Fact Sheet 03 EN
October 2020

Evaluation of primary injury to fish at hydropower sites

Methodological recommendations for quantifying the risk of injury and mortality to fish during the passage of hydropower sites

FORUM FISCHSCHUTZ & FISCHABSTIEG

Key messages

- Studies to determine the risk of injury to fish at hydropower sites should consider the comparability of results.
- This requires a minimum of methodological standardisation. A uniform protocol for recording injuries is a basic prerequisite for this.
- Experimental studies with, individually marked fish guarantee reliable data and a high degree of comparability.

Evaluation of fish protection facilities and bypasses: Recommendations for a standardised methodology

The complexity and specifics of hydropower sites as well as the different local fish fauna make it difficult to draw analogies between sites. It is therefore even more important to minimise methodological influences on the study and to make it comparable. There is currently no standard available for evaluating fish injury. However, recent studies (Müller et al. 2017; Pander et al. 2018; Wagner et al. 2021) of primary injury at hydropower sites have consistently shown that various factors in planning, data collection and evaluation can have a significant influence on the result of the study. The need for uniform standards to ensure comparability of results is therefore high and represents an important aspect in quantifying the risk of injury at hydropower sites or by different types of turbines. This facilitates the identification of preferred solutions for fish protection as well as their proof of function. A solid data basis forms the prerequisite for comprehensibly quantified efficiency criteria and increases the acceptance of measures. Based on previous findings on the implementation of injury studies, the limits and possibilities of the currently available methodology were discussed in the German Participatory Forum on Fish Protection and Downstream Migration. The results were incorporated into this Fact Sheet. The most important steps in the standardisation of study planning, data collection and evaluation to establish a robust methodology are presented below.

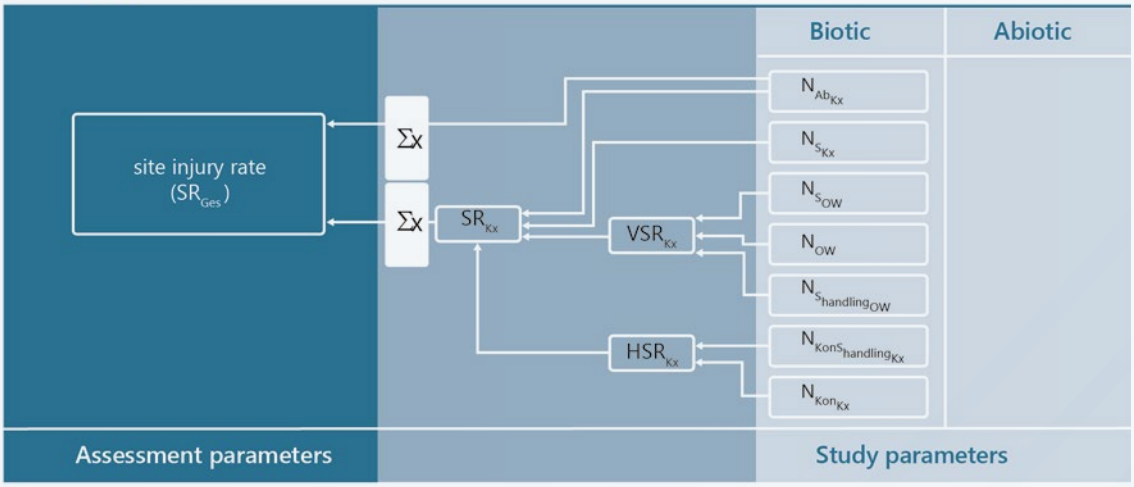
Planning of the study based on the working guideline according to Schmalz et al. (2015) and DWA (2021)

A planning tool for a site evaluation is available in Schmalz et al. (2015) and DWA (2021). Due to the diverse hazards to which fish are exposed during the passage of hydropower sites, not only the turbine but all downstream migration corridors must be investigated. For this reason, both corridor-specific and overall site-related assessment parameters are specified:

- Corridor-specific injury rate
- Corridor-specific mortality / survival rate
- Site injury rate
- Site-specific mortality / survival rate

These assessment parameters include various study parameters that must be determined and quantified in the field. Factors influencing the results, such as the previous injury of the fish and the study-related influences, are excluded. For the assessment parameter site injury rate, the derivation of the necessary study parameters is exemplified in the following figure.

Derivation of the study parameters in field studies for the determination of the site injury rate



SR_{Ges} = site injury rate [-]

SR_{Kx} = corridor-specific injury rate [-]

VSR_{Kx} = previous injury rate in the corridor x [-]

HSR_{Kx} = handling-related injury rate in the corridor x [-]

$N_{S_{Kx}}$ = Number of fish migrated via corridor x and injured [n]

$N_{Ab_{Kx}}$ = Number of fish migrated via corridor x [n]

$N_{S_{OW}}$ = Number of injured fish caught in the headwaters of corridor x [n]

N_{OW} = Number of fish caught in the headwaters of corridor x [n]

$N_{S_{handling_{OW}}}$ = Number of handling-related injured fish caught in the headwaters of corridor x [n]

$N_{KonS_{handling_{Kx}}}$ = Number of handling-related injured fish of the used control group migrated via corridor x, [n]

$N_{Kon_{Kx}}$ = Number of fish in the control group in corridor x [n]

Source: DWA 2021

The study of the injury risk thus requires seven study parameters. They are based on net fishing downstream of the relevant migration corridors. For mortality assessments, telemetric methods are also partly used (Okland et al. 2017). These are only to a limited extent comparable with net fishing data and do not provide information on primary, non-lethal injuries. In scientific studies, telemetry studies or individual tagging and refishing can provide valuable information on the effect of non-lethal injury on the likelihood of survival in natural water bodies.

Discharge and operational conditions can have a considerable influence on the mortality and injury risk of fish during site passage. Therefore, it is crucial to clarify already during the planning of the study, which conditions need to be analysed to be able to make reliable statements on the aspects of the study derived from the assessment objective.

★ Recommendation

The DWA publication „Methodische Grundlagen zur standörtlichen Evaluierung des Fischschutzes und Fischabstieges“ (DWA 2021) provides comprehensive assistance in the development of a site-specific concept for the study of fish injury at hydropower plant sites.

Discharge and operating conditions at the hydropower plant site influence the results. They must therefore be considered and may require an adjustment of the study design.

In principle, all migration corridors of a site are to be considered for the assessment of the injury rate.

Discussion

In the German Participatory Forum on Fish Protection and Downstream Migration, it was also discussed that officially specified thresholds for mortality or injury rates only make sense if the inaccuracies in their measurements are known. They should therefore be stated in the results of the studies. To assess the results, information on the discharge and operating conditions is indispensable.

An experimental approach increases the comparability between studies

When planning the studies, the fundamental question arises as to whether naturally downstream migrating fish or introduced experimental fish should be used and thus whether an experimental approach is required. Both approaches have their advantages and disadvantages.

The decisive disadvantage when focus only on naturally downstream migrating fish is the methodological problem of determining the previous injury rate of the fish in the headwaters with downstream migration “intention”” in a representative way. For previously injured fish, neither electrofishing nor net fishing can assume the same catch efficiency as for healthy fish, as the mobility and activity of the two groups is very likely to differ. This aspect can lead to considerable inaccuracies in the data when calculating injury rates for a corridor and the entire site. When determining the mortality rate, this effect is less pronounced, but may also lead to incorrect results. Furthermore, a quantification of the method-related injury is also necessary in the case of natural downstream migration. The use of the control group necessary for this, including the tagging of fish can be considered an animal experiment in the European Union (EU) requiring official approval, which means that the expense is just as high as when applying for approval for the experimental approach.

Advantages and disadvantages of using naturally downstream migrating fish or an experimental approach to determine the mortality and injury risk

Method	Advantages ⊕	Disadvantages ⊖
Natural downstream migration	» No handling of fish before site passage » No costs for providing fish » Natural downstream migration behaviour is given and therefore the corridor-specific downstream migration rates that would otherwise have to be determined additionally » Naturally existing species and size spectrum is analysed » Usually not classified as an animal experiment in the EU	» Available sample size and species spectrum unknown and not to be influenced » Previous injury to the fish can hardly be determined in a representative manner » Studying desired discharge or operating conditions requires a long investigation period
Experimental approach	» Previous injury of the fish can be determined exactly » Available sample size can be influenced and is known » Desired discharge or operating conditions are easy to study	» Animal experiment » Handling of fish before site passage with catch and transport » Fish procurement causes costs » When using farmed fish, a natural behaviour of the test fish cannot be assumed

Source: IGF Jena 2020

When using the experimental approach, the previous injury rate and the method-related injury can be determined exactly. This, and the possibility of standardising the species and size spectrum used, ensures a high degree of comparability of the data. Furthermore, the calculation of the assessment parameters can be based on data from a sample of intact or at most slightly injured fish. This means that the results are much less influenced by previous injuries. Since the fish in this approach are deliberately introduced into the headwaters of potentially harmful corridors and are anaesthetised and marked, the studies are classified as animal experiments that require official approval. The effort of the experimental approach is higher than that of fishing naturally migrating fish due to the preparation work.

By introducing experimental fish at a specific point in time, certain discharge and operational conditions can be studied in a targeted manner. Natural downstream migration is usually subject to limited predictable dynamics, making it difficult to estimate the optimal phases of studies.

For this reason, longer study periods often must be planned than with the experimental approach.

Another advantage of the experimental approach is the possibility to focus specifically on selected species during the study. Reasons for this can be their relevance under species protection law (e. g. salmon) or the use of uniform fish species at all sites to improve the comparability of the results. In addition, the influence of local species composition on the results can be eliminated. The latter is important for comparison between sites because sensitivity varies widely between species.

★ Recommendation

If high comparability with other sites is required, an experimental approach with targeted experimental fish should be used to determine primary mortality and injury rates.

Previous injury handling-related injury must be considered when calculating injury rates.

Discussion

The German Participatory Forum on Fish Protection and Downstream Migration also called for standard monitoring to work with a uniform set of available proxy species that represent all target species in terms of body proportions, swimming ability and sensitivity. It was additionally noted that mortality studies can also be carried out with farmed fish.

A standardised assessment of fish injury is needed

To determine the injury to fish at a hydropower site, it is unavoidable to catch a representative sample of animals and examine them for injuries. A distinction must be made between the type of injury and the intensity of injury. There are various approaches in Germany for this (Holzner 1999; Schmalz & Schmalz 2007; Schmalz 2010; Schneider et al. 2012; UBA 2012; Schneider & Hübner 2014; Wagner 2013a, 2013b und 2013c; Schmalz 2016; Wagner 2016; Müller et al. 2017; Wagner et al. 2019; Wagner et al. 2021).

For comparability of data between studies, injuries are to be recorded on the basis of quantitative criteria. The more consistent the protocols, the more comparable the data. A standard protocol with unlimited applicability is not yet available. This would have to include all relevant injuries and intensities but would have to reduce the examination effort to a level that is feasible for widespread practical application. The very differentiated injury protocol developed by Müller et al. (2017) allows a detailed recording of injuries according to strictly quantitative criteria. It currently represents the most well-founded basis.

A protocol with a reduced scope was developed focusing on injuries that are expected to affect fish in the medium to long term (Wagner et al. 2021) to reduce the field work effort, The injury protocol by Wagner et al. 2021 is available on the website of the German Participatory Forum on Fish Protection and Downstream Migration. Future research results will help to further develop these protocols based on a broader data base. In the context of scientific projects, detailed injury analyses are also important in some cases, justifying costly diagnostic procedures such as X-rays.

The accuracy of the injury record requires a trade-off between data quality and examination effort. The more precise the examination of the animals, the longer the duration and the partially necessary anaesthesia phase of the fish. Thus, impairment of the animals increases with the examination effort.

The data resulting from the injury protocol according to Müller et al. (2017) allow a sensitive data analysis with multivariate statistical methods. However, no direct conclusions of the severity of impairment can be drawn on this basis. An additional step of „translating“ the injuries into impairment levels is required. Only on this basis can injury rates be quantified since they must relate to predefined degrees of impairment. A proposal for this is contained in Wagner et al. (2021).

★ Recommendation

Uniform protocols should be used to document injuries. The monitoring effort must not be so high at to prevent widespread use in practice.

Injury patterns on fish must be assigned to a degree of impairment that corresponds to the severity of the injury.

Scientific projects may require more elaborate injury analyses.

Evaluation of injuries on a per-individual basis

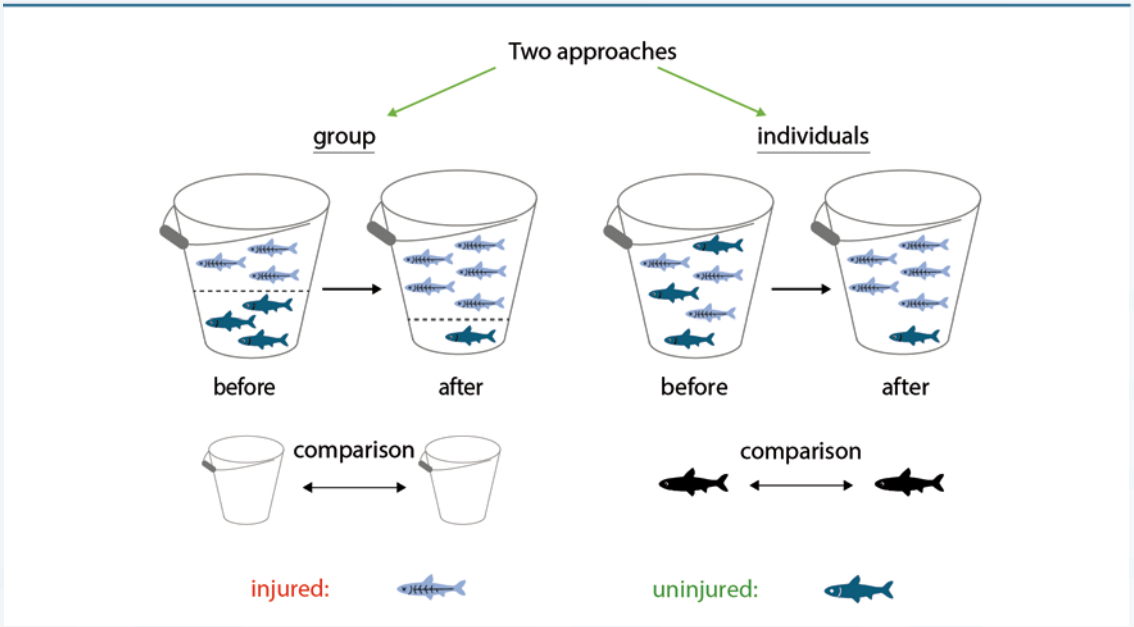
Passage-related injuries can be determined for a group of fish or for the individual fish on the basis of the documented previous injuries. Depending on which approach is chosen, the results of the study may differ. In the group approach, the proportion of injured animals determined after site passage is related to the proportion of fish already injured before passage. The per individual approach allows a direct comparison of the injury intensity of each fish before and after the site passage. A prerequisite for this is the individual marking of the fish (e. g. by means of Passive Integrated Tags (PIT)). Photographing each fish before and after passage has proven useful for validating the data (Wagner et al. 2019; Wagner et al. 2021).

With the individual approach, it is possible to determine the effect of previous injury on the passage-related risk of injury accurately and with a smaller number of test animals than with the group approach. In addition, this approach is more sensitive, as the direct before-and-after comparison enables recording of any passage-related injuries. It has been shown, however, that because of higher sensitivity to pressure fluctuations, tagged fish may have a higher risk of injury than untagged fish. The transmitter load, as a ratio of the transmitter mass to the body mass, has a decisive influence (Carlson et al. 2012). Due to the low mass and density of PIT, this influence is reduced compared to radio or acoustic telemetry transmitters but must be considered when choosing the size of fish to be tagged. For turbine types with a high probability of mechanical damage (e. g. direct hits) and low pressure fluctuations, the influence of the transmitter load is probably negligible. Systematic studies on this are still pending. In the group approach, only the damage where a fish has a higher degree of impairment after passage is quantifiable.

★ Recommendation

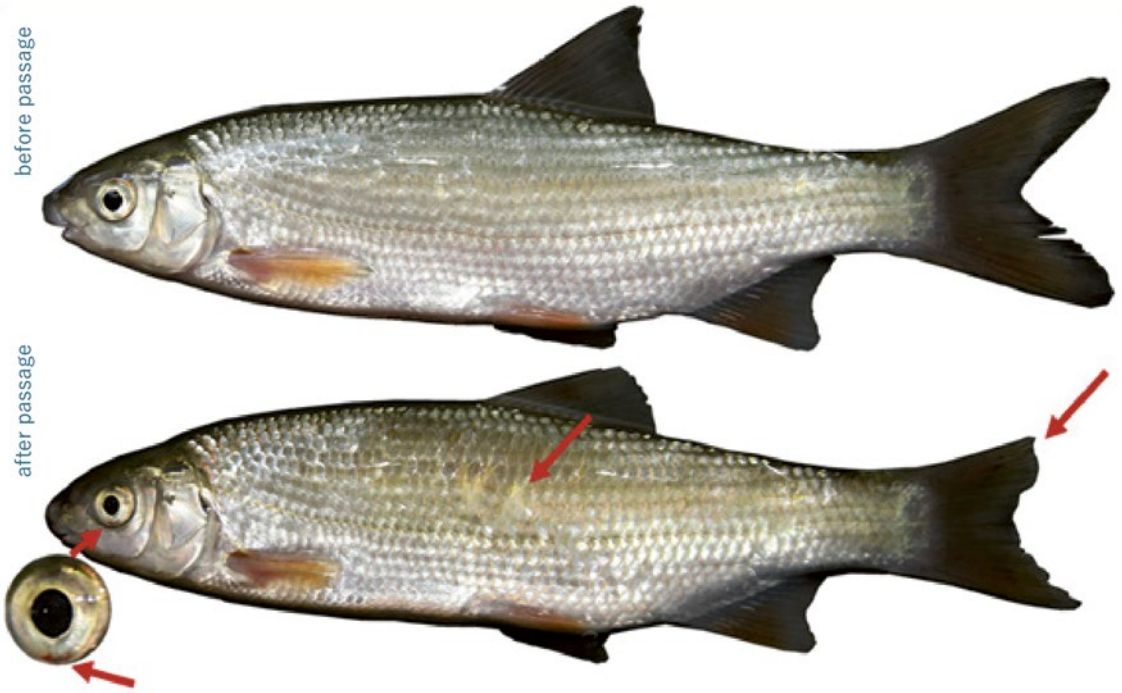
The documentation of injuries before and after passage at the individual level enables a differentiated analysis of the risk of injury.

Group and individual approach to quantifying passage-related injuries at a hydropower site



Source: Wagner & Warth 2019 – Presentation in the German Participatory Forum on Fish Protection and Downstream Migration 12/2019

Comparison of the injuries of a common nase before and after the passage of a hydropower site



The red arrows in the photographically documented injury image after passage mark three additional injuries: 1) the amputation of the upper tail fin tip, 2) the loss of single scales on the body and 3) a slight haemorrhage in the eye.

Source: Wagner et al. 2021

Reducing the influences of the study design on the results

In studies investigating the risk of injury and mortality of fish during the passage of hydropower sites, the animals are inevitably caught and handled at least once. Injuries to the fish cannot be ruled out in this process. It is therefore imperative that they are quantified and considered when calculating the passage-related effects.

These injuries range from minor injuries such as loss of scales or injuries to the fins to skin tears, bruises, injuries to the eyes and tissue haemorrhages, and even death. The longer the emptying intervals of the fishing gear, the more fish can be injured and the more severe are the injuries that occur (Schmalz 2010, Schmalz 2011, Pander et al. 2018).

Stow nets are mostly used to catch fish migrating downstream at hydropower sites. Careful selection of the net design and adaptation to local conditions are important to reduce the risk of injury in these gears. Systematic comparative studies of a trap box and a trap net at the stow net end (Pander et al. 2018) showed that the catch effectiveness of both combinations differs by species. Furthermore, no generalisable statements can be made regarding the risk of injury. This means that trapping devices must be specifically adapted to the target species and local conditions. This concerns not only the type of trap chamber, but also its size and positioning in the flow.

Nevertheless, some general statements can be made (Forum Fischschutz & Fischabstieg 2020). The following should be avoided:

- high fish densities in the fishing chambers;
- strong flows in the fishing chamber, as fish tire quickly and are pressed against the net;
- high turbulence in the fishing chambers, as otherwise the fish often chafe against the net walls;
- high amounts of floating debris in the fishing gear, as fish may collide with it;
- long retention time.

The influence of the stow net including the trap chamber on the injury and mortality rate varies according to the conditions and must therefore be determined at least site-specifically and under the discharge and operating conditions relevant to the study. Control groups are used for this purpose. In addition to the actual fishing gear the fish handling as transport, caging, netting or injury analysis also cause a risk of injury. For this reason, these effects must be reduced as far as possible. In general, it is imperative that these are recorded by suitable control groups and considered in the subsequent data evaluation.

Mortality rates may to a considerable extent depend on the duration the fish are kept after site passage or removal from the fishing gear. A trade-off between detecting passage-related mortality and caging-related mortality is required. If the caging period is too short, there is a risk of not detecting passage-related mortality. A caging period that is too long increases caging-related mortality. The two cannot be clearly separated. For this reason, it is important to keep the fish under very good conditions and to keep the caging period as short as possible. In North America (Schilt 2007) and Europe (DWA 2021), fish are often observed for 48 hours, although in scientific studies a longer period is possible (Pander et al. 2018).

★ Recommendation

Methodological influences are to be kept as low as possible but must be quantified by bringing in control groups.

Slight injuries are unavoidable when catching and handling the fish.

Discussion

The following additional suggestions were developed in the German Participatory Forum on Fish Protection and Downstream Migration:

- **Validity criteria (e. g., maximum value) should be available for the mortality rate of the control group.**
- **Minimum requirements should be formulated for the trapping devices (maximum flow velocity, minimum volume of the codend...).**
- **Individual evaluations of different flow and operational conditions as well as individual species are desirable.**
- **The raw data should be available.**

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Date

October 2020

This Fact Sheet was commissioned by the German Federal Environment Agency. The responsibility for the content of this Fact Sheet lies with the authors. It is neither an agreed position within the German Participatory Forum on Fish Protection and Downstream Migration, nor an official opinion of the Federal Environment Agency or the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection.

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Acknowledgements

This Fact Sheet is based on the recommendations of the „Arbeitshilfe zur standörtlichen Evaluierung des Fischschutzes und Fischabstieges“ (Schmalz, Wagner & Sonny 2015), which was taken up and expanded by the WW 7.2 working group of the DWA in a thematic volume (DWA 2021). In addition, extensive fish ecological studies on fish protection were carried out from 2016-2020 (Müller et al. 2017; Pander et al. 2018; Wagner et al. 2021), which focused, among other things, on the review and further development of the methodology for studying the risk of injury. Their results, as well as the discussion results of the 8th Workshop of the German Participatory Forum on Fish Protection and Downstream Migration in December 2019, were incorporated into this Fact Sheet.

Our special thanks go to Melanie Müller, Joachim Pander, Jürgen Geist and Wolfgang Schmalz for their comments on the draft Fact Sheet and their constructive criticism. We further thank Stephan Naumann and Rita Keuneke for their support in the preparation of the Fact Sheet, critical review and constructive comments, as well as Stephan Heimerl, Detlev Ingendahl, Gerhard Kemmler, Jonas Kötting, Walter Reckendorfer and Harald Uphoff for critical review and constructive comments.

About the German Participatory Forum on Fish Protection & Downstream Migration

The German Participatory Forum on Fish Protection & Downstream Migration is a series of events that serves to exchange information and experiences on fish protection and downstream fish migration from a professional point of view across interests. In the context of the forum, fish protection is understood to be plant-related fish protection and not the general protection of fish to preserve the population and the species.

The Forum was founded by the German Federal Environment Agency in 2012. It is funded within the framework of the Environmental Research Plan of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

More information on the forum, on the results of the workshops, on fish protection and fish descent facilities as well as on research projects is available at: www.forum-fischschutz.de [German].