REPORT

Fish mortality at hydropower plants

IDENTIFYING PROBLEMS AND CO-CREATING SOLUTIONS

Financial Support

Newton Fund

FAPEMIG

Host

UFSJ Universidade Federal de São João del-Rei

Partnership

University of Southampton

Organization

Easy Telling

1

THE SIZE OF THE PROBLEM AND ITS IMPACT

The losses to Brazil, the country with the highest number of fish species from fresh water on the planet

There is a silent and veiled mortality in rivers and dams in Brazil. Despite generating energy classified as clean and renewable, the operation of hundreds of hydropower plants across the country has killed 128 tons of fish over the last decade. This amount means the loss of millions of fish, affecting biodiversity, fisheries stocks and, consequently, local communities that rely on fishing.

This issue is highlighted in a detailed survey conducted by a group of experts in fish research from the Federal University of São João del-Rei (UFSJ) and ETH Zürich, Switzerland, in partnership with the University of Southampton, England. For about ten years, they have evaluated the effects of abrupt variations in pressure as a cause of fish mortality and collected data on the occurrence of episodes of large-scale mortality in Brazilian hydropower plants. The summary of their findings is included below:

» Large-scale fish mortality is recorded in almost all Brazilian hydrographic basins. Most events are related to the operation of the turbines and spillway gates.

» Variation in the pressure within turbines or other dam structures causes injuries to fish, namely barotrauma, which can lead to death. The chance of death depends on the intensity of pressure variations, and different species of fish may be more susceptible to this risk.

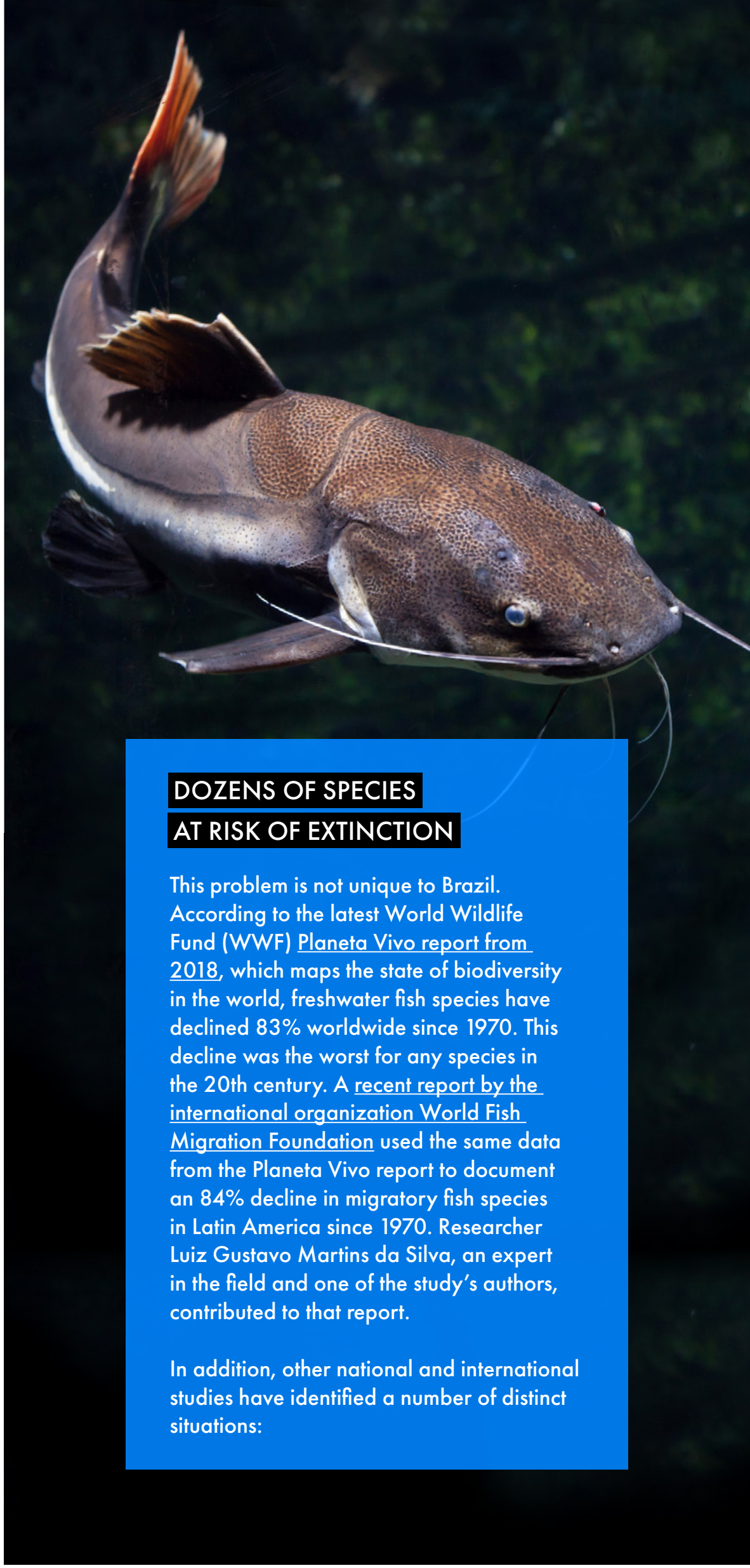
» There is still a significant amount to learn with respect to this topic, but these results also point toward the development of potential solutions.

> *After about a decade of investigating the problem, we have developed a more accurate diagnosis of the cause-consequence relationships of these large-scale mortality events. However, it is estimated that the numbers obtained are underestimated, which requires a combined effort involving all sectors to discuss the subject, open data and co-create solutions."*
>
> **Luiz Gustavo Martins da Silva**, a specialist in the area and one of the authors of the study.

The fish die not only because they physically collide with the turbine blades but also due to the rapid decompression or pressure variation generated by them. This can cause trauma, ranging from swim bladder rupture, stomach eversion and eyes poping out of the skull to the appearance of embolisms (obstructions caused by air bubbles that come out of the blood), with a risk of death, even if not immediate after the injury. The lack of or excess oxygen due to the plant's operational processes may also be among the causes.

The death of dozens of species of fish due to the construction and operation of hydropower plants, although underreported, is quite common and generates social, environmental and financial losses in Brazil and worldwide. In 75% of the cases, the construction of large dams throughout the world has cost almost 100% more than initial estimates. The Chinese government, for example, allocated an additional US$26 billion to mitigate the ecological impact of the Three Gorges dam.

In Brazil, in addition to the 128 tons of dead fish and the resulting environmental impact, there are losses of all kinds. Fines imposed on Brazilian hydropower plants for a range of violations of the law already exceed 600 million reais. This causes economic losses for energy producing companies and for fishermen and riverine communities that rely on fisheries as a source of income. These violations can occur at different phases of the projects, including during the allocation of the project, the construction of the plant, testing and when it is fully operational.



DOZENS OF SPECIES AT RISK OF EXTINCTION

This problem is not unique to Brazil. According to the latest World Wildlife Fund (WWF) Planeta Vivo report from 2018, which maps the state of biodiversity in the world, freshwater fish species have declined 83% worldwide since 1970. This decline was the worst for any species in the 20th century. A recent report by the international organization World Fish Migration Foundation used the same data from the Planeta Vivo report to document an 84% decline in migratory fish species in Latin America since 1970. Researcher Luiz Gustavo Martins da Silva, an expert in the field and one of the study's authors, contributed to that report.

In addition, other national and international studies have identified a number of distinct situations:

450 dams could lead to the extermination of a third of the world's river fish in the Amazon (South America), Congo (Africa) and Mekong (Asia) basins, where 4,000 species of fish live[1].

The Belo Monte hydropower plant alone puts at risk a number of species (range from 45 to 63) that only exist in the Xingu River[2].

In the Amazon basin, the construction of hydropower plants has affected populations along the rivers as well as threatened approximately 2,300 species of fish found in the region[3].

After the installation of dams on the Tocantins River, there was a 25% reduction in the number of fish on this waterway, which flows into the mouth of the Amazon River[4].

In the region of the Tucuruí dam (PA), fish declined by almost 60% immediately after the construction of the dam and more than 100,000 people living around the river were affected[5].

[1] *Sabaj Perez (2015).*
[2] *Fitzgerald, D. B., M. H. Sabaj Perez, L. M. Sousa, A. P. Gonçalves, L. Rapp Py-Daniel, N. K. Lujan, J. Zuanon, K. O. Winemiller & J. G. Lundberg, 2018. Diversity and community structure of rapids-dwelling fishes of the Xingu River: Implications for conservation amid large-scale hydroelectric development. Biological Conservation 222:104-112 doi:10.1016/ j.biocon.2018.04.002.*
[3] *Michigan State University, nos Estados Unidos, em artigo publicado em 5 de novembro de 2018 na revista Proceedings of the National Academy of Sciences of the United States of America (PNAS).*
[4] *Ibid.*
[5] *Ibid.*

THE ECONOMIC PROBLEM: FINES AND WORK STOPPAGES

Belo Monte (Xingu River, Pará): the interruption of the plant's activities due to fish mortality events generated an estimated daily loss of R$1 million for the electric companies during turbine testing and R$12 million in damages for the construction company in 2008[6].

» 50 million reais in fines in 2019 for Sinop Energia, the company responsible for the Sinop Hydropower Plant (Mato Grosso), due to the death of 13 tons of fish in the Teles Pires River, on the border between Mato Grosso and Pará[7].

» More than R$43 million in fines in to Norte Energia, the company responsible for the Belo Monte Plant (Pará), after the mortality of 16.2 tons of fish during the reservoir filling process in 2016[8].

Jirau (Rondônia): daily loss of R$6 million due to work stoppages as a result of high risk to fish species in 2009[10].

[6] *Justiça suspende licença de operação de usina hidrelétrica em MT após mortandade de peixes, G1, 27 maio 2009*
[7] *Morte de peixes paralisa turbinas em Belo Monte, Estadão, 13 mar. 2018*
[8] *Belo Monte é autuada em R$ 7,5 milhões pelo Ibama por descumprimento ambiental, Revista Época, 27 abr. 2017*
[9] *Belo Monte parada dá R$ 12 milhões de prejuízo por dia à construtora, EBC, 27 ago. 2012*
[10] *Eletrobrás: Jirau parada gera perda diária de R$ 6 mi, G1, 27 maio 2009*

2 LEADING CAUSES, TESTED SOLUTIONS, AND RECOMMENDATIONS

Solving the problem brings advantages for the environment and for businesses

For some time, the world has sought solutions to avoid or at least reduce the environmental and economic losses caused by this problem. Fish-friendly technologies, which seek to reduce the negative impacts of hydropower dams on fish, are a topic of attention among research groups and specialized international consultancies. Based in the United States, Electric Power Research Institute (EPRI) and Pacific Northwest National Laboratory (PNNL) are among the main ones focused on this issue. Both are a private and independent entities which are linked to university production and receive funding from several sources.

In Europe, the FITHydro project (Fishfriendly Innovative Technologies for Hydropower - “Fishfriendly” Technologies - Friendly to fish - and Innovative for Hydropower Plants) has developed several solutions to make hydropower production and fish maintenance compatible. This type of project, and the knowledge and strategies it has generated, took four years to realize. Financed by the European Union and coordinated by the Technical University of Munich, its main objective is to provide the parties involved in the construction of hydropower plants with effective, financially-feasible and environmentally friendly measures and solutions to address this challenge, allowing for both the conservation of fish species and the development of the electricity sector.

The objective of this study is to identify the causes of these events that have already been documented in scientific research, in addition to evaluating initiatives that have worked in different places around the world to develop solutions involving all parties. “Science has a lot to contribute through studies and proposing solutions. Fapemig, as a funding agency, does its part to guarantee resources for such investigations, which allow not only the advancement of knowledge, but also the sustainable development of Minas Gerais,” says Paulo Sérgio Lacerda Beirão, interim president of Fapemig, the funding agency for the UFSJ research on the effects of barotraumas and their consequences for large-scale fish mortality events.

The analysis of these studies will allow the development of new methods specific to Brazil that:

» **Identify** the main causes of large-scale fish mortality;

» **Develop** new guidelines based on scientific evidence to change or adapt the decision-making process on where and how to build hydropower plants in the country. Today, this focuses less on potential environmental impacts and their costs. With projects already in development, there are few measures available to control these impacts and, as a result, the cost is much higher;

» **Raise** awareness of the need to conduct research and identify gaps in scientific and technological knowledge to determine limits, parameters and solutions that prevent large-scale fish mortality;

» **Estimate** the measures and investments needed to minimize this problem in Brazil;

» **Propose** solutions to the problem in conjunction with environmental agencies and companies in the electricity sector;

» **Turn Brazil** into a leader on this issue in South America and other regions of the world where the hydropower sector is rapidly growing.

Carlos Bernardo Mascarenhas Alves

Yellow mandi with everted stomach (outward) after a rapid decompression event.

Luiz Gustavo Martins da Silva

Corvina with exophthalmos (bulging eyes) after an event of rapid decompression.

Luiz Gustavo Martins da Silva

Yellow mandi with a skull fracture after collision with hydropower plants turbines.

1

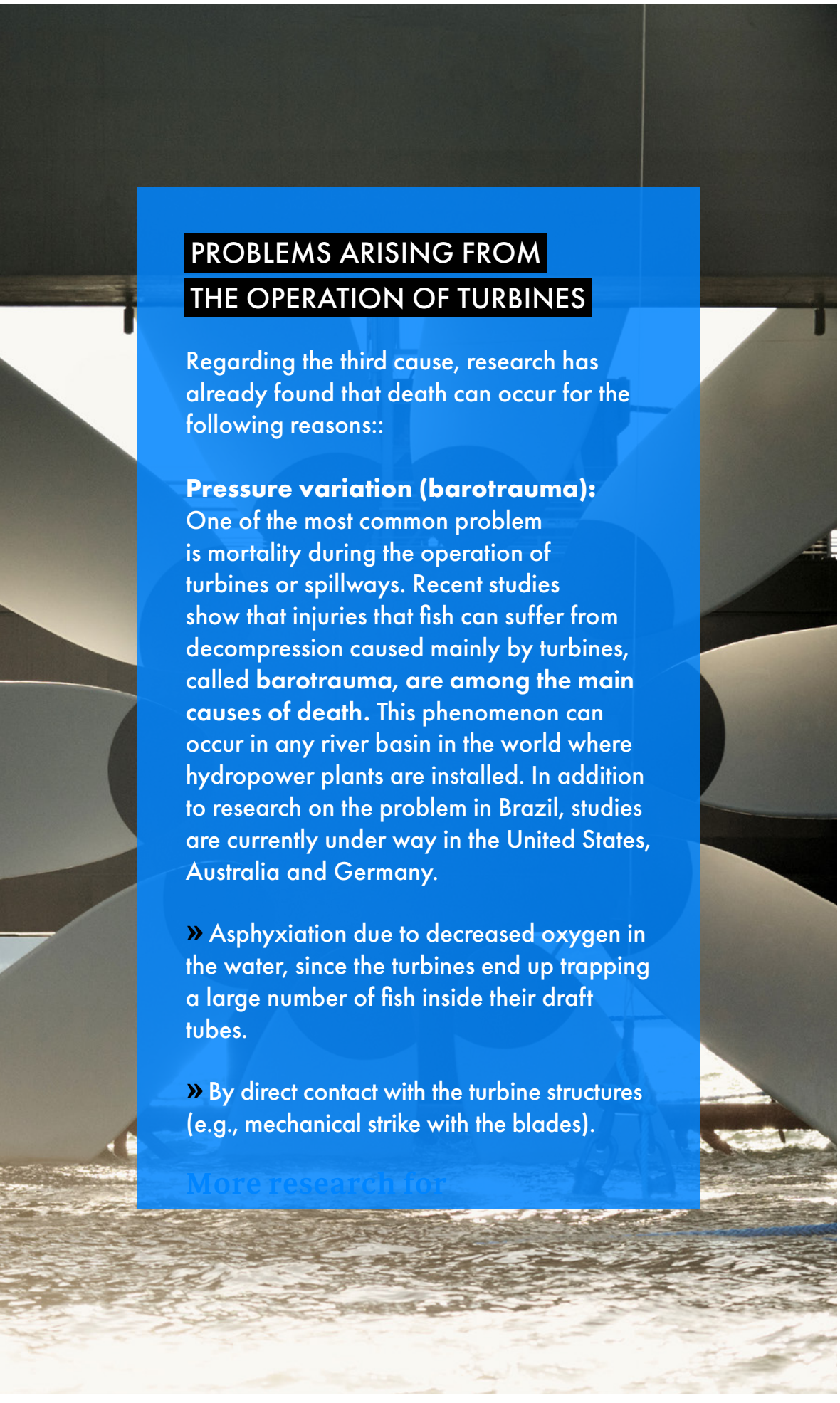
Main causes of fish mortality by hydropower plants

An analysis of environmental fines and prosecutions by the Federal and State Prosecutors in the regions of the Amazon, Araguari, Rio Grande, Itabapoana, Paranaíba, São Francisco, Tapajós and Tocantins identified at least three possible causes of turbine-related deaths.

Passage of species through spillways, which discharge/divert all unused water for power generation and serve as pipelines to drain water from plants or operate these structures: this generates a very high concentration of oxygen (gas supersaturation), which can cause fish to die from asphyxiation.

Fish stranding in small pools of insufficient water, during reservoir filling or after opening spillways: this can also occur during the regular operation of some hydropower plants, leading to the rapid filling and emptying of the river channel below the plant.

Operation and maintenance of turbines: possible passage of fish through the turbines and entry into draft tubes.



PROBLEMS ARISING FROM THE OPERATION OF TURBINES

Regarding the third cause, research has already found that death can occur for the following reasons::

Pressure variation (barotrauma): One of the most common problem is mortality during the operation of turbines or spillways. Recent studies show that injuries that fish can suffer from decompression caused mainly by turbines, called **barotrauma, are among the main causes of death.** This phenomenon can occur in any river basin in the world where hydropower plants are installed. In addition to research on the problem in Brazil, studies are currently under way in the United States, Australia and Germany.

» Asphyxiation due to decreased oxygen in the water, since the turbines end up trapping a large number of fish inside their draft tubes.

» By direct contact with the turbine structures (e.g., mechanical strike with the blades).

More research for

2

Solutions tested in Brazil and worldwide

Initiatives in other countries

There is a large worldwide movement to discuss the problem of fish mortality, from the design phase of hydropower facility to its operation. The data generated in these countries, mainly in the United States, have been used to assist in the design of new turbines. Some dams on the Columbia River have been replaced with new models that, in theory, will generate less harmful pressure variation for fish.

Turbine manufacturing companies for new plants designed for the Mekong River basin in Southeast Asia, had to present projects and machine designs that would be better-suited to the environment or cause less harmful decompression to fish species.

Strategies in Brazil

In Brazil, one of the solutions designed to prevent fish from entering hydropower power plant turbines during stoppage (when the turbine has to be turned off for maintenance or when generation is not required) was the installation of “screens”/“grids” next to the suction tubes. A study published in the scientific journal *Neotropical Ichthyology*[11] highlighted the effectiveness of this strategy. However, this solution worked and works when the turbine is stopped, without considering possible injuries that occur during its operation.

How to incorporate solutions from other countries in Brazil

Any solution developed in other countries can be implemented in different contexts and situations in Brazil, with appropriate adaptations according to the target species for these measures. This is due to the fact that researchers have found that the alternatives that work for fish in other parts of the ocean don’t always solve local problems.

[11] *Andrade, F., I. G. Prado, R. C. Loures & A. L. Godinho, 2012. Evaluation of techniques used to protect tailrace fishes during turbine maneuvers at Tres Marias Dam, Brazil. Neotropical Ichthyology 10(4):723-730.*

Luiz Gustavo Martins da Silva

MAIN OBSTACLES TO POSSIBLE SOLUTIONS IN BRAZIL

» Limited number of studies on the issue.

» Lack of adequate legislation (which requires a discussion of the problem while the project is being implemented).

» Lack of financing and limited availability of resources for the development of research in this area.

» Absence of technology for direct application to the plants in order to avoid mortality.

» Lack of subsidies for companies in the electricity sector to invest in solutions and technologies to minimize the problem, making them budgetarily feasible.

Brazilian researchers at the Federal University of São João del-Rei (UFSJ), in partnership with researchers at the University of Southampton and funded by the British Council/Fapemig, tested acoustic systems as a behavioral "barrier" to keep species out of danger from power plants. Other studies, in partnership with the Hydraulic Research Center of the Federal University of Minas Gerais, evaluated the potential use of electric barriers, strobe lights and even biological barriers.

Theoretically, these barriers encourage fish to move or avoid areas that would be harmful, such as turbine intakes. The Southampton group has several studies demonstrating the effectiveness of sound barriers for a number of European species, but there are no studies to understand the influence of this type of system on Brazilian species, and in the tropics in general. While this solution can be useful, it will need to be tested and adapted to the fish here.

In addition, by studying the effects of rapid decompression in fish through laboratory simulation of the pressure variation caused by the turbines, researchers can contribute information that may inform solutions. The results of these experiments, for example, will provide data that will allow turbine manufacturing companies to develop new designs and technologies to minimize the occurrence of lethal pressure variations in fish, while maintaining energy efficiency. They can also show the susceptibility of native species to the development of barotraumas, which pose severe risks to fish survival.

3

Why it is worthwhile for hydropower companies to invest in solutions to the problem

Savings in resources: Large expenses, such as the payment of environmental fines or the need to adapt and change structural projects after the plant is completed, can be avoided in the future. Implementing tools/technologies to mitigate the problem while the project is still in the design phase can allow for decision making at a time when the costs of these actions are lower and can be included in the general budget, before the plant goes up for sale. As an example, if this had been done before the construction of the Belo Monte Plant, the company would have saved at least R$14 billion. This is because it is estimated that the construction, budgeted for R$16 billion, cost R$30 billion due to stoppages and fines resulting from non-compliance with environmental rules[12].

Improvement to the companies' image: In 2007, Companhia Energética de Minas Gerais (Cemig) created the Peixe Vivo Project, which reduced the average annual biomass of dead fish by about 75% during the operation and maintenance of hydropower plants. The initiative, which is still in effect, will expand and develop measures for the conservation of fish fauna in river basins where the company's plants are operational. In addition to this significant result, the company formed internal partnerships, bringing together maintenance and operations engineering and environmental teams, to develop safer energy generation activity for fish.

More transparent channel with environmental agencies: Over the years, Cemig, through the Peixe Vivo Project, has demonstrated the importance of initiatives to reduce the impact of the operation and maintenance of hydropower plants. Cemig is also carrying out a new project to assess whether other factors, in addition to those already identified, lead to the death of fish during the day-to-day operation of the plant, in order to better address these issues.

Greater potential to attract investments from external financiers: The Brazilian electricity sector has the potential to stand out in the world market and generate a contribution to global resources. However, strategies that harm the environment have kept investors away and hampered the development of companies (for the reasons explained in the section above).

effective solutions

We need more studies to understand:

» How barotrauma affect the survival of different types of fish exposed to passage mechanisms associated with electricity generation (turbines and spillways);

» Where do fish come from when they make contact with the turbines or spillways (from the reservoir or the river just below the dam?);

» The relationship between the occurrence of the injury suffered in turbines with large-scale mortality and the direct and indirect estimation of the number of dead fish. Many die due to direct interaction with the structures of a plant or indirectly. However, indirect mortality is more difficult to quantify, even though it may be more harmful to fish populations;

» The relationship between mortality events and turbine maneuvers and operations;

» Which other physical (mechanical strike with the turbine blades) or hydraulic (mutilation of parts of the fish due to turbulence that cause currents with opposite forces - shear) factors cause deaths in hydropower power plant turbines;

» What is the susceptibility of different species to turbine mortality.

[12] *Um ano após início de funcionamento, Belo Monte paga o preço das polêmicas, UOL, 3 jun. 2017.*

4

Recommendations

In the face of scientific evidence and experiences from other parts of the world, we suggest five urgent measures to remedy this problem in Brazil in order to save millions of tons of fish and avoid economic losses in the form of fines to mitigate environmental impacts:

» **Fund and develop more research in this area.**

» **Invest in technology and training specialists in this field.**

» **Sensitize everyone involved about the problem, including hydropower plant workers, environmental agencies and communities.**

» **Predict, plan and quantify environmental impacts at all stages of a hydropower plant project.**

» **Update legislation in accordance with best practices in other countries.**

WE DETAIL EACH ONE BELOW:

Fund and develop more research in the area to understand

» The path taken by the fish for passage through or contact with the turbines. It is not known whether a good portion of the fish killed after contact with the dams were already below them and entered the turbines during operational maneuvers or if they came from top to bottom, in a possible downward movement, and actually descend through the turbines (as is the case with salmon, for example).

» What types of hydraulic variations and causes of injury can occur when restarting turbines after maintenance programs.

» Which groups of fish are most susceptible to the development of barotraumas and, consequently, are more vulnerable to hydropower projects.

Andrey Leonardo Fagundes de Castro

Andrey Leonardo Fagundes de Castro

Invest in technology and training specialists in this field

» Technologies already exist to assess how all of these parameters that can cause injury to fish vary in turbines, but international funding and collaboration are required to apply them.

» It is necessary to have investments in research and strong graduate programs in this field in order to form a critical mass of specialists capable of working on these issues.

Sensitize everyone involved about the problem, including hydropower plant workers, environmental agencies and communities.

» Electricity sector companies need to understand the problem and the importance of allowing access to their facilities so that research can be carried out in places where large-scale death events are frequent.

» Environmental agencies should make their assessments more flexible for companies that are interested and willing to provide access to their facilities for the collection, research and processing of data about these events.

b) Projects in operation or under construction

» After the plants are developed, correcting environmental impacts can cost much more than doing so during the design stage. At this stage, we can only mitigate or control them. These actions are necessary not only to avoid fines and ensure the sustainability of the electricity sector, but also to promote fishing. Especially in the Amazon region, fishing is a source of income and food for a wide range of families.

Predict, plan and quantify environmental impacts at all stages of a hydropower plant project

It is possible to envisage ways to mitigate fish mortality in all three phases of the project:

a) Project planning or in the inventory stage

» A strategic planning process needs to be established to select and develop those projects with the least potential impact first. Luiz Gustavo Martins da Silva, a former researcher at UFSJ and currently at ETH Zürich, developed a tool for joint data analysis using Geographic Information Systems technology that aims to contribute to the selection of sites for the construction of small hydropower plants. This study, published in the scientific journal *Journal of Environmental Engineering*, shows how it would already be possible to select and prioritize the licensing of plants in areas with lower potential to generate negative socioenvironmental impacts..

» To avoid killing fish in turbines, it is possible to incorporate some mitigation strategies during the planning and designing period. In addition to reducing impacts, they can significantly decrease the investments needed to solve future problems.

[13] *Selection for Hydropower Development: A GIS-Based Framework to Improve Planning in Brazil, Journal of Environmental Engineering, Volume 144, Issue 7 - July 2018.*

Update legislation in accordance with best practices in other countries

» It is necessary to adapt current Brazilian laws so that the problem is defined as something specifically associated with hydropower projects. Currently, companies are fined under the Environmental Crimes Law, which levies fines in cases of wild animal mortality, but it does not specify the need to resolve this mortality issue in the case of hydropower plants. There are also no specific laws which require plants to present solutions or studies to mitigate the death of species for the regulatory and bidding processes of new dams.

CONCLUSION

The results of the report make it clear that the problem of mortality of fish in hydropower plants is much more extensive than expected. Despite alarming, the figures obtained are, certainly, underestimated, as the episodes reported happened in less than 1% of installed Brazilian hydropower plants. Action is needed now to eliminate the problem in new dams or minimize it in existing facilities. For this, the sector needs a joint effort of everyone involved in the mortality episodes to, first, expand access to data and information about events that occur across the country. More scientific studies are also needed to support the decision making in environmental licensing and guide more specific technological solutions for fish species in Brazil.

More broadly, there is an urgent need to better plan the installation of new and genuinely sustainable hydropower plants that preserve the enormous fish diversity in Brazil.

Acknowledgement

To Fapemig for research funding (APQ-04822-17 - CONFAP Call - British Council: Institutional Links 2017).
To the British Council for research funding (Institutional Links grant, ID 332396528).
To the Newton Fund and British Embassy in Brazil for funding and support in organizing the event entitled “Fish mortality by hydropower plants: identifying problems and co-creating solutions”.
To the members of the Molecular Ecology Laboratory & Ichthyology of DCNAT, UFSJ.
To Cemig for the supply of copies of fish from the Fish Farming Station of CEMIG in Itutinga.
To colleagues at the International Center for Ecohydraulics ”, the University of Southampton, for collaboration in experimental activities and publications.
To colleagues Diego Arruda and Maíra Brito (Fundo Newton) and Maria Paola de Salvo (EasyTelling) for dedication and immeasurable support in publicizing Brazilian science, providing tools and expertise so that the message could breakthrough the walls of the academy.

R E P O R T

Fish mortality at hydropower plants

IDENTIFYING PROBLEMS AND CO-CREATING SOLUTIONS

Researchers authors

Luiz G. M. Silva - Stocker Lab, ETH Zurich, Zurich, Switzerland

Andrey L. F. de Castro - Laboratory of Molecular Ecology & Ichthyology, Department of Natural Sciences, University Federal of São João del-Rei, Sao Joao del Rei, Brazil

Paul Kemp - International Center for Ecohydraulics Research, University of Southampton, Southampton, England.

Knowledge translation and editing: **EasyTelling**, (edition: Maria Paola de Salvo and Fernanda Collaviti. Review: Renato Bacci), **www.easytelling.com.br**

Financial Support

Newton Fund

FAPEMIG

Host

UFSJ Universidade Federal de São João del-Rei

Partnership

University of Southampton

Organization

Easy Telling