hydropower facilities aimed at protecting native fish.

MATERIALS AND METHODS

Study area

The study was conducted at TMD, which is located on the upper stretch of the São Francisco River, Minas Gerais, Brazil (Figure 1). The dam is 2700 m long and 65 m in height with a reservoir flooding a maximum area of 1040 km². The powerhouse operates with six Kaplan units (GU) with maximum power generation capacity of 65 MW, which corresponds to discharge of 150 m³ s⁻¹ per turbine. The draft tube for each turbine is about 15 m long with two sections of 4 m (height) × 6 m (width) (Andrade et al., 2012). The tailrace comprises about 155 m (length) by 182 m (width) with an area of approximately 19 870 m² and maximum depth of approximately 19 m at total discharge 435 m³ s⁻¹ (Loures and Pompeu, 2015). The spillway...
channel is on the right shore, and its exit is located approximately 350 m downstream from the tailrace (Figure 2). The dam is not equipped with fish passage facilities.

**Fish sampling and tagging procedures**

Fish were captured using cast nets and tagged from 31 October to 4 November 2011. Capture sites were located in the tailrace and in the river up to 3 km downstream of the dam. Handling of fish from the capture to return to the tagging site did not exceed 20 min. Prior to tagging, fish were held for 2 h in a covered plastic tank (0.68 m length × 0.41 m width × 0.35 m height) filled with river water constantly renewed using a water pump. The maximum number fish in the tank at the same time was five individuals. To ensure that there were no adverse effects of capture and translocation, fish were placed in an anaesthetic bath containing eugenol (clove oil) diluted in 1 mL:40 L of water proportion (Hahn et al., 2007) until operculum ventilation rate became slow and irregular (2–3 min), then weighed and measured (total length, cm). A total of 90 fish were tagged (50 Curimba and 40 Mandi). The mean size of Curimba was 31.8 cm, ranging from 24 to 45 cm, whereas the mean size of Mandi was 21.8 cm, with values ranging from 19 to 26 cm.

Surgery was conducted in the field using a rectangular plastic tank (0.57 m length × 0.50 m width × 0.17 m height) filled with river water renewed after every three procedures and treated with Labcon Protect Plus (Alcon Pet, Incorporated, Camboriú, Santa Catarina, Brazil) to aid fish recovery (Godinho et al., 2007). During surgeries, we provided aeration to the tanks and monitored water temperatures to minimize any additional stress to fish. For the surgery, fish were immersed in the plastic tank and immobilized using electronarcosis (Heney et al., 2002) with a non-pulsed DC current with 30 V for both species (Godinho and Kynard, 2006). After immobilization, the voltage was lowered to 26 V and 25 V for Curimba and Mandi, respectively, to allow the fish to breathe normally during surgery procedure. A sterilized acoustic transmitter was inserted into the body cavity through a small incision (1–2.5 cm in length) made on the middle ventral line (Mandi) and lateral body above the anal fin (Curimba). The incision area, surgical instruments and acoustic transmitters were disinfected with an iodine solution. Incisions were closed using monofilament non-absorbable sutures (Nylon, USP 3/0, Needle: 3/8 circle-2cm, Brasuture Ind. Com. Imp. e Exp. Ltda., São Sebastião da Grama, São Paulo, Brazil) tied using two to five interrupted stitches secured with reinforced surgeon’s knots (Deters et al., 2010; Wagner et al., 2011). Surgeries were conducted by a minimum of two experienced surgeons. The incision site was not swabbed, and no antibiotics were administered to fish post-operatively. Surgeries lasted for 8–12 min.

Tagged fish were placed in a tank (1.5 m length × 1.2 m width × 0.9 m height) filled with river water constantly renewed using a water pump to recover from the anaesthetic and surgery stress for at least 4–6 h prior to release. The maximum number of tagged fish in the tank at the same time was 15 individuals. No mortalities were observed during this period. Curimba were tagged with 795 LG acoustic transmitters (4.5 cm height × 1.55 cm diameter and weighing.

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**Figure 2.** Location of hydrophones, data logger, turbine area and fish release area in the tailrace of Três Marias Dam, São Francisco River, Minas Gerais, Brazil (the letter X indicates a turbine that did not operate during the study period).
12 g in air), whereas model 795 LX (3.0 cm height × 0.90 cm diameter and weighing 4.3 g in air) acoustic transmitters were used for Mandi, both manufactured by Hydroacoustic Technology Incorporated (HTI; Seattle, WA, USA). The acoustic transmitters comprised 0.6–2.8% and 1.6–3.5% of total body weights for Curimba and Mandi, respectively.

Fish release

Following surgery, tagged fish that showed normal opercular ventilation and swimming movements were released. Fish were released in the tailrace in batches of five to six individuals. For the release, fish were hand netted in the recovery tank and immediately placed into a smaller tank (0.78 m length × 0.56 width × 0.41 m height) transferred to the northwest shore of the tailrace (left shore, Figure 2). This area was selected because of the presence of lower flow velocities, which reduced 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 based on data gathered from previous tests conducted in the tailrace, which indicated a detection range of 100 m. Based on this finding, tags were set to operate at one ping every 3.2–5.3 s and with a transmit pulse width of 5.0 ms. This setting allowed tags to have battery lives ranging from 350 to 500 days (tag model LX) and 220 to 400 days (tag model LG).

Tracking of fish movements in the tailrace was conducted from 31 October 2011 to 16 February 2012. From a total of 2597 h, it was possible to work with 2092 h of fish movements. For the remainder of this time period (Figure 3), fish movements were not tracked because of technical problems with the acoustic tag receiver. All hydrophones were georeferenced and connected to the data logger (HTI Model 290 Acoustic Tag Tracking System) using hydrophone cables (HTI Model 690). This acoustic system operated at 307 kHz, and it continuously received and stored all tag transmission pulses for each hydrophone simultaneously. The tagged fish positions were calculated following procedures described by Ransom et al. (2008).

Data analyses

Four variables were chosen to describe fish movements in the tailrace: post-release residency time, number of visits per individual, number of visits per specific time and duration of residency. Post-release residency time was calculated as the elapsed time between initial release of tagged fish and their first exit from the tracking area (Figure 2). The number of visits per individual was calculated as the total number of times an individual fish was detected entering the tailrace. The number of visits per specific time was defined as the number of visits of fish to the tailrace for each tracking day. Last, the duration of residency was considered as the elapsed time spent by an individual fish in the tracking area between each entrance into (return) and exit from the tailrace.

Post-release residency of fish in the tailrace was evaluated by time to event analysis. Times to departure from the tailrace for Curimba and Mandi were interpreted using the Kaplan–Meier function, censoring for when tags were immobile under the assumption they represented mortalities.
or tag loss. Additionally, a non-parametric test (Log rank) was applied to verify significant differences between the curves of the two species. A Cox hazards model was used to identify the influence of individual size on the post-release residency time. These analyses were performed with the ‘survival’ package in R (R Development Core Team, 2012).

Significant differences between species in total number of visits per individual were determined using Mann–Whitney U-test (significant differences were considered for \( p < 0.05 \)). The influence of individual size in relation to the total number of visits per individual was evaluated using Spearman’s Rank Correlation Coefficient (non-parametric tests were used, because of the prevalence heteroscedasticity and lack of normality in these data). Additionally, the same analyses were performed to evaluate differences on the duration of residency variable.

The number of visits per day to the tailrace was evaluated in relation to the potential influences of diel period (i.e. diurnal and nocturnal), turbine discharge and spillway discharge. For this, we applied generalized linear models for each species. Because the data exhibited high variance to mean ratio (dispersion test = 2.17, \( p < 0.05 \)), the negative binomial distribution was used in the model. This distribution predicted well the numbers of zero (Zeileis et al., 2008) and provided the best fit to the data (Chi-square goodness-of-fit test, \( p > 0.05 \)) (Cameron and Trivedi, 1998). Analysis of deviance was performed to choose the best model. If the predictor was not statistically important in the model, then it was removed from the analyses (Hastie & Pregibon, 1992). These analyses were implemented using the AER, mass and pscl packages in the R software (R Development Core Team, 2012).

We included the diel period as predictor variable because recent studies have indicated greater diurnal and nocturnal activity for Characiformes and Siluriformes, respectively (Pompeu and Martinez, 2006; Fernandez et al., 2007; Loures and Pompeu, 2012). Based on field observations, we delimited the diel period from 6:00 am to 6:59 pm for diurnal period and from 7:00 pm to 5:59 am for nocturnal period.

Water discharge in the tailrace was also included as a continuous predictor in the model because previous studies have highlighted the influence of discharge on fish movement (Linnik et al., 1998; Rivinoja et al., 2001; Thorstad et al., 2003; Scruton et al., 2007). Once this variable is directly related to operational discharges, we used the values of turbine discharge to represent the water discharge in the tailrace. It is noteworthy that out of six turbines, only one turbine was not operating because of maintenance during the whole study period (Figure 2).

Finally, spillway discharge was also included as a continuous predictor in our analyses. Silva et al. (2012) observed an influence of spillway discharges on the abundance of fish downstream from the TMD. We calculated the mean of spillway discharge per day and diel period. The spillway during the period of study remained opened from 23 December to 6 February with the discharge ranging from 130 to 2604 m³s⁻¹ (Figure 3). Turbine and spillway discharges data were provided by Companhia Energética de Minas Gerais (CEMIG) which operates TMD.

RESULTS

All of the tagged fish left the tailrace before the end of the study period (16 February 2012). The majority (>75%) left the tailrace in less than one week. The average elapsed time from release to the first exit from the tailrace (post-release residency) was 2.81 days for Curimba and 10.79 days for Mandi (Figure 4). A significant difference between the curves of proportion of tagged fish remaining in the tailrace

![Figure 4. Daily Kaplan–Meier survivorship function for tagged Curimba and Mandi in the tailrace of Três Marias Dam, from 31 October 2011 to 16 February 2012. Open circles represent censored individuals](image-url)
was observed using Log rank test \((p = 0.0073)\). Additionally, the Cox regression indicated that post-release residency of Curimba was 2.07 times shorter than Mandi time \((p < 0.002)\) and there was no significant influence of fish size on this variable \((p > 0.05)\).

Although all the tagged fish left the tailrace, 35 individuals (19 Mandi and 16 Curimba) returned, and in most cases, performing visits (returns) more than twice (ranging 1–38 times per individual). Despite the median of the total number of visits per individual having been higher for Mandi, there was no statistically significant difference between the two species (Figure 5). There was a significant negative correlation between the total number of visits and individual size for Mandi \((r = -0.59, p < 0.05)\), whereas the correlation between these two variables was not observed for Curimba. The duration of residency was also significantly longer for Mandi (median of 28.8 h) than for Curimba (median of 5.9 h) (Mann–Whitney test, \(U = 33, p < 0.01)\). However, there was no correlation between the duration of residency and size of individuals for both species.

Analyses of factors affecting number of visits per day to the tailrace indicated that the best predictor for Curimba was diel period (Figure 6, Table I). The model showed that the number of fish visiting the tailrace during the diurnal period was about 96.7% higher than for the nocturnal period. We did not find a significant association between turbine and spillway discharge and movements of Curimba. On the other hand, diel period, turbine and spillway discharge were significantly associated with movements of Mandi toward the tailrace. In contrast to Curimba, we found that individuals of Mandi were more likely to visit the tailrace at night. Model coefficients (Table I) indicated that a change from diurnal to nocturnal period increased the number of Mandi visiting the tailrace by a factor of 2.29. The model also showed a significant influence of operational discharges (turbine and spillway) on fish movements of Mandi. The exponent of the coefficients in the model indicated that for a unit increase in the turbine and spillway discharge \((\text{m}^3\text{s}^{-1})\), we would expect an increase in the number of visits by a factor of 1.002 and 1.0002, respectively (Table I).

**DISCUSSION**

In recent years, telemetry has become a powerful tool to understand how fish respond to dams and attempts to manage fish passage in Brazil. Most studies have been directed towards solving one of the biggest concerns in fish conservation, the efficacy of fish passage for migratory species (Pompeu and Martínez, 2006; Agostinho et al., 2007b; Fontes Júnior et al., 2012; Wagner et al., 2012). Other studies have addressed the migratory behaviours of selected Neotropical species (Godinho and Kynard, 2006; Godinho et al., 2007; Hahn et al., 2011). However, none of these has addressed fish behaviour immediately downstream from dams to understand fish movements and their implications for threats posed by dam operations. The major threat to fish below hydropower dams in Brazil is associated with high mortality because of fish entering and becoming entrained within the draft tubes of turbines (Agostinho et al., 2007a), and the knowledge of fish movement patterns in the tailrace can be an essential step to determine strategies to minimize this impact.

We found that both species rapidly dispersed (generally within a week) from the tailrace following initial tagging and release. These rapid outward movements from the tailrace may have been linked to stress and/or additional recovery following initial tagging, and an overall high rate of movement. For example, high variability we observed in the number of visits to the tailrace performed by Curimba and Mandi indicates that these species are in constant movement between the tailrace and the areas downstream from the dam. A comparable study of Atlantic salmon in Canada indicated visits were much less frequent (1–21 entrances over a year; Scruton et al., 2007). Within Brazil, study of another Curimba species—*Prochilodus lineatus* Valenciennes, 1847—Silva (2004) detected only a single entrance of radio tagged fish into the tailrace of Igarapava and Jaguara Dams located in Grande River Basin. Unsuccessful attempts to migrate upstream can lead the fish to seek out other migratory routes and move out of the tailrace toward tributaries (Antonio et al., 2007). Nevertheless, the absence of tributaries near to the dam may undertake a new fish movements attempts through the tailrace (Scruton et al., 2007). The first large tributary downstream from Tres Marias dam, the Abaeté River, is located 34-km distance. It
is also important to note that the outward movement of fish from the tailrace can also be because of unfavourable conditions within the area, such as noise, vibration and dissolved gas (Scruton et al., 2007).

The duration of residency was also significantly greater for Mandi, indicating that this species remains longer periods within the area when compared to Curimba. Although both species exhibit reproductive migrations during rainy season (i.e. from November to March), Curimba are known as longer distance migrants, while Mandi perform shorter distance movements (Sato and Godinho, 2003). The shorter migration behaviour and consequently a smaller home range area for Mandi can explain the greater the number of visits and the duration of residency for this species. Greater residency of Mandi in the tailrace may place it at greater risk of impacts from hydropower operations (Scruton et al., 2007). Indeed, smaller individuals of this species (mean length of 22 cm) are the most prevalent among fishes to be entrained within turbines at TMD (CEMIG unpublished data), which is consistent with our observation that smaller individuals of Mandi are more likely to return to the tailrace, relative to larger individuals.

Our analysis of factors affecting the number of visits (returns) to the tailrace indicated divergent responses of the two species. Although diel period was an important factor, the two species responded very differently: major movements for Curimba were observed during the day whereas Mandi was more active at night. Silva (2004) also described that most of the migratory movements of Curimba (P. lineatus) at the fish ladder of the Igarapava Dam in Brazil occurred during the day while is expected to have predominantly nocturnal habits, remaining hidden during the daylight (Santos et al., 1984). Moreover, this result agrees with observations by Loures and Pompeu (2012) in the same study site, where captures of Characiformes and Siluriformes were greater in diurnal and nocturnal periods, respectively.

The Três Marias operational discharges were also important factors affecting fish movement. Despite that Curimba movements did not respond to turbine discharges, there were an increase of Mandi movements to the tailrace at higher turbine discharge. The high swimming performance and benthic orientation of Mandi (Santos et al., 2008) may facilitate its movement into the tailrace, even during higher discharge. Other studies evaluating the efficiency of fish passage have similarly demonstrated that discharge has an important influence on the upstream movements of migratory species, as evidenced by the abundance of fish in the passage facilities at dams (Fernandez et al., 2004; Pompeu and Martinez, 2006). Silva et al. (2012) also showed that spillway and turbine discharges increased the abundance of fish downstream from Baguari Dam located in Doce

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**Table I. Poisson regression estimates of the effects of three predictors (diel period [daytime was the baseline], turbine and spillway discharge) on the number of visits to the tailrace of Três Marias dam by Curimba and Mandi from 31 October 2011 to 16 February 2012. Bold text indicates a significant relationship ($p < 0.05$)**

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Estimate</th>
<th>Std. error</th>
<th>t Value</th>
<th>p Value</th>
</tr>
</thead>
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<td>Curimba</td>
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</tr>
<tr>
<td>Intercept</td>
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<td>0.144</td>
<td>1.967</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diel period (nighttime)</td>
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<td>0.532</td>
<td>-6.425</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mandi</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
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<td>0.423</td>
<td>-3.530</td>
<td>&lt;0.001</td>
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<tr>
<td>Turbine</td>
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<td>Diel period (nighttime)</td>
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<td>0.003</td>
</tr>
</tbody>
</table>
River Basin, Minas Gerais, Brazil. Direct study of fish movements in other systems also indicates that fish are attracted to the tailraces of hydropower facilities during high flows (Linnik et al., 1998; Rivinoja et al., 2001; Thorstad et al., 2003; Scruton et al., 2007). The number of visits of Mandi was also influenced by spillway discharge. The spills events can stimulate the movements of fish between spillway plunge pool area and the tailrace because of the proximity of these two areas in which explains the higher number of visits to the tailrace at higher discharge. The attraction of fish during spillway discharge and consequently movements to the tailrace was already assumed by Andrade et al. (2012), although the data analyses were inconclusive.

Collectively, our findings for Mandi, including its longer residency within the tailrace, higher median of the number of visits to the tailrace and responses to turbine and spillway discharges indicate that it is more sensitive, and potentially more vulnerable to dam operations, relative to Curimba. This may be compounded by the high swimming performance and benthic orientation of Mandi, which can facilitate entry into the draft tubes of turbines, explaining why it is the species that appears to be most affected by turbine operation (Santos et al., 2008; Andrade et al., 2012). With an increased understanding of the behaviour and vulnerability of both species studied here, dam operations may be modified to reduce the entrainment of fishes in the draft tubes.

It is worth noting here that preventive measures adopted to minimize the impact on fish at TMD have already 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 associate mortality. Furthermore, fish monitoring conducted regularly immediately downstream from the dam has allowed for real-time decision-making in the context of altering hydropower operations to minimize risks when large numbers of fish are present in the tailrace (Andrade et al., 2012). Further adaptation of these management programmes to respond to new scientific information may prove more effective. For example, Loures and Pompeu (2012) recommend that activities most likely to impact fish may be undertaken in months of low precipitation, which correspond to periods of lowest abundance of fishes in the tailrace of TMD. Furthermore, results of this work suggest that whereas turbine operations during the day may represent a higher risk for Curimba, operations during the night can put mainly Mandi at risk. We also highlight that the greater attraction of fish to the tailrace at higher turbine and spillway discharge can represent higher risk of Mandi. Based on these findings, the impact on fish community can be minimized synchronizing the manoeuvres that may represent risk to the fish with variables related to the dam operation (turbine and spillway discharge). For instance, maintenance of turbines performed at lower turbine and spillway discharge scenarios may reduce fish entrainment. On the other hand, a sudden stop of turbines after higher turbine discharges and spills events may lead to a massive entrainment of fishes in the draft tubes because of greater abundance of fish in the tailrace. It should be pointed out that although more fish may be in the tailrace during higher flows, they may not be present in very close proximity to turbines, where they may be more vulnerable. For example, Andrade et al. (2012) observed a greater number of trapped fish inside the draft tubes of turbines during minimum discharge. Perhaps, it is the case that whereas higher discharge can attract fish to the tailrace, higher discharges also prevent fish from being too close to the turbines, thus reducing the number of individuals that are entrained.

Ultimately, results of this study indicate the probability of impacts should increase with (i) total numbers of fishes within the tailrace, and (ii) the proportion of these individuals that are in close proximity to turbines, with higher probability of entrainment. Studies that more explicitly evaluate these two events together are needed to more precisely evaluate vulnerabilities. In this study, we have been able to demonstrate responses of fishes to dam operations linked to variability between and within species, hydropower operations and riverine conditions. Certainly, fish movement data can provide hydropower managers with useful information about the likelihood of occurrence of a fish injuries/kills events because 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 fish kill in turbines.

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FACTORS INFLUENCING MOVEMENTS OF TWO MIGRATORY FISHES


