Fish mortality at hydropower plants

Protection Measures and Solutions

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Abstract

The construction and operation of hydropower plants for energy generation is a major issue in sustainable energy production. Nevertheless, hydropower plants have a negative impact on fish populations. It is crucial to understand the causes and consequences of fish mortality in hydropower plants in order to find sustainable solutions that reconcile the need for energy with the conservation of aquatic ecosystems. This article examines the fish protection measures that can be implemented to reduce fish mortality and maintain ecological balance. Based on the main literature reviewed, this article mainly refers to Germany in terms of studies carried out and hydropower plants.

Keywords: Fish mortality, Turbine-related injuries, Fish migration aids, Fish-friendly turbines, Mortality rates

1 Introduction

The number of hydropower plants is increasing rapidly worldwide. In Europe alone, 21,000 plants are already in operation, while a further 8,500 planned plants are waiting to be realized [1]. The impact of hydropower plants on fish populations is an increasingly important issue. The mortality of fish in such plants is a complex and controversial issue. The construction and operation of hydropower plants can have a significant impact on the aquatic environment by altering natural habitats and affecting fish populations. The Water Resources Act emphasizes the importance of protecting fish through appropriate measures at hydropower plants. Such begs the question: *What measures can be taken for reducing fish mortality at hydropower plants?* This article first delineates the risks posed to fish in hydropower plants. It then explores various potential solutions aimed at mitigating these risks and preserving fish populations in such settings.

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2 Legal area

The implementation of fish protection measures at hydropower plants is highly relevant, as this is required by the Water Resources Act. According to Section 35 (1) of this Act, the use of hydropower may only be permitted if suitable measures are also taken to protect fish [2]. If no measures are implemented in this regard, the hydropower plant may not be put into operation. This regulation does not apply exclusively to specific fish species or water body types. According to this, plant operators must prove that the operation of the hydropower plant has no negative impact on the fish population or that sufficient measures are implemented to protect and maintain the population [3]. In order to achieve the objectives of the EC Water Framework Directive in many watercourse systems in Germany, measures are needed to improve fish passability both upstream and downstream. The installation of fish ladders at weirs and other barriers to fish migration as well as the integration of fish protection and downstream fish migration systems at hydropower plants, are of particular importance to achieve this goal. It is therefore urgently necessary to review the current state of knowledge on the effectiveness of fish protection and downstream fish migration systems. This requires methodological approaches to ensure a comparison of the efficiency of different concepts and to develop recommendations for preferred solutions [4].

3 Risks and Implications of Hydropower Plant Encounters for Migratory Fish

When fish migrate downstream, there is a possibility that they will be caught and pulled along by the turbines in hydropower plants and thus pass the obstacle. This could expose them to conditions that increase the risk of injury and mortality. These risks vary depending on fish species, developmental stage, size, turbine type and operating conditions. The main injury mechanisms occurring are due to contact with the turbine blade and the pressure drop in the turbine. Other mechanisms include shear forces and turbulence. Given the comparatively high costs of

https://doi.org/10.25974/ren_rev_2024_07

fish protection measures and the associated technical or operational risks, a clear basis for decision-making on appropriate fish protection regulations is essential [5]. High killing risks arise when certain species have to travel long distances due to their behavior and reproductive cycle. Species that are forced to migrate are generally more likely to come into contact with hydropower plants. As hydropower plants are positioned as transverse structures in the main watercourse, the downstream movement inevitably requires passage through these structures. As a result, species such as the eel (Anguilla anguilla) and the anadromous sea trout (Salmo trutta) are particularly at risk. In the case of anadromous fish species that migrate repeatedly, the migrating juveniles in particular are at risk. These juveniles are often not protected from passing the turbines by screens. Potamodromous species such as the nase (Chondrostoma nasus) sometimes traverse extensive distances within a water system and are therefore also at risk of passing existing hydropower sites during their migration. Compared to typical river fish species, lake species are generally less likely to encounter hydropower plants. Although the probability of encounter for lake species was classified as very low, it cannot be completely ruled out that certain lake species may encounter hydropower plants, particularly in the vicinity of lake outlets or storage power plants [3].

3.1 Injuries caused by turbines

As fish mortality is mainly caused by turbines, the rest of the article refers to turbine-related fish mortality. A study showed fish experiments at one of the world's first construction sites for a shaft hydropower plant (SHPP) on the Loisach near Großweil in southern Bavaria to investigate the mortality of fish at this plant. The fish were released in front of the hydropower plant and then caught again. The hydropower plant has a head of 2.5 meters, a power plant discharge of 22 cubic meters per second and an output of 420 Kilowatt-hours (kWh). The power plant also has two identical, double-regulated, horizontally arranged Kaplan bulb turbines, each with four blades [6]. The study focused on how the fish population reacted to the specific operating conditions and structural features of this plant. The potential for fish mortality and injury following turbine passage of the SHPP was investigated. The fish species used for the study included:

- European eel (Anguilla anguilla L.)
- Common nase (Chondrostoma nasus L.)
- Brown trout (Salmo trutta L.)
- Perch (Perca fluviatilis L.)
- Barbel (Barbus barbus L.)
- Roach (Rutilus rutilus L.)
- Grayling (Thymallus thymallus L.) and
- Danube salmon (Hucho hucho L.)

For each of these fish species, the widest available size range was used, which was within a range of 3 to 67 centimetres [7]. The recaptured test fish showed various injuries after passing through the turbines. The most common were fin tears and scale loss, which were found in 83% and 66% of the recaptured fish respectively. More serious injuries such as amputations and bruises to the head and body occurred less frequently and were only found in 2.7% and 3.7% of the recaptured treated fish respectively after turbine passage [7]. A comprehensive assessment of fish injuries requires the capture of fish below hydropower plants. Both recapture and subsequent handling can cause stress to the fish, resulting in significant injuries such as fin tears, scale loss or skin lesions [8].

3.2 Turbine-related fish mortality

The mortality rates of the various test fish species in relation to the SHPP study varied significantly. There were clear differences in the specific mortality rates of the individual fish species. Mortality after passage through the turbines was significantly increased for all test fish species. Particularly high turbine-related mortality rates were found in roach, with 20% at high turbine loads and 44% at low turbine loads [7]. Furthermore, fish tests at different locations with three different turbine types - the Kaplan turbine, the screw turbine and the Very-Low-Head turbine (VLH turbine) yielded different results in terms of fish mortality rates. In general, maximum mortality rates of less than 83% can be determined for conventional Kaplan turbines and less than 64% for novel turbines. The lowest average mortality rates, with mean values between 2% and 6%, were recorded for the VLH turbines [9] as slow-turning turbines such as very-low-head turbines and water wheels are less harmful than most conventional turbine types [1]. This was followed by the screw turbines with 3% to 6% and the conventional Kaplan turbine with 5% to 8%. At locations with the highest maximum and average mortality rates were both Kaplan and one of the VLH sites recorded. Here, most of the severely injured fish died immediately after passing through the turbines. Accordingly, the pattern of fish injuries and mortality is strongly dependent on various factors, such as the life stage of the fish [1], the type of turbine, the location and the specific characteristics of the fish. The circumferential speed of the runner has a more significant influence on fish injuries than other turbine parameters. In the case of Kaplan turbines, blade runout is the decisive factor for the risk of mortality. The same applies to VLH turbines, whereby their passage mainly leads to collision-related injuries that are either internally visible or of lesser severity, such as internal vertebral fractures or deformations as well as bone fractures. Furthermore, the number of turbine blades, the drop height and the total length of the fish have a significant influence on certain types of injury. Loss of scales, internal fractures, pigmentation and fin amputations, for example, increase with the number of turbine blades. This tendency is particularly evident in VLH turbines with eight blades, which have a comparatively low impeller speed, however, leading to an increased probability of low-intensity collisions. In addition, the rate of body part amputations increases with increasing drop height. A comprehensive overview of the presence or absence of fish damage, as well as fixed effects such as turbine or hydropower plant and fish characteristics, but also random effects such as location and fish species, can be seen in Figure 5 by Mueller et. al [9]. Furthermore, vertebral fractures also increase with increasing total length of the fish and the circumferential speed of the impellers. This emphasizes that the European eel, as the longest fish in this study, has the highest mortality rate in the Kaplan turbines [9]. From this it can be concluded that the risk of mortality generally increases with the size of the fish, with larger fish tending to have the highest risk of mortality [1].

4 Possible Solutions for Reducing Fish Mortality at Hydropower Plants

In the context of this paper, two specific approaches are now briefly presented that aim to reduce or avoid fish mortality at hydropower plants.

These are:

- Fish-friendly turbine design
- Fish migration aids

4.1 Fish-friendly turbine design

The best solution are turbines that reduce fish mortality due to technical and operational configurations and at the same time successfully prevent the animals from entering the turbines in the first place [1]. Fish-friendly turbines such as the Minimum-Gap-Runner are characterized by a small number of turbine blades. They have a large diameter, a comparatively low rotational speed, low head and generate only minimal negative pressure. These characteristics make it possible to significantly reduce mortality to below 3%. Similarly turbines currently under development, such as the Alden turbine, also reduce the mortality of fish, which in tests caused mortalities of 0% to 2% in 20 centimeter long individuals of various fish species [10]. The goal in developing a fish-friendly turbine is to maintain high efficiency while minimizing low-pressure zones. This is achieved by having a low number of blades and minimizing gaps to avoid fish entrapment. The reduction of the gaps has a positive effect on the scouring of the blade profiles, both on the pressure and suction side of the turbine. This measure has a positive effect in two ways. Firstly, the risk of cavitation is reduced at this point. Cavitation leads to abrupt pressure drops followed by rapid pressure increases, which would be potentially harmful to fish. Secondly, minimizing the gap positively contributes to reducing zones of high turbulence that could otherwise affect the fish laterally [5].

4.2 Fish migration aids

4.2.1 Slotted pass

The main principle behind the construction of a slotted pass is to divide the entire height difference of the dam between the upstream and downstream water into numerous smaller water level differences. This is achieved by the arrangement of basins whose dividing walls are well permeable for the passage of fish through narrow slits [11]. With the slot pass, which is also known as the "vertical slot pass", one or two open slots run vertically across the entire transverse wall, which leads to improved passability. The number of slots installed depends on the size of the watercourse and the available discharge capacity [12]. The fish migrating upstream must orient itself to the current in order to recognize the outgoing current, which emanates from both the fish ladder and the attracting current. The attracting current is generated, for example, by sheet piles or guide piles consisting of armourstones or wooden pile foundations. These guide the fish into the entrance of the fish facility. Once the fish has found the entrance to the system, there is a high probability that it will be able to swim through it successfully. It is important that the maximum current speed is maintained [13].

4.2.2 Fish lift

Fish lifts are characterized by a movable lifting basket or container that enables the fish to be transported from the level of the underwater to the level of the upper water [14]. In this system, a luring current guides the upward-migrating fish into a cage. In order to overcome the height difference with the fish lift, the cage acts as a transport container for the fish and is pulled upwards with the help of a winch. The fish are then transported to the upper water. As soon as the difference in height has been overcome, the transport container opens and the fish are guided down a chute into the upper water. However, the descent of the fish requires additional equipment [15]. Another variant of the fish lift is the fish lift sluice. This has a structure consisting of floats, fixed connecting pieces

https://doi.org/10.25974/ren_rev_2024_07

and perforated plates. This arrangement enables the transport system to float up and down without additional external energy. This means that even large differences in height can be overcome without taking up too much space. During the transport phase of the fish over the height, it is not possible for them to enter the lifting basket or the container from below. Access to the fish lift can be via a slotted pass [14].

4.2.3 Fish ladder snail

The fish ladder screw conveyor is used to transport the fish effortlessly and without injury to the headwaters [16]. This type of fish migration aid differs between the monotube auger and the twin-tube auger. The monotube screw conveyor is a simple screw conveyor that is driven by an electric motor. The systems realized to date have diameters between 1,000 and 1,400 mm. The double-tube screw consists of two concentric, counter-rotating screws. The outer screw is used to move the inner fish ladder screw and also serves to generate energy. The diameter of the fish ladder screws manufactured to date is 1.2 m, while the diameter of the outer tube screw varies between 1.8 m and 2.4 m. With fish ladders, the water is generally transported upstream. For the fish that migrate upstream against the current, an internal guiding current is generated in the lower part of the fish ladder screw. This directs the fish into the screw conveyor so that they can be transported further from there [14]. The guiding current encourages fish and other aquatic creatures to swim into the slowly rotating fish ladder on their own [16].

4.2.4 Fish ladder

There are various types of near-natural fish ladders. These include riverbed ramps and slides, bypass channels and streams. Bottom ramps and glides are integrated directly into the course of the river and do not require any special adjustments to the adjacent bank area. This involves placing boulders about 1 meter in size on the bed substrate to create natural currents. Care is taken to create different current strengths to allow different species of fish to swim upstream. The bypass channel is an artificially created, stream-like river course. This form of fish ladder is very popular as it creates additional habitats and spawning grounds. Fish swimming upstream are guided to the bypass channel by an attracting current, which they can then pass through [12].

Table 1 summarizes the advantages and disadvantages of the fish migration aids described in Chapter four, based on the literature reviewed.

Tab. 1: Overview of the advantages and disadvantages of fish migration aids

Fish migration aids	Advantages	Disadvantages
Slotted pass	Suitable for upstream and downstream hikes [17], Suitable for confined spaces [12]	High quantities of water required [17]
Fish lift	Space-saving and height-independent [14]	Not suitable for a downhill hike [14]
Fish ladder snail	No susceptible risk of injury [16], Low energy consumption [16], Uniform conveying [16], No scaring effect on fish [16], Introducing the motive water at the inlet [14]	Additional energy required [14]
Fish ladder	Optics adapted to nature [12]	Costs depend on the size of the river [12]

5 Conclusion

In summary, the application of fish protection measures is essential. Studies have shown that the mortality rate of fish at hydropower plants is high and that these affect the fish population. Accordingly, this article describes two separate main measures to meet the requirements of the Water Resources Act and to address the question: *What measures can be taken for reducing fish mortality at hydropower plants?* This includes a fish-friendly turbine design, which aims to reduce fish mortality by reducing gaps, cavitation and turbulence [5] as well as various possible fish migration aids to overcome barriers. The paper argues for ongoing research, comprehensive strategies and a balanced approach to ensure both fish protection objectives at hydropower plants and the protection of the aquatic environment. However, it is up to the hydropower plant operator to decide which of these measures will be implemented.

6 Outlook

In order to continue to ensure fish protection at hydropower plants in the future, further investigations

https://doi.org/10.25974/ren_rev_2024_07

are required. The following approaches could be proposed as potential improvements:

- Further investigation of effectiveness and continuous improvement of new turbine designs
- Application of monitoring and control systems to reduce the interaction between fish and turbines
- Development of new fish protection measures to further reduce fish mortality

There is only a low risk of killing fish if there is adequate fish protection. Therefore, the aim of hydropower plants should be to improve the ecologically and energetically balanced solution.

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https://doi.org/10.25974/ren_rev_2024_07