Fish-ecological monitoring at the hydrodynamic screw "HYDROCONNECT" with "Albrecht fishLift inside" at the Jeßnitz River in Lower Austria

University of Natural Resources and Life Science, Vienna, Austria

Department of Water, Atmosphere and Environment

Institute of Hydrobiology and Aquatic Ecosystem Management

Thesis submitted for the award of the title "Master of Science" (MSc) by:

MAXIM GRIGULL

Vienna, March 2015

Supervised by:

Dipl.-Ing Bernhard ZEIRINGER

Ao.Univ.Prof. Dipl.-Ing. Dr.nat.techn. Stefan SCHMUTZ

Declaration of academic honesty

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

…………………………… ………………………………………………..

Date Signature

Acknowledgement

I would like to thank the Institute of Hydrobiology and in particular Ao.Univ.Prof. Dipl.-Ing. Dr.nat.techn. Stefan Schmutz for the creation of this wonderful Master programme. It gave me the opportunity to study and work with experts in a field of great interest to me.

Especially I want to thank Dipl.-Ing. Bernhard Zeiringer for his exceptional supervision of this thesis, his valuable remarks, constructive discussions and for always having time for me and my requests.

A great thank you goes to Walter Albrecht and his team, who not only invented HYDROCONNECT, but also provided me with shelter during my stays at the Jeßnitz, great knowledge on all concerning matters and cooperation at my stays and during my absence.

Aside from Bernhard and Walter, several other people were involved in this thesis: Armin, Stefan, Robert and Rudi – thank you for your assistance!

The fish farm Füsselsberger near Lunz provided us with two danube salmons for one experiment, thank you for that.

My special thanks go to my family for their never-ending support and also for their endurance, when I once again talk about fish.

My deepest gratitude goes to my wife. Kristina – thank you for improving every single aspect of my life.

Abstract

The river continuum, especially in consideration of longitudinal continuity, is highly impaired worldwide due to manmade transversal structures mostly used for power generation. This affects fish in their life cycle and ultimately results in a decline in fish abundance and species richness. To counter this trend, fish migration facilities must be built at transversal structures. Common attempts are oftentimes not satisfying, as they function only for one direction, are of high construction and maintenance costs, need a lot of space or simply do not work. The invention of HYDROCONNECT, a modified successor of the Archimedean screw, could provide a new solution for small run-of-river powerplants not only in Austria, as fish can migrate unharmed up- and downstream. By conducting two upstream and one downstream migration experiment, the concept of HYDROCONNECT was assessed and verified. All tested fish species and age classes adapt it for migration and are not harmed as to why this invention seems reasonable to reach river continuity for fish.

Kurzfassung

Durch die Errichtung anthropogener Querbauwerke ist das Fließgewässerkontinuum, besonders im Hinblick auf die längswärts gerichtete Passierbarkeit, sehr stark eingeschränkt. Dies beeinträchtigt Fische in ihrem Lebenszyklus und führt zu einem Rückgang der Bestände bis hin zum Verlust von Arten. Um diesem Trend entgegen zu wirken, müssen Fischwanderhilfen an Querbauwerken errichtet werden. Herkömmliche Ansätze sind oftmals nicht zufriedenstellend, da sie nur für eine Richtung konzipiert worden sind, hohe Bau- und Wartungskosten haben, viel Platz brauchen oder schlichtweg nicht funktionieren. Die Erfindung von HYDROCONNECT, einem verbesserten Nachfolger der Archimedes-Schnecke, könnte nicht nur in Österreich ein neuer Lösungsansatz für Fließwasserkraftanlagen sein. Durch zwei Aufstiegs- und ein Abstiegsexperiment wurde das Konzept von HYDROCONNECT überprüft und es konnte gezeigt werden, dass alle getesteten Fischarten und Altersklassen in dieser Strom produzierenden Anlage unbeschadet auf- und abwandern können.

Content

1. Introduction

Originally, lotic (or running) waters were linear systems in equilibrium of flow, where water- and material- transport was possible unhindered from its spring to mouth. This condition was named “River Continuum Concept” by VANOTTE et al (1980). Aquatic organisms could migrate freely with or against the current, depending on their swimming capabilities. This was especially true for fish, as all fish migrate to measurable amounts during their life cycle. This involves movement in annual, seasonal or daily cycles for spawning, dispersion, feeding, shelter and colonization (LARINIER & TRAVADE, 2002). When men began to use waterbodies to their advantage and adapt them to their needs, the lotic continuum was changed and, as a consequence, often destroyed. Particularly measures for flood protection, power generation and perennial navigation divided the former fully passable aquatic systems in single compartments, among which only limited possibilities for fish migration exist nowadays. In Austria, around 28,000 barriers exist in rivers which led to a general degradation of habitat for all aquatic organisms and, as a result, in a decline of species richness (SCHMUTZ, 2011). To counter this trend of degradation and biodiversity loss, river continuity is one of the main issues targeted by the “Directive 2000/60/EC of the European Parliament and the Council establishing a framework for the Community action in the field of water policy” (in short “Water Framework Directive” abbreviated with “WFD”). The WFD demands, among other things, that all waterbodies reach a “good ecological status” or a “good ecological potential” by the latest in 2027 (WFD, 2000). This includes, that transversal structures which interfere with fish migration must be taken down or made passable. As electricity demands keep on rising, the deconstruction of dams and impoundments is not likely to happen. Therefore it is important to find a trade-off between water power generation and fish passability at water powerplants and other transversal structures. Several versions of fish bypasses have been invented in the past, yet they mostly deal with upstream fish migration. Downstream migration becomes more and more prominent and few attempts to deter fish from entering the turbines or the construction of “fish friendly turbines” have already been undertaken. However, it does not solve the problem of river continuity. This holds also true for the Archimedean screw, which is otherwise very suitable for fish migration, as there are no fast moving turbine blades, no cavitation and no shear stress to cause fish injuries. HYDROCONNECT is a modified successor of the original Archimedean screw and was invented by Walter Albrecht in Lower Austria. It is cause of this master thesis and seems to be a very good step towards the goal of river continuity, as it provides power generation and fish migration at once.

The following research questions were used to assess the functioning of HYDROCONNECT in concern of fish migration:

- Do all tested fish species adapt HYDROCONNECT for the migration they are tested for?
- Can the majority of age classes of tested fish species adapt HYDROCONNECT for up- and downstream migration?
- Are fish injured while and after using HYDROCONNECT?
- Does fish migration at HYDROCONNECT work upstream and downstream?

1.1 Aim of this master thesis

The main question of this thesis deals with the fact, whether prevalent fish at the study site, namely brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), bullhead (*Cottus gobio*) and some other tested potamal species can adapt HYDROCONNECT as Fish Migration Aid (FMA) in both directions (upstream and downstream). If they do so, the migrating age classes and chances of injury are of interest.

The importance of a different approach to hydropower generation will be shown by shortly describing average fish mortalities and the reasons at regular turbine types. Furthermore the suitability of HYDROCONNECT for fish migration and water body continuity is explained. Subsequently, the results of the different experiments are described and discussed.

1.2 Study site

The HYDROCONNECT is located in the bioregion Limestone Alps at the altitude category two (200 – 499 m) at the epirithralic Jeßnitz River in Lower Austria (see Figure 1). From its spring to confluence with Erlauf River, the Jeßnitz River has a length of 5 km and a catchment area between 10-100 km^2. Even though seven artificial, impassable transversal structures like weirs and/or groundsills impair fish migration, its biological condition in regard of hydromorphological strain is graded with “good”. The chemical condition is also graded with “good”. Downstream of HYDROCONNECT, only one transversal structure impairs fish migration between the Erlauf River and the Jeßnitz River (see Figure 2).

According to NÖGIS (2014), the Jeßnitz River - officially named Jeßnitz_01 (SB) with waterbody number 411580000 - has no need for action in concern of the Water Framework Directive.

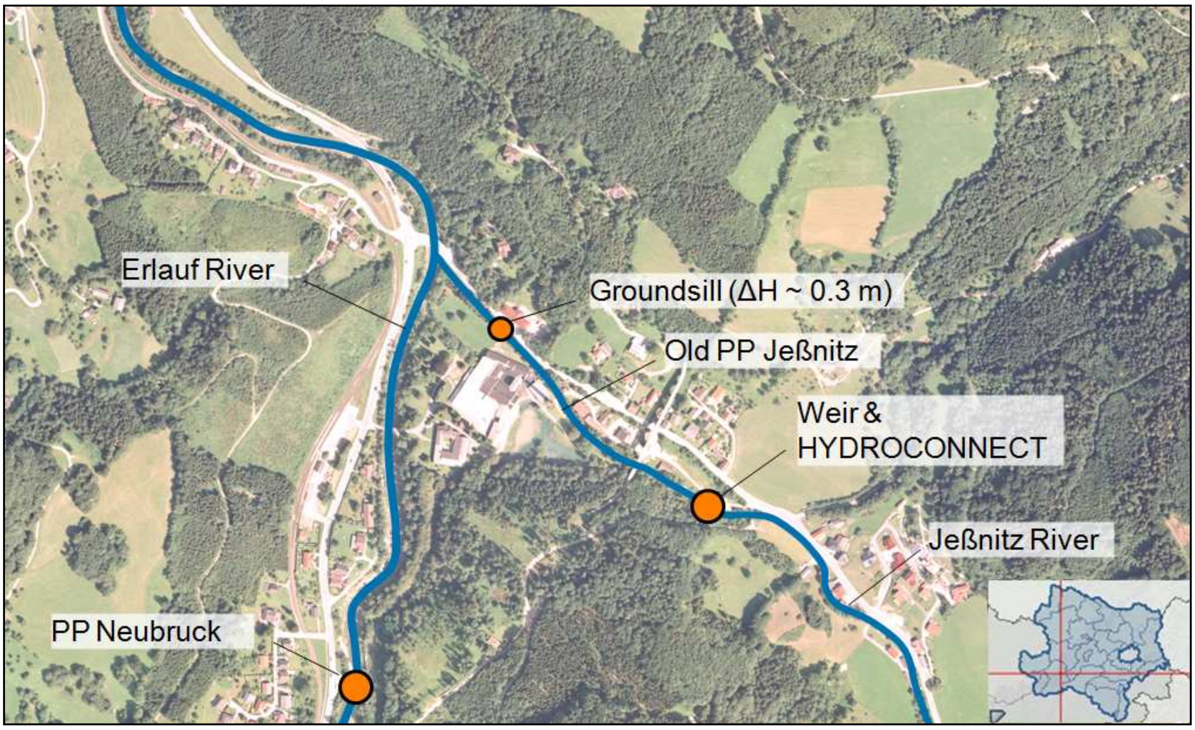

Figure 1: Aerial view of the study site and its situation in Lower Austria (NÖGIS, 2014, modified).

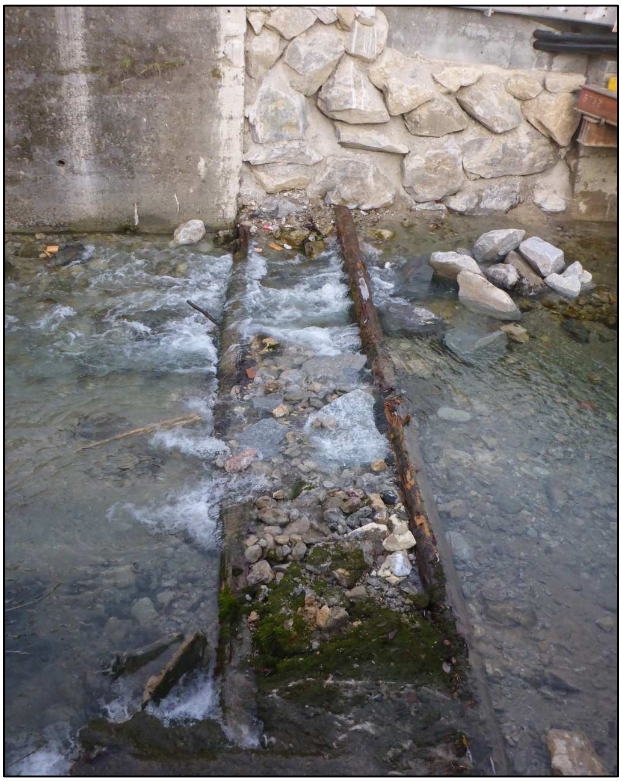

Figure 2: Groundsill downstream of HYDROCONNECT at the Jeßnitz River in Lower Austria. In this picture, it is partly stripped down due to construction work at the bridge 2 m upstream of this groundsill. At the end of construction work, the area between the two logs was again filled with gravel to look like the bottom half of this picture.

1.3 Experimental setup

At the upstream end of the experiment, a containment basin is situated which is connected by a fish slide with the inner tube (Albrecht fishLift inside) of HYDROCONNECT. This way, all upstream migrating fish arrive in the containment basin. The intake channel, which leads water into the outer tube (turbine) of HYDROCONNECT, could be closed by a screen to keep fish from leaving the intake channel on any other way than through the turbine. HYDROCONNECT contains of the already mentioned outer (turbine) and inner (Albrecht fishLift inside) tube which are fixed to each other and have opposite rotations. With its downstream end, the inner tube (Albrecht fishLift inside) is level with the riverbed, to enable migration of non-swimming fish species like the bullhead (*Cottus gobio*).

To be able to rotate, HYDROCONNECT is mounted on a holding device and held by a strap. The current collectors are mounted to the sides of the strap. The outer tube (turbine) is set in motion by the works water from the intake channel. As the outer tube (turbine) is turned by transporting water from higher to lower elevation, it also rotates the inner tube (fishLift) which transports a share of the processed works water back up, over the fish slide into the containment basin. At the downstream end of the setup is an experimental pool, which could also be closed by a screen. This pool can be used to keep fish brought in from other waters or for compact upstream migration experiments.

Fish can migrate in both directions: downstream through the outer tube (turbine) and upstream through the inner tube (Albrecht fishLift inside). Upstream migration is comprehensible by the amount of fish in the containment basin. The setup can be seen in Figure 3 and Figure 4.

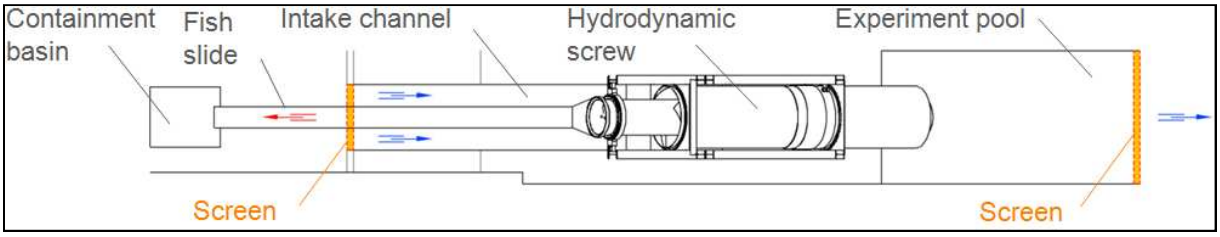

Figure 3: Top view on the experiment setup of HYDROCONNECT. The red arrow indicates waterflow from the inner tube (Albrecht fishLift inside) via the fish slide in the containment basin, the blue arrows indicate waterflow downstream (ZEIRINGER, 2014).

Figure 4: Aerial view on the study site HYDROCONNECT at the Jeßnitz River in Lower Austria (ZEIRINGER, 2014).

2. Methods

2.1 Literature search

Literature search was conducted by screening existing literature. Internet search with the keywords river continuum, hydrodynamic screw, fish migration, fish friendly, fish mortality, run-of-river powerplants, brown trout migration and several combinations of the above mentioned returned useful results.

2.2 Biomass calculation

To calculate the biomass per hectare (ha) one must know the fished area, abundance and weight of the fish. The fished area was identified using an aerial photo of the Jeßnitz in AutoCAD 2014. Further processing was done in Microsoft Excel 2007.

2.2.1 Abundance

The abundance was estimated by electro fishing with a portable device via the Seber & LeCren two-catch method (1967). This method is subject to several conditions, which are:

- The first catch needs to have a significant effect on the population and the second catch is therefore smaller than the first
- The fishing effort has to be the same for both catches. Fish, which could not be caught in the first catch, must be as likely to capture as the ones caught in the first fishing.
- No immigration, emigration, mortality or recruitment of fish between the two fishings
- The first catch must be removed from the population or marked, to be distinguishable from the second catch
- The whole population must be available

The stock size ($N_{calc.}$) can then be calculated by the two catches (C_1 and C_2) via the following formula:

$$N_{calc.} = \frac{C_1^2}{C_1 - C_2}$$

To apply this method, the water body was subdivided into three sections: Headwater, head of reservoir and tailwater. Fish could not migrate from one stretch to another during the fishing, as the tailwater is always blocked with a weir at the upstream end and the head of reservoir and headwater are blocked by a ground sill. Sampling started downstream and each stretch was sampled individually.

The headwater and the head of the reservoir were sampled only once, as these two sections are significantly shorter than the tailwater section. This section was sampled twice. The fish were counted, determined at species level and measured in length. The weight was not taken to speed up the process and keep stress for the fish at a minimum. When only one run took place, the catch success was estimated and then applied as second catch. To clarify, this is explained for the headwater stretch: In the first fishing, 154 individuals were caught with a fishing success of around 90 %. As no second fishing took place, 15 fish were thought to be the second catch (10 % of 154 individuals), resulting in a total of 169 individuals for this stretch.

The calculated individuals per hectare ($cal.\ Ind._{ha}$) were estimated as following:

$$cal.\ Ind._{ha} = \frac{N_{calc.}}{Fished\ area} * 10000$$

where $cal.\ Ind._{ha}$ = calculated individuals [ha]; $N_{calc.}$ = stock size [Ind.]; $Fished\ area$ = fished area [m²].

The stock for each different fish species was calculated using

$$\frac{Ind._{\%} * cal.\ Ind._{ha}}{100}$$

where $Ind._{\%}$ = share of caught individuals per species on total catch [%]; $cal.\ Ind._{ha}$ = calculated individuals [ha].

2.2.2 Weight

Different formulas were taken to calculate the average weight of each fish. These formulas are:

For brown trout (*Salmo trutta*)

$$1.4 * 10^{-5} * Fish\ length^{2.9381}$$

For rainbow trout (*Oncorhynchus mykiss*)

$$1.7 * 10^{-5} * Fish\ length^{2.9056}$$

Using these formulas, one gets an average weight for each fish by using its length. The formulas were applied to every fish caught but bullhead (Cottus gobio), as this species was only assessed quantitatively. By summing up all weights of one fish species, the total biomass per species and fished stretch was conducted.

2.2.3 Biomass

The total biomass per fished stretch ($B_{tot.}$) was again calculated using a formula developed by Seber & LeCren (1967):

$$B_{tot.} = \frac{B_{cap.}}{N_{tot.}} * N_{calc.}$$

where $B_{tot.}$ = total biomass per fished stretch; $B_{cap.}$ = captured biomass; $N_{tot.}$ = total catch; $N_{calc.}$ = calculated Stock.

The total biomass per fished stretch ($B_{tot.}$) was then up-scaled to meet 1 hectare.

2.3 Upstream migration experiment

The experiment took place between 8th and 23rd of November 2013, during spawning season of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). This is due to the fact that during spawning season, the fish are motivated and willing to migrate to the headwaters for reproduction. The experiment was conducted without a screen to block the entrance to the turbine in the tailwater (compare Figure 3, Figure 4). That way, free fish migration was possible. Quantitative electro-fishing was done in the tailwater, the head of reservoir and in the headwater of HYDROCONNECT with portable devices. Caught species were

- brown trout (*Salmo trutta*)
- rainbow trout *(Oncorhynchus mykiss)*
- bullhead (*Cottus gobio*)

with brown trout (*Salmo trutta*) and bullhead (*Cottus gobio*) being key species. All fish were determined, measured, checked for injuries and released in the tailwater to enable possible upstream migrations. Around 50 % of the brown trout (*Salmo trutta*) and rainbow trout *(Oncorhynchus mykiss)* taken from the headwater were tagged with Visible Implant Elastomer (see Figure 5), to distinguish them from the fish caught in the tailwater. Upstream migrating fish end up in the containment basin, where they were taken out with a dip net. They got determined and measured again and checked for injuries like loss of scales, flesh wounds, bruises or scratches, then released back into the tailwater of HYDROCONNECT, to see whether they would ascend once more.

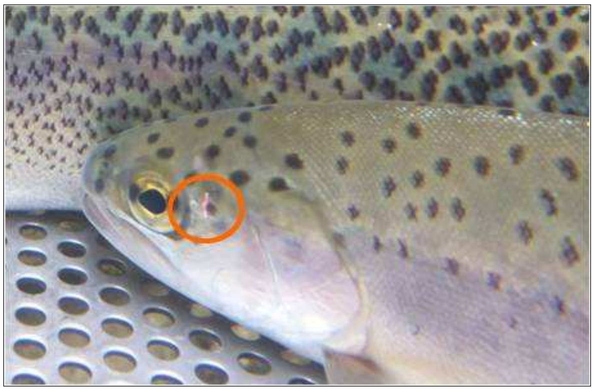

Figure 5: Visible Implant Elastomer tag on a rainbow trout (Oncorhynchus mykiss) caught via electro-fishing in the time span of 8th to 23rd Nov. 2013 in the River Jeßnitz.

2.3.1 Upstream migration experiment with potamal fish species

This experiment took place between 8th and 14th of December 2013. The experimental design differed to the previously explained upstream migration experiment only in terms of a closed experiment-pool and the fish species used. Due to the closed screen at the experiment pool, fish could not exit the pool but through the inner tube of HYDROCONNECT.

The fish for this setup were caught in the Marchfeldkanal and Rußbach in Lower Austria on 10th of December 2013 via electrofishing by boat. Caught species were

- barbel (*Barbus barbus*)
- nase (*Chondrostoma nasus)*
- chub (*Squalius cephalus*)
- roach (*Rutilus rutilus*)
- pike (*Esox lucius*)

Two danube salmon (*Hucho hucho*) were borrowed from the fish farm “Füsselsberger” near Lunz am See.

All fish were stocked in the closed experiment pool as soon as possible to reduce the stress caused by transportation. After concluding the experiment, all fish were released in the waters they came from.

2.4 Downstream migration experiment

The purpose of this experiment was to prove the unharmed downstream migration of different fish species and life stages. This was done by conducting the following two experiments.

2.4.1 Pretest

The pretest took place between 18th and 20th of December 2013 in order to verify whether downstream migration of rithralic species at HYDROCONNECT is feasible or not. The experiment setup was as shown in Figure 3 and Figure 4 with closed screens at the intake channel and the experiment pool. This way, the stocked fish could not escape while the experiment lasted. Before testing, the intake channel and experiment pool were fished with electro fishing to clear them of fish. Subsequently, the intake channel was stocked with brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*) and one bullhead (*Cottus gobio*) which were caught via electro fishing. Following this step, the containment basin was cleared of fish. In the following hours, the containment basin was regularly checked for fish. The experiment was concluded after the first fish were present in the containment basin, as this verified upstream migration and preliminary downstream migration.

2.4.2 Experiment

This experiment was conducted with the same setup and species as shown in chapter 2.4.1 Pretest. In addition, video cameras were installed below the water surface at the intake channel and experiment pool to record the behavior of fish during the whole experiment. As long as the experiment lasted, fish which appeared in the containment basin were determined, measured, noted and put in the intake channel for possible further downstream migrations. The experiment was concluded by electro fishing at the intake channel and experiment pool and by clearing the containment basin of any fish present. This way, the whole downstream migration was quantifiable.

2.5 Hydromorphology

To be able to depict the hydromorphology of the Jeßnitz below HYDROCONNECT, the experiment pool and its outlet have been divided into several transects which had their flow velocity and depth mapped using an Electromagnetic Flow Meter and the multi-dot-method on 10th of February 2014. The transects directly downstream of the inner tube were sampled every 0.2 m, starting from the orographic right bank. Every 0.2 m, the velocities at the water surface, at 80 %, 40 % and 20 % water depth were measured ($v_{100\%}$, $v_{80\%}$, $v_{40\%}$, $v_{20\%}$). For $v_{0\%}$, the velocity was calculated using the formula $v_{0\%} = 0.5 * v_{20\%}$, as the probe for measuring the flow velocity could not be placed directly on the ground.

For each of these water depths ($v_{100\%}$ to $v_{0\%}$), three different parameters were assessed:

- Sample point X [m]
- Depth Y [m]
- Flow velocity Z [m/s]

resulting in a total of 120 measurements for each of the first three transects.

As the works water which exits the outer tube is the attraction flow for the inner tube, short distances of 0.5 m between the transects were chosen to depict the zone directly downstream of HYDROCONNECT precisely. The first three transects have a distance of 0.5 m to each other with the first transect being directly at the downstream end of the inner tube. Transect four was mapped 1 m downstream of transect three, as the turbulences which were caused by the works water already decreased to moderate amounts at that distance from the inner tube. That is why the assessment was done using larger steps between each measurement point from here on.

The correction and cleaning of the data took place in Microsoft Excel 2007, the actual modeling was conducted by Bernhard Zeiringer using the Surfer Software. Further processing was done by him in AutoCAD 2014.

The full assessment with all eight transects is listed in Table 4 to Table 11 in the Annex.

3. Results

3.1 Literature search

Common turbines are not considered compatible with fish and therefore need additional devices to keep the fish out of the turbine, resulting in additional costs and maintenance. On average, Pelton turbines have a mortality rate of 100 %. They are, however, rarely used in run-of-river power plants. Francis turbines have an average mortality of 37 % and Kaplan turbines reach an average mortality of around 9 %. These numbers depend on the characteristics of the turbine, its functioning, the height difference as well as fish size (TRAVADE & LARINIER, 1990).

Archimedean screws, named after its presumable inventor Archimedes of Syracuse (287 BC to 212 BC), were originally used to transport water from one point to another, mostly to overcome height differences for irrigation or drainage purposes. Water was transported by turning a surface, which is shaped as a screw, in a hollow tube. Whenever the screw was turned, water was moved (OLESON, 2008). The reverse of its original functioning, namely driving the turbine by water, makes power generation with this type of turbine possible. “Since 2001, Archimedean screws have been used for commercial power generation” (LASHOFER et al., 2013). Archimedean screws for power generation are an “ultra-low-head technology” and “still a niche product”, their average efficiency is around 69 %, ranging up to 75 % at peak performance (LASHOFER et al., 2011), and can be considered compatible with fish (SPÄH, 2001; FISHTEK, 2007; SCHMALZ, 2010). However, roach, (*Rutilus rutilus*), bream (*Abramis brama*) and tench (*Tinca tinca*) experienced injuries which, according to SCHMALZ (2010), can be connected to the clearance, the length of the Archimedean screw and the diameter.

The clear advantages of Archimedean screws in comparison to common turbine types are less construction effort and less space requirements, therefore rapid amortization, low maintenance costs (ANDRITZ-ATRO, 2014), and its overall fish compatibility.

HYDROCONNECT

HYDROCONNECT provides all the advantages of Archimedean screws, but none of its disadvantages. There is no clearance between the outer shell and the screw which leaves almost no possibility for fish to get harmed. The lack of clearance also prevents possible jamming by woody debris or ice. Regular amounts of bed load can pass HYDROCONNECT with ease. As the turbine rotates with very few rounds per minute (rpm) (13 to 22 rpm at around 200 l/s during the trial phase), regular amounts of bed load do not damage the turbine (ALBRECHT, 2013).

3.2 Biomass calculation

The electro-fishing took place on 8th and 18th of November 2013. The fished area is listed in Table 1.

Table 1: By electro-fishing fished sections at the Jeßnitz River in Lower Austria on 8th and 18th of November 2013 (rounded values).

fished sections at the Jeßnitz	width [m]	length [m]	fished area [m²]
headwater	6	127	**760**
head of reservoir	9	47	**419**
tailwater	6	218	**1308**
∑ sum	21	391	**2486**

For the headwater section, a total of 154 individuals were caught which leads to a calculated biomass of 254 kg/ha for the headwater section. In the head of reservoir, directly upstream of HYDROCONNECT, 71 individuals got caught which amounts in a calculated biomass of 112 kg/ha for this section. A total of 221 individuals were caught in the tailwater which leads to a calculated 108 kg/ha for the tailwater section. At the fished area of 2486 m², a total of 446 individuals were caught. This amounts in a calculated biomass of 474 kg/ha for the concerned sections at the Jeßnitz River (see Table 2).

Table 2: Caught individuals by electro-fishing at the three defined sections of the Jeßnitz River in Lower Austria and resulting calculations for individuals/hectare and biomass in kg/hectare. Rounded values for all calculations. Electro-fishing took place on 8th and 18th of November 2013. Biomass was not calculated for bullhead.

sections	fish species caught	ind. caught [n]	share [%]	calc. ind [n/ha]	calc. biomass [kg/ha]
headwater	bullhead (*Cottus gobio*)	15	10	219	n.a.
	brown trout (*Salmo trutta*)	66	43	965	96
	rainbow trout (*Onchorhynchus mykiss*)	73	47	1067	158
	headwater total	**154**	**100**	**2251**	**254**
head of reservoir	bullhead (*Cottus gobio*)	28	39	745	n.a.
	brown trout (*Salmo trutta*)	28	39	745	61
	rainbow trout (*Onchorhynchus mykiss*)	15	21	399	51
	head of reservoir total	**71**	**100**	**1889**	**112**
tailwater	bullhead (*Cottus gobio*)	37	17	289	n.a.
	brown trout (*Salmo trutta*)	157	70	1227	92
	rainbow trout (*Onchorhynchus mykiss*)	27	12	211	16
	tailwater total	**221**	**100**	**1727**	**108**

3.3 Upstream migration experiment

The abundances and length classes of the 446 caught fish (Table 2), which were subsequently stocked in the tailwater of HYDROCONNECT to conduct this experiment, are shown in the following Length-Frequency-Diagrams for each species and catch area respectively.

Fish from the tailwater

157 individuals of brown trout (*Salmo trutta*), ranging from >50 mm to <500 mm in length, were stocked below HYDROCONNECT (see Figure 6).

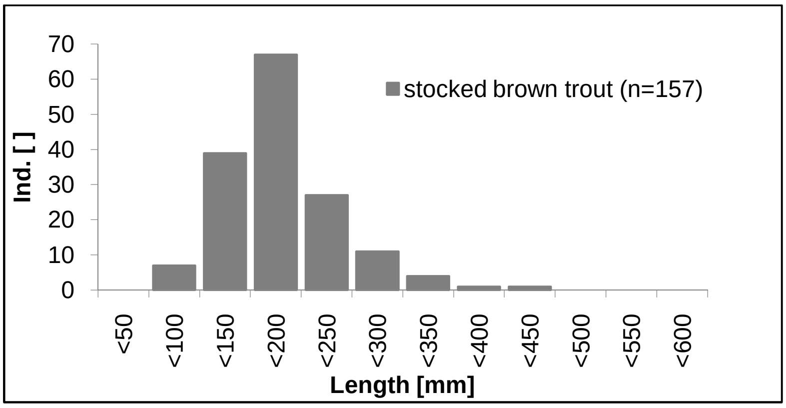

Figure 6: Length-Frequency-Diagram of brown trout (Salmo trutta), caught in the tailwater and subsequently stocked below HYDROCONNECT at the Jeßnitz River in Lower Austria on 8th of November 2013.

27 individuals of rainbow trout (Oncorhynchus mykiss), ranging from >100 mm to <400 mm in length, were stocked below HYDROCONNECT (see Figure 7).

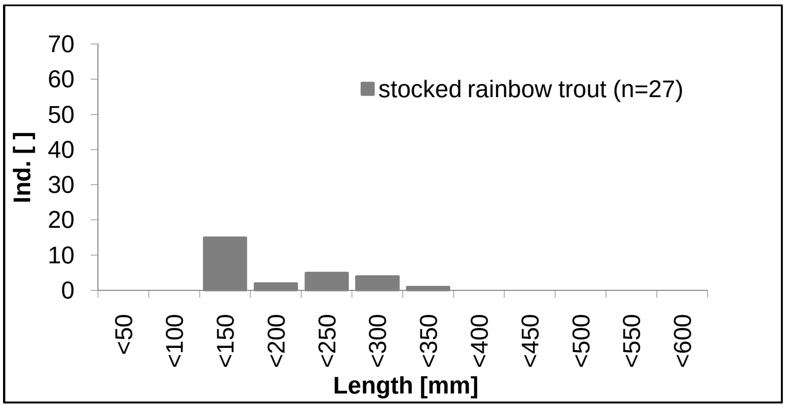

Figure 7: Length-Frequency-Diagram of rainbow trout (Oncorhynchus mykiss), caught in the tailwater and subsequently stocked below HYDROCONNECT at the Jeßnitz River in Lower Austria on 8th of November 2013.

37 individuals of bullhead (Cottus gobio), ranging from >40 mm to <130 mm in length, were stocked below HYDROCONNECT (see Figure 8).

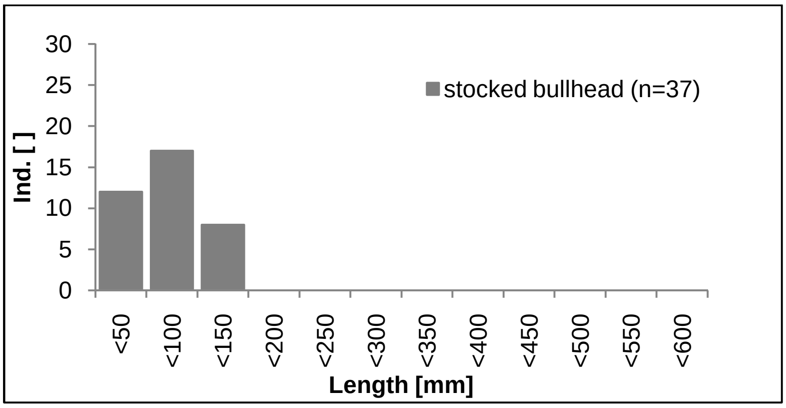

Figure 8: Length-Frequency-Diagram of bullhead (Cottus gobio), caught in the tailwater and subsequently stocked below HYDROCONNECT at the Jeßnitz River in Lower Austria on 8th of November 2013.

Fish from the headwater and head of reservoir

93 individuals of brown trout (*Salmo trutta*), ranging from >50 mm to <400 mm in length, were stocked below HYDROCONNECT. 53 of these individuals were caught on 8th of November 2013, of which 28 got tagged with Visible Implant Elastomer. 40 got caught on 18th of November 2013. All fish caught on the second date got tagged. Each fish was released directly after its catch, leading to two stocking dates (see Figure 9).

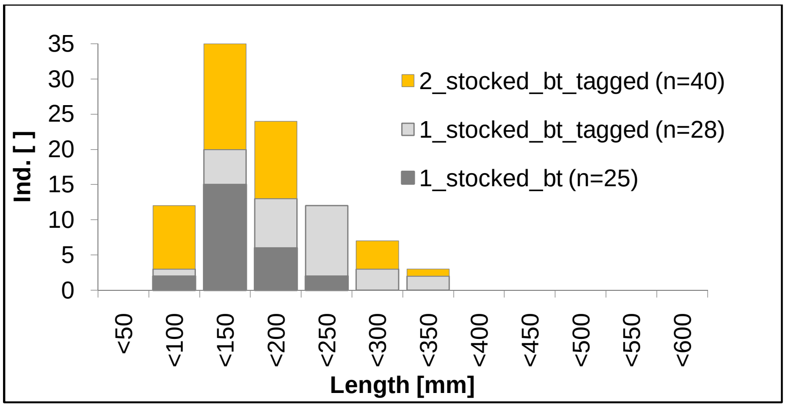

Figure 9: Length-Frequency-Diagram of brown trout (Salmo trutta), caught in the headwater and head of reservoir and subsequently stocked below HYDROCONNECT at the Jeßnitz River in Lower Austria on 8th (1) and 18th (2) of November 2013. Some of the individuals got tagged with Visible Implant Elastomer. n_{total} = 93.

86 individuals of rainbow trout (*Oncorhynchus mykiss*), ranging from >100 mm to <450 mm in length, were stocked below HYDROCONNECT. 61 animals were caught on 8th of November 2013, of which 33 got tagged. 25 pieces got caught on 18th of November. All of them got tagged (see Figure 10).

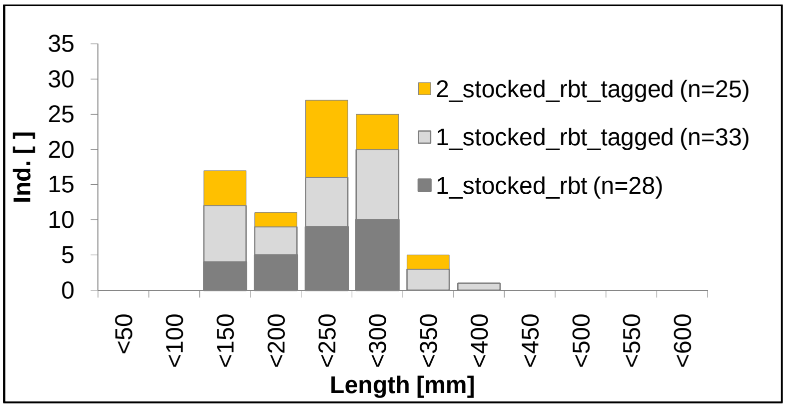

Figure 10: Length-Frequency-Diagram of rainbow trout (Oncorhynchus mykiss), caught in the headwater and head of reservoir and subsequently stocked below HYDROCONNECT at the Jeßnitz River in Lower Austria on 8th (1) and 18th (2) of November 2013. Some of the individuals got tagged with Visible Implant Elastomer. n_{total} = 86.

43 individuals of bullhead (*Cottus gobio*), ranging from >50 mm to <200 mm in length, were stocked below HYDROCONNECT. 13 animals were caught on 8th of November 2013; all 30 individuals of the second catch on 18th of November 2013 were tagged (see Figure 11).

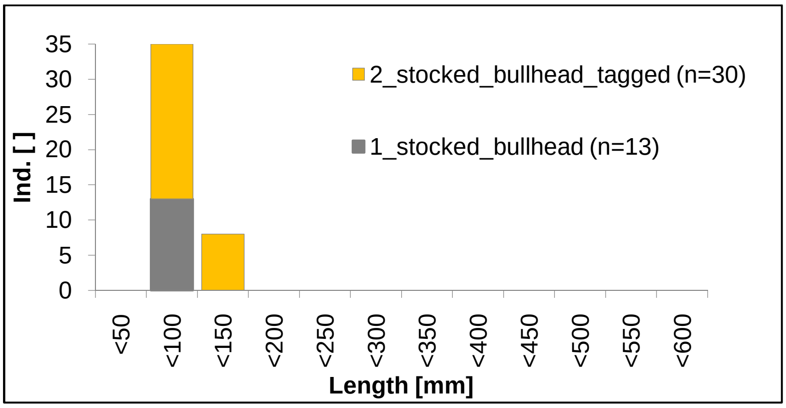

Figure 11: Length-Frequency-Diagram of bullhead (Cottus gobio), caught in the headwater and head of reservoir and subsequently stocked below HYDROCONNECT at the Jeßnitz River in Lower Austria on 8th (1) and 18th (2) of November 2013. The second catch was tagged with Visible Implant Elastomer. n_{total} = 43.

Upstream migration

Of the stocked 446 fish, 69 individuals migrated upstream through the inner tube (fishLift) of HYDROCONNECT in the timespan of November 8th to 23rd of November 2013. In total, this amounts to 15.5 % of all stocked fish within 15 days. That is equivalent to more than one percent per day. Of these 69 individuals, 38 were brown trout (*Salmo trutta*) (total share of 55 %: 45 % between 8th and 17th of November 2013, 55 % between 18th and 23rd of November 2013), 25 rainbow trout (*Oncorhynchus mykiss*) (total share of 36 %: 44 % between 8th and 17th of November 2013, 56 % between 18th and 23rd of November 2013) and 6 bullhead (*Cottus gobio*) (total share of 9 %: 33 % between 8th and 17th of November 2013, 67 % between 18th and 23rd of November 2013). Fish in the containment basin got checked for injuries like loss of scales, flesh wounds, bruises or scratches. None of the aforementioned occurred. The Length-Frequency-Diagrams for each species are shown in Figure 12 to Figure 14.

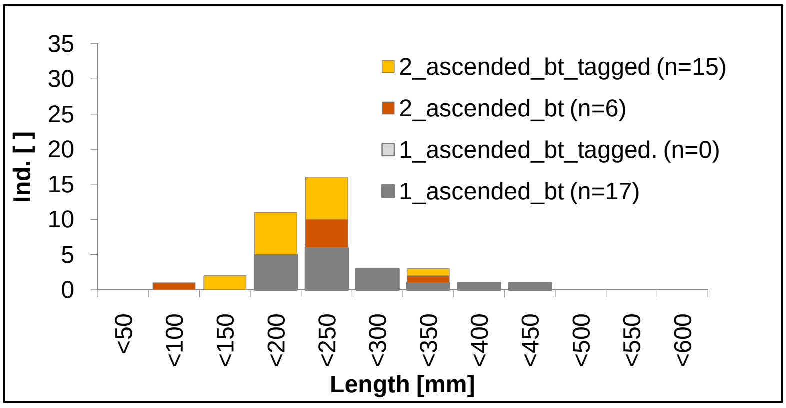

Figure 12: Length-Frequency-Diagram of upstream migrating brown trout (Salmo trutta) (bt) using HYDROCONNECT at the Jeßnitz River in Lower Austria between 8th and 17th (1) and 18th to 23rd (2) of November 2013. n_{total} = 38.

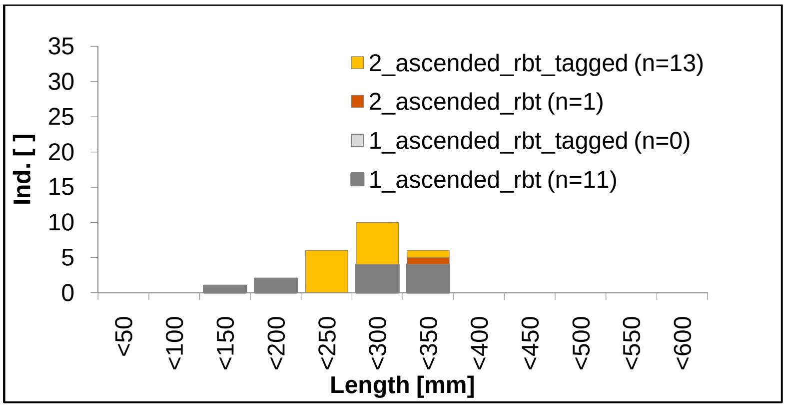

Figure 13: Length-Frequency-Diagram of upstream migrating rainbow trout (Oncorhynchus mykiss) (rbt) using HYDROCONNECT at the Jeßnitz River in Lower Austria between 8th and 17th (1) and 18th to 23rd (2) of November 2013. n_{total}l = 25.

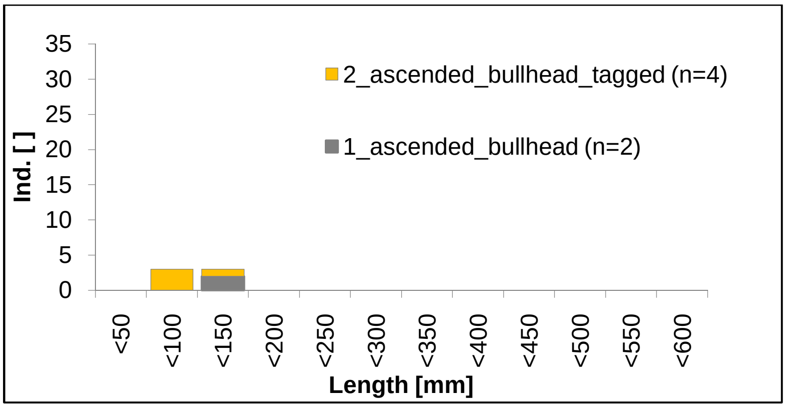

Figure 14: Length-Frequency-Diagram of upstream migrating bullhead (Cottus gobio) using HYDROCONNECT at the Jeßnitz River in Lower Austria between 8th and 17th (1) and 18th to 23rd (2) of November 2013. n_{total} = 6.

3.3.1 Upstream migration experiment with potamal fish species

All caught fish from the Marchfeldkanal and Rußbach were subsequently stocked in the closed experiment pool downstream of HYDROCONNECT. Their upstream migrations are listed in Table 3.

A total of 76 % of the stocked individuals used HYDROCONNECT to migrate upstream at least once. The according Length-Frequency diagrams are shown in Figure 15 to Figure 26. None of the upstream migrating fish was hurt during the process of migration.

Table 3: Caught fish via electro-fishing in the Marchfeldkanal and Rußbach on 10th of March 2014. The abundance of each species as well as the concerning ascends and re-ascends and the respective shares are listed. Rounded values for the shares.

Fish species	Stocked ind. [n]	Share [%]	Ascend [n]	Share [%]	Re-ascend [n]	Share [%]
chub (*Squalius chephalus*)	11	33	5	45		
barbel (*Barbus barbus*)	9	27	9	100	8	89
nase (*Chondrostoma nasus)*	8	24	8	100	5	63
danube salmon (*Hucho hucho*)	2	6	1	50	1	100
roach (*Rutilus rutilus*)	2	6	1	50		
pike (*Esox lucius*)	1	3	1	100		
∑ Sum	***33***	**100**	***25***	**76**	***14***	**56**

Eleven chub (*Squalius chephalus*), ranging from >300 mm to <500 mm in length, were stocked in the closed experiment pool below HYDROCONNECT (see Figure 15). Five individuals (45 %) used HYDROCONNECT to migrate upstream (see Figure 16).

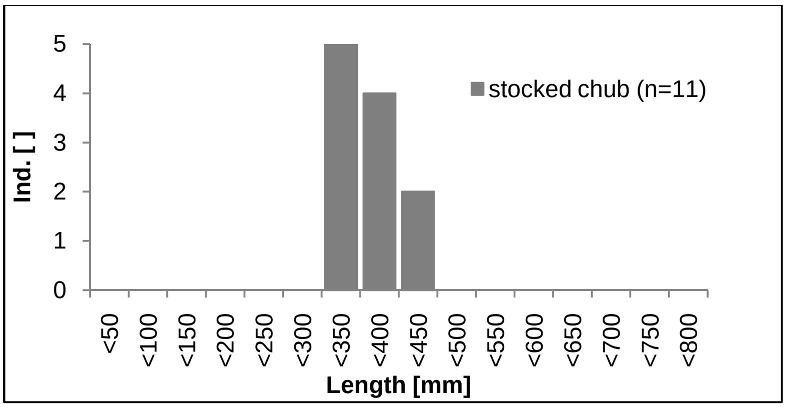

Figure 15: Length-Frequency-Diagram of chub (Squalius chephalus), caught at the Marchfeldkanal and Rußbach in Lower Austria and stocked in the closed experiment pool downstream of HYDROCONNECT on 10th of December 2014.

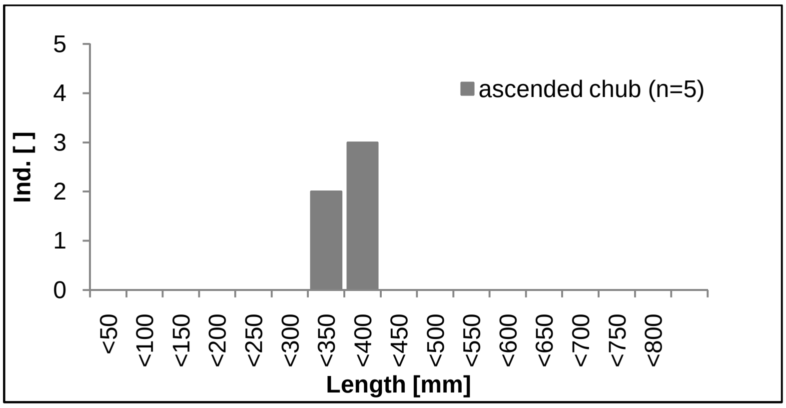

Figure 16: Length-Frequency-Diagram of upstream migrating chub (Squalius chephalus) using HYDROCONNECT at the Jeßnitz River in Lower Austria between 10th and 15th of December 2014.

Nine barbel (*Barbus barbus*), ranging from >350 mm to <750 mm in length, were stocked in the closed experiment pool below HYDROCONNECT (see Figure 17). All nine individuals (100 %) used HYDROCONNECT to migrate upstream, eight individuals (89 %) migrated upstream twice (see Figure 18).

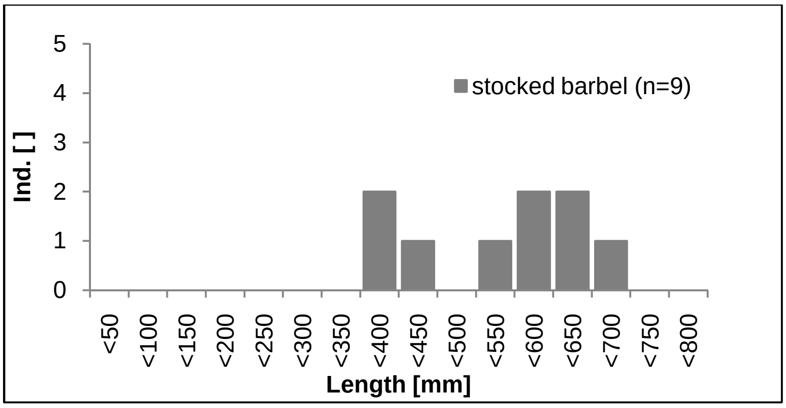

Figure 17: Length-Frequency-Diagram of barbel (Barbus barbus), caught at the Marchfeldkanal and Rußbach in Lower Austria and stocked in the closed experiment pool downstream of HYDROCONNECT on 10th of December 2014.

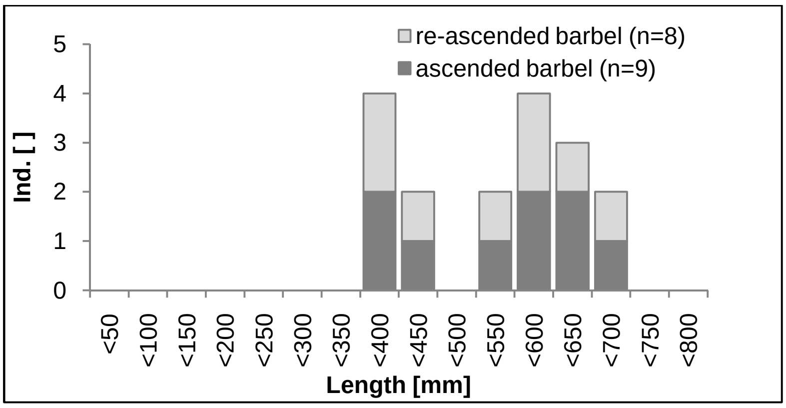

Figure 18: Length-Frequency-Diagram of upstream migrating barbel (Barbus barbus) using HYDROCONNECT at the Jeßnitz River in Lower Austria between 10th and 15th of December 2014. Re-ascended means they migrated upstream more than once. n_{total} = 17.

One pike (*Esox lucius*), with a length of 330 mm, was stocked in the closed experiment pool below HYDROCONNECT (see Figure 19). It used HYDROCONNECT to migrate upstream (see Figure 20).

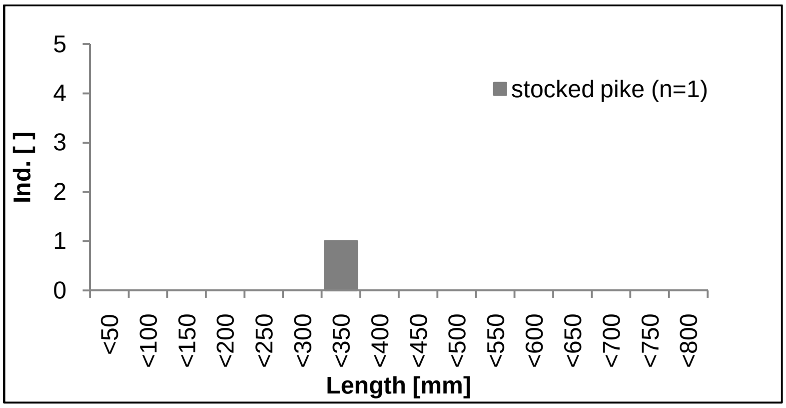

Figure 19: Length-Frequency-Diagram of pike (Esox lucius), caught at the Marchfeldkanal and Rußbach in Lower Austria and stocked in the closed experiment pool downstream of HYDROCONNECT on 10th of December 2014.

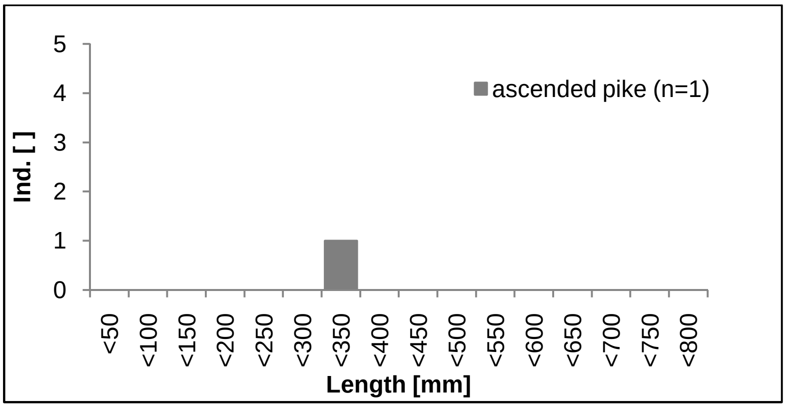

Figure 20: Length-Frequency-Diagram of upstream migrating pike (Esox lucius) using HYDROCONNECT at the Jeßnitz River in Lower Austria between 10th and 15th of December 2014. n_{total} = 1.

Two danube salmon (*Hucho hucho*), with 590 mm and 680 mm in length, were stocked in the closed experiment pool below HYDROCONNECT (see Figure 21). One individual (50 %) used HYDROCONNECT to migrate upstream twice (see Figure 22).

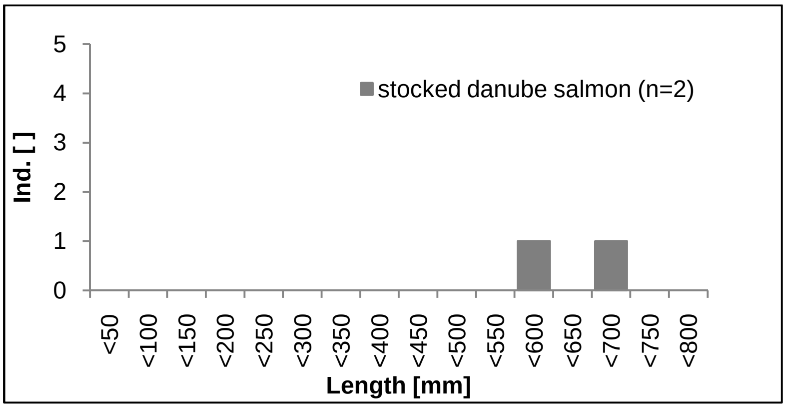

Figure 21: Length-Frequency-Diagram of danube salmon (Hucho hucho), from the fish farm “Füsselsberger”, stocked in the closed experiment pool downstream of HYDROCONNECT on 10th of December 2014.

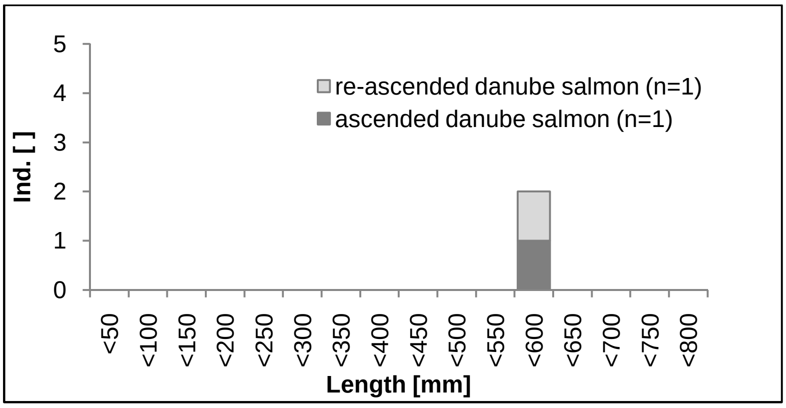

Figure 22: Length-Frequency-Diagram of upstream migrating danube salmon (Hucho hucho) using HYDROCONNECT at the Jeßnitz River in Lower Austria between 10th and 15th of December 2014. Re-ascentded means they migrated upstream more than once. n_{total} = 2.

Eight nase (*Chondrostoma nasus*), ranging from >200 mm to <600 mm in length, were stocked in the closed experiment pool below HYDROCONNECT (see Figure 23). All eight individuals (100 %) used HYDROCONNECT to migrate upstream, five individuals (63 %) migrated upstream twice (see Figure 24).

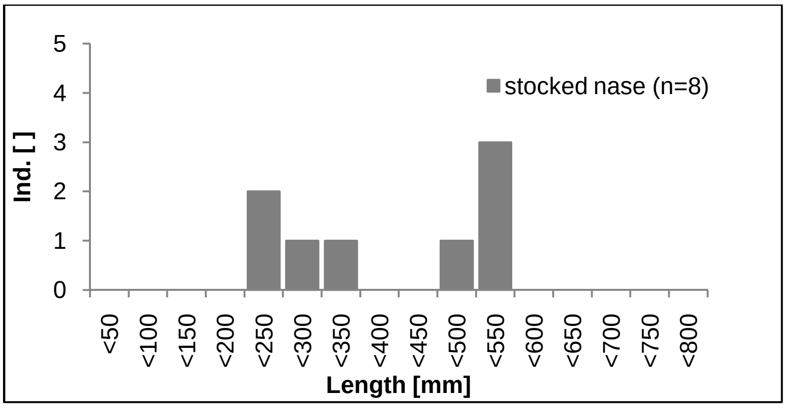

Figure 23: Length-Frequency-Diagram of nase (Chondrostoma nasus), caught at the Marchfeldkanal and Rußbach in Lower Austria and stocked in the closed experiment pool downstream of HYDROCONNECT on 10th of December 2014.

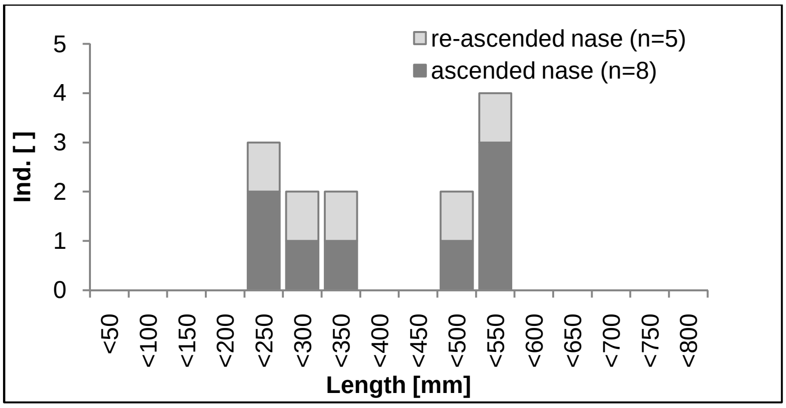

Figure 24: Length-Frequency-Diagram of upstream migrating nase (Chondrostoma nasus) using HYDROCONNECT at the Jeßnitz River in Lower Austria between 10th and 15th of December 2014. Re-ascent means they migrated upstream more than once. n_{total} = 13.

Two roach (*Rutilus rutilus*), each with 120 mm in length, were stocked in the closed experiment pool below HYDROCONNECT (see Figure 25). One individual (50 %) used HYDROCONNECT to migrate upstream (see Figure 26).

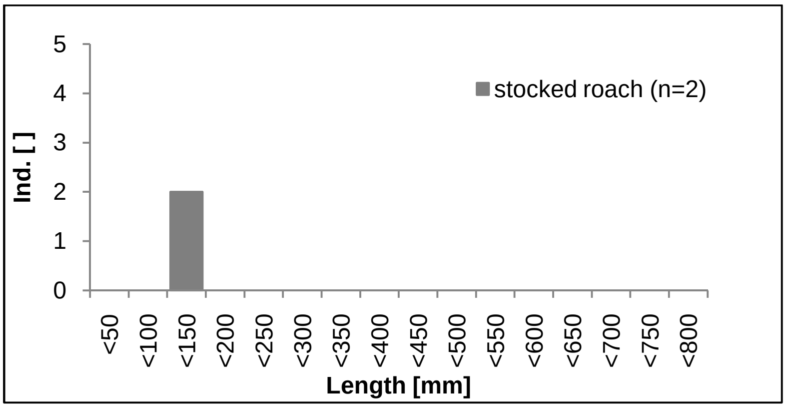

Figure 25: Length-Frequency-Diagram of roach (Rutilus rutilus), caught at the Marchfeldkanal and Rußbach in Lower Austria and stocked in the closed experiment pool downstream of HYDROCONNECT on 10th of December 2014.

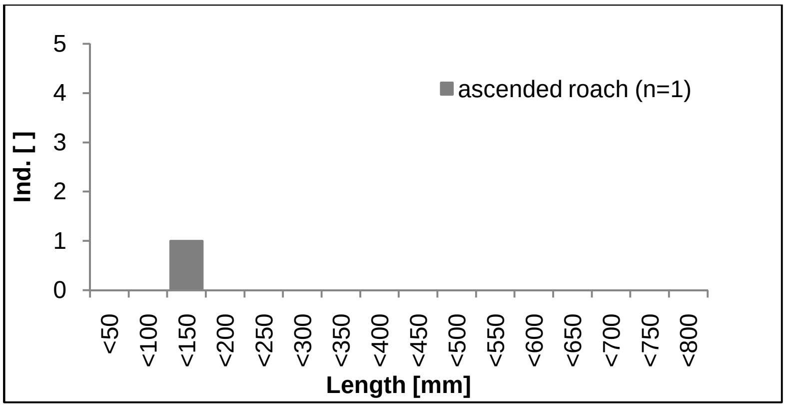

Figure 26: Length-Frequency-Diagram of upstream migrating roach (Rutilus rutilus) using HYDROCONNECT at the Jeßnitz River in Lower Austria between 10th and 15th of December 2014. n_{total} = 1.

3.3.2 Total upstream migrations

During the whole operation of HYDROCONNECT from 20th of October 2013 to 29th of April 2014, a total of 115 individuals migrated upstream freely (see Figure 27). Of these, 72 animals (62.6 %) were brown trout (*Salmo trutta*), 33 individuals (28.7 %) were rainbow trout (*Oncorhynchus mykiss*) and ten animals (8.7 %) were bullhead (*Cottus gobio*). All but one of these migrations happened with open screens while the system was freely passable. Considering the stocked 446 individuals, this is a share of more than 25 %. The ascend of one brown trout (*Salmo trutta*) during the upstream migration experiment with potamal fish species results in a total upstream migration of 40 individuals during that compact experiment. Considering the 33 stocked individuals, this is a share of 118 %, as some of the stocked individuals ascended twice.

3.3.3 Grading of upstream migration

On a scale of one to five, where one is the best and five is the worst possible grade, the qualitative upstream migration in regard to species and life stages can be graded with one – meaning it is fully functional and all tested fish species and life stages can migrate upstream. This holds true for not only the key species brown trout (*Salmo trutta*) and bullhead (*Cottus gobio*), but also for the non-native rainbow trout (*Oncorhynchus mykiss*).

Using the same scale, the quantitative upstream migration in regard to amount of upstream migrating species and short distance migrants can be graded with two to three – meaning it is functional, as many individuals who want to migrate upstream are able to do so.

A more detailed grading can be seen in Table 12 in the Annex.

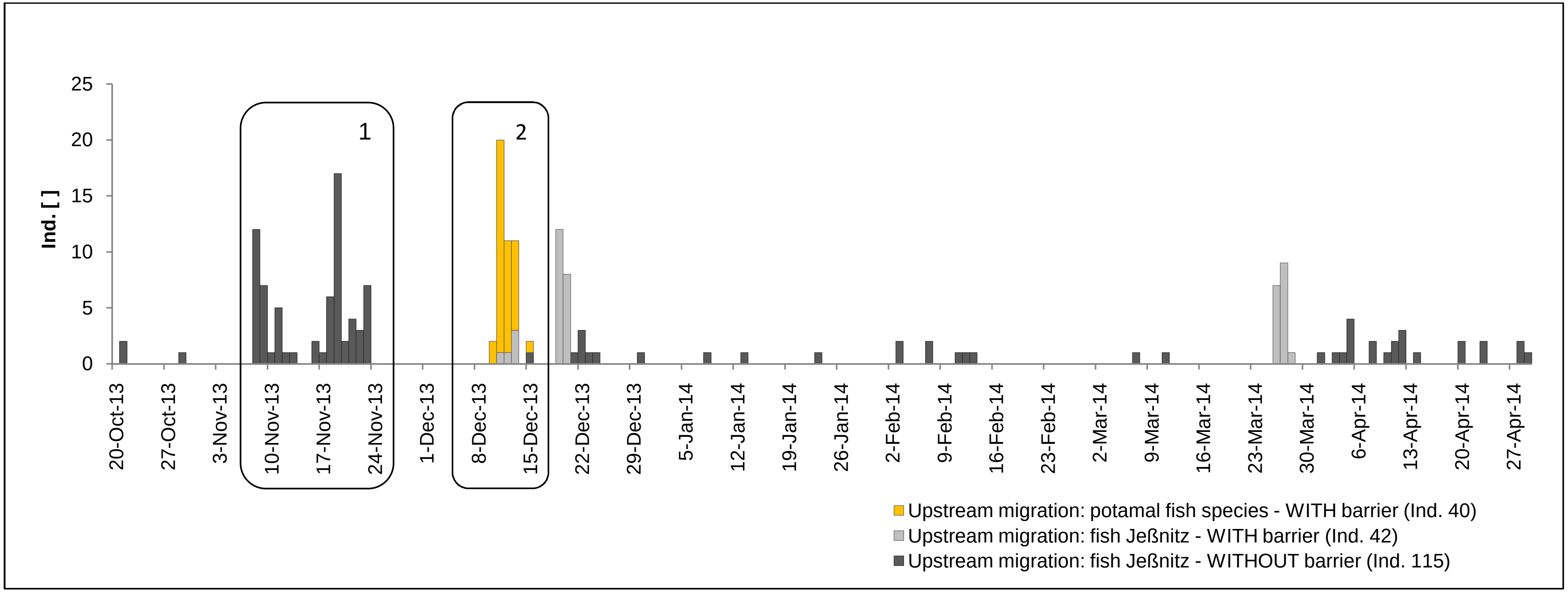

Figure 27: Total upstream migrations during the operation of HYDROCONNECT. Upstream migration experiment was conducted on 8th to 23rd of November 2013 (box one, 69 upstream migrations). The upstream migration experiment with potamal fish species (yellow, box two, 40 upstream migrations) was done on 10th to 15th of November 2013. Upstream migration with barrier shows the individuals which migrated upstream either during the potamal fish experiment or during the downstream migration pretest and experiment between 10th to 14th of December 2013 and 26th to 27th of March 2014.

3.4 Downstream migration experiment

3.4.1 Pretest

During the pretest, a total of 61 individuals (47 brown trout (*Salmo trutta*), 13 rainbow trout (*Oncorhynchus mykiss*) and one bullhead (*Cottus gobio*)) were stocked in the intake channel. The Length-Frequency-Diagrams of these fish are shown in Figure 28, Figure 30 and Figure 32. After several hours, twelve brown trout (*Salmo trutta*) (26 %) and eight rainbow trout (*Oncorhynchus mykiss*) (62 %) showed up unharmed in the containment basin. The bullhead (*Cottus gobio*) did not appear. The quantitative downstream migration was not assessed. Since the containment basin and the experiment pool were cleared of fish at the beginning of the experiment, the appearance of fish in the containment basin proved that fish descended from the intake channel into the experiment pool, as they followed their descend by an upstream migration (see Figure 29 and Figure 31). These findings made way for the actual experiment.

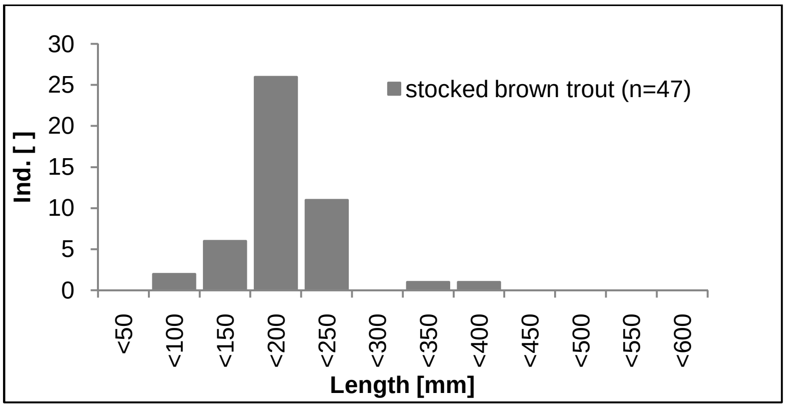

Figure 28: Length-Frequency-Diagram of brown trout (Salmo trutta), caught in the Jeßnitz River in Lower Austria and stocked in the intake channel of HYDROCONNECT on 18th of December 2013.

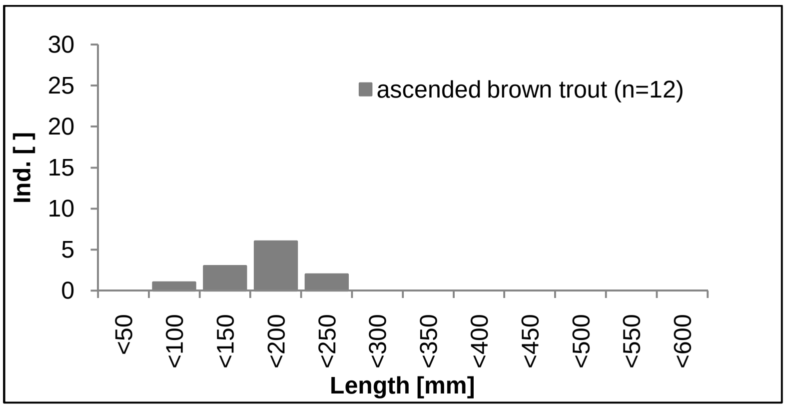

Figure 29: Length-Frequency-Diagram of downstream and upstream migrating brown trout (Salmo trutta) using HYDROCONNECT in the Jeßnitz River in Lower Austria between 18th and 20th of December 2014. Downstream migration was not quantitatively assessed.

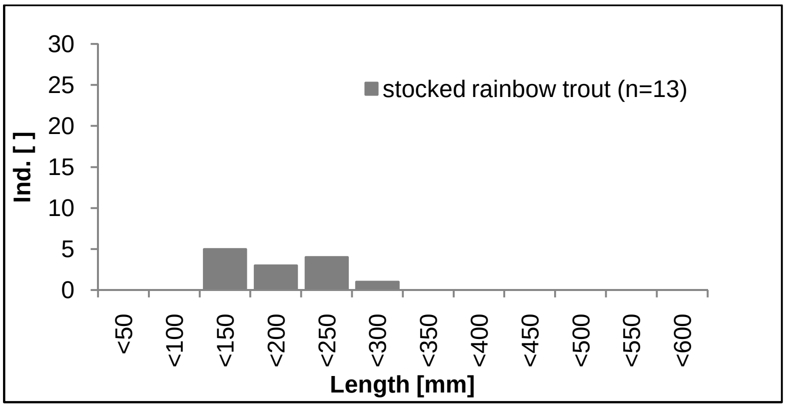

Figure 30: Length-Frequency-Diagram of rainbow trout (Oncorhynchus mykiss), caught in the Jeßnitz River in Lower Austria and stocked in the intake channel of HYDROCONNECT on 18th of December 2013.

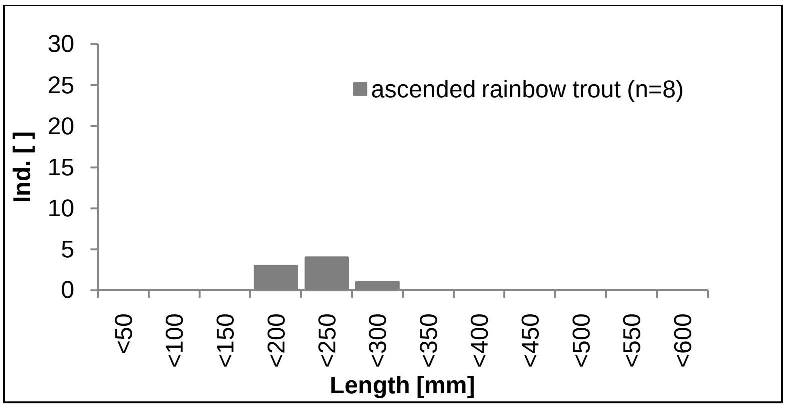

Figure 31: Length-Frequency-Diagram of downstream and upstream migrating rainbow trout (Oncorhynchus mykiss) using HYDROCONNECT in the Jeßnitz River in Lower Austria between 18th and 20th of December 2014. Downstream migration was not quantitatively assessed.

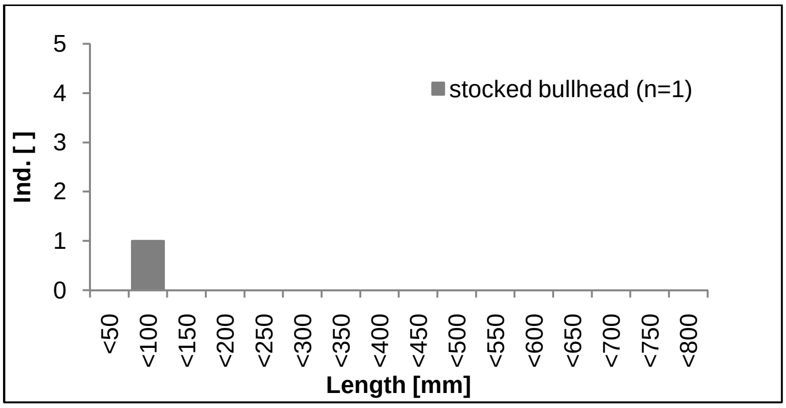

Figure 32: Length-Frequency-Diagram of bullhead (Cottus gobio), caught in the Jeßnitz River in Lower Austria and stocked in the intake channel of HYDROCONNECT on 18th of December 2013.

3.4.2 Experiment

A total of 140 individuals (88 brown trout (*Salmo trutta*), 29 rainbow trout (*Oncorhynchus mykiss*), 23 bullhead (*Cottus gobio*)) were stocked in the intake channel, resulting in 96 downstream migrations (69 %) and 17 subsequent upstream migrations (12 %). 44 of the stocked individuals remained in the intake channel during the experiment. Length-Frequency-Diagrams and the according migrations are shown in Figure 33 to Figure 38.

88 brown trout (*Salmo trutta*), ranging from >50 mm to <450 mm in length, were stocked in the closed intake channel of HYDROCONNECT (see Figure 33). 59 individuals (67 %) used HYDROCONNECT to migrate downstream, eight individuals (14 %) migrated upstream afterwards (see Figure 34).

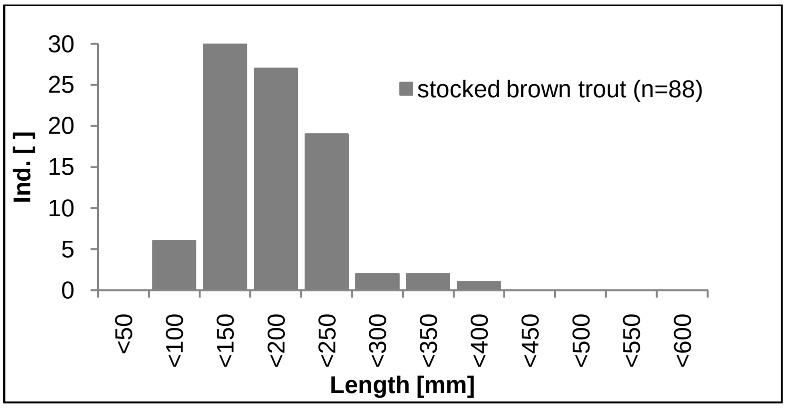

Figure 33: Length-Frequency-Diagram of brown trout (Salmo trutta), stocked in the intake channel of HYDROCONNECT in the Jeßnitz River in Lower Austria on 26th of March 2014.

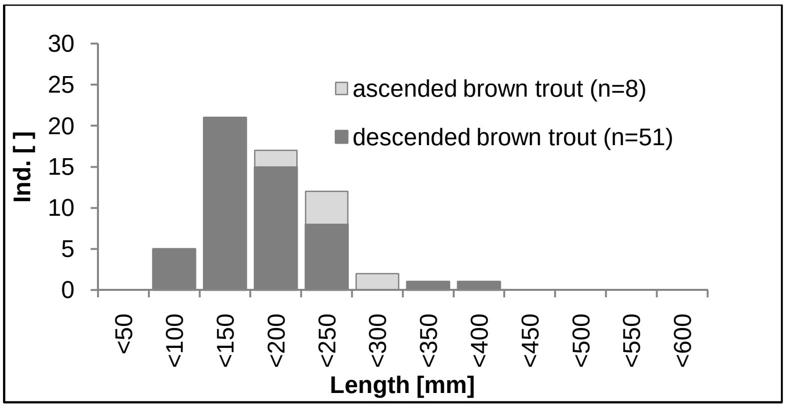

Figure 34: Length Frequency-Diagram of downstream (descended) and subsequently upstream (ascended) migrating brown trout (Salmo trutta) between 26th and 27th of March 2014, after they have been stocked in the intake channel of HYDROCONNECT at the Jeßnitz River in Lower Austria. n_{total} = 59.

29 rainbow trout (*Oncorhynchus mykiss*), ranging from >100 mm to <400 mm in length, were stocked in the closed intake channel of HYDROCONNECT (see Figure 35). 17 individuals (59 %) used HYDROCONNECT to migrate downstream, five individuals (17 %) migrated upstream afterwards (see Figure 36).

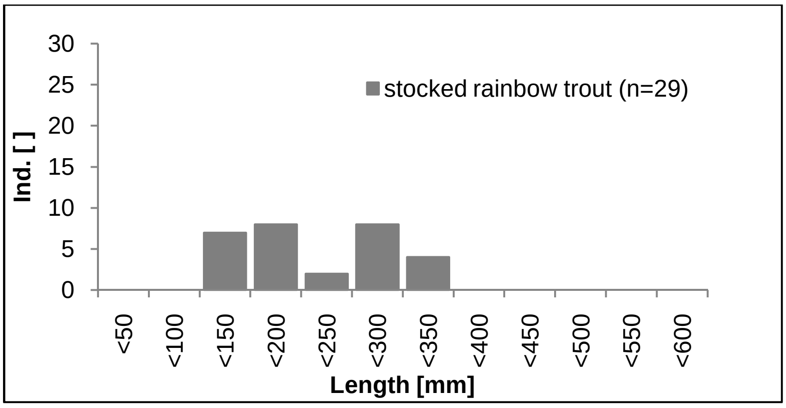

Figure 35: Length-Frequency-Diagram of rainbow trout (Oncorhynchus mykiss), stocked in the intake channel of HYDROCONNECT at the Jeßnitz River in Lower Austria on 26th of March 2014.

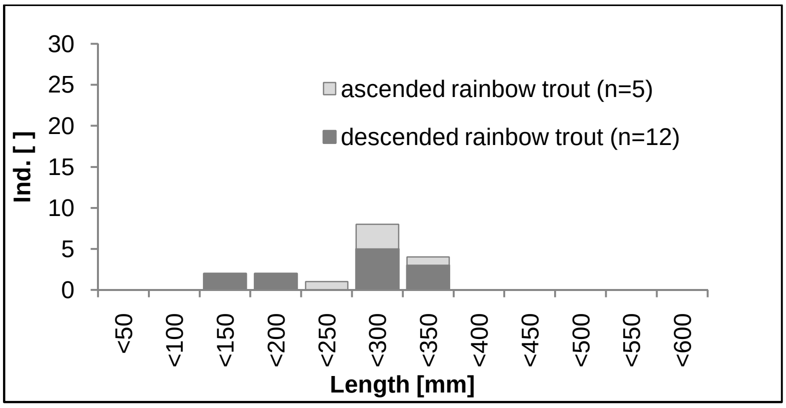

Figure 36: Length Frequency-Diagram of downstream (descended) and subsequently upstream (ascended) migrating rainbow trout (Oncorhynchus mykiss) between 26th and 27th of March 2014, after they have been stocked in the intake channel of HYDROCONNECT at the Jeßnitz River in Lower Austria. n_{total} = 17.

23 bullhead (*Cottus gobio*), ranging from >50 mm to <200 mm in length, were stocked in the closed intake channel of HYDROCONNECT (see Figure 37). 20 individuals (87 %) used HYDROCONNECT to migrate downstream, four individuals (17 %) migrated upstream afterwards (see Figure 38).

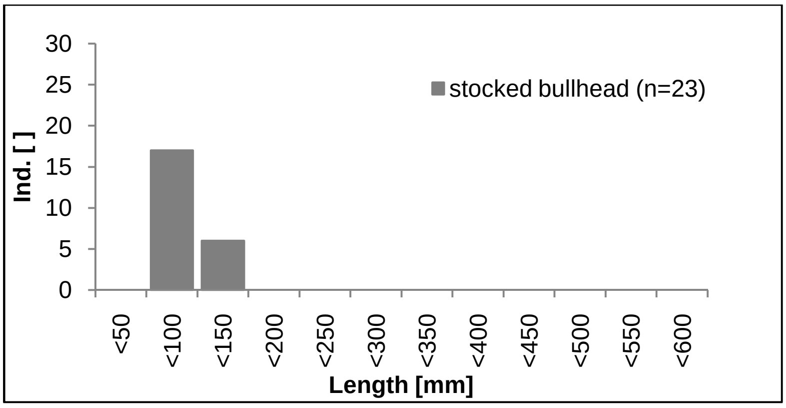

Figure 37: Length-Frequency-Diagram of bullhead (Cottus gobio), stocked in the intake channel of HYDROCONNECT at the Jeßnitz River in Lower Austria on 26th of March 2014.

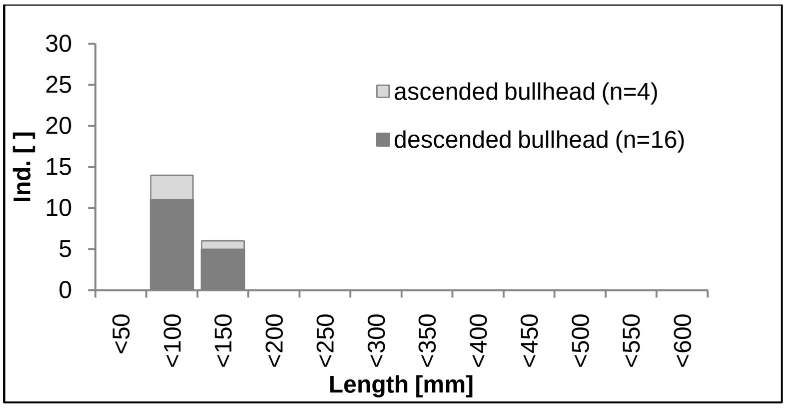

Figure 38: Length Frequency-Diagram of downstream (descended) and subsequently upstream (ascended) migrating bullhead (Cottus gobio) between 26th and 27th of March 2014, after they have been stocked in the intake channel of HYDROCONNECT at the Jeßnitz River in Lower Austria. n_{total} = 20.

3.4.3 Grading of downstream migration

On a scale of one to five, where one is the best and five is the worst possible grade, the qualitative downstream migration in regard to species and life stages can be graded with one – meaning it is fully functional and all tested fish species and life stages can migrate downstream. Using the same scale, the quantitative downstream migration in regard to amount of downstream migrating species and short distance migrants can be graded with two – meaning it is functional, as many individuals who want to migrate downstream are able to do so.

A more detailed grading can be seen in Table 13 in the Annex.

3.5 Hydromorphology

The modeled topview of the experiment pool downstream of HYDROCONNECT and the situation of the transects used to model the flow velocities are shown in Figure 39.

The x and y-axis are given in meters. On the x-axis the sampling for each vertical was done, the y-axis shows the distance to origin.

The pool has a maximum depth of around 0.75 m directly at the outlet of the works water at the orographic left side of the inner tube as well as in the middle of the pool. The bottom of the inner tube is level with the river bed at a depth of around 0.6 m to 0.7 m.

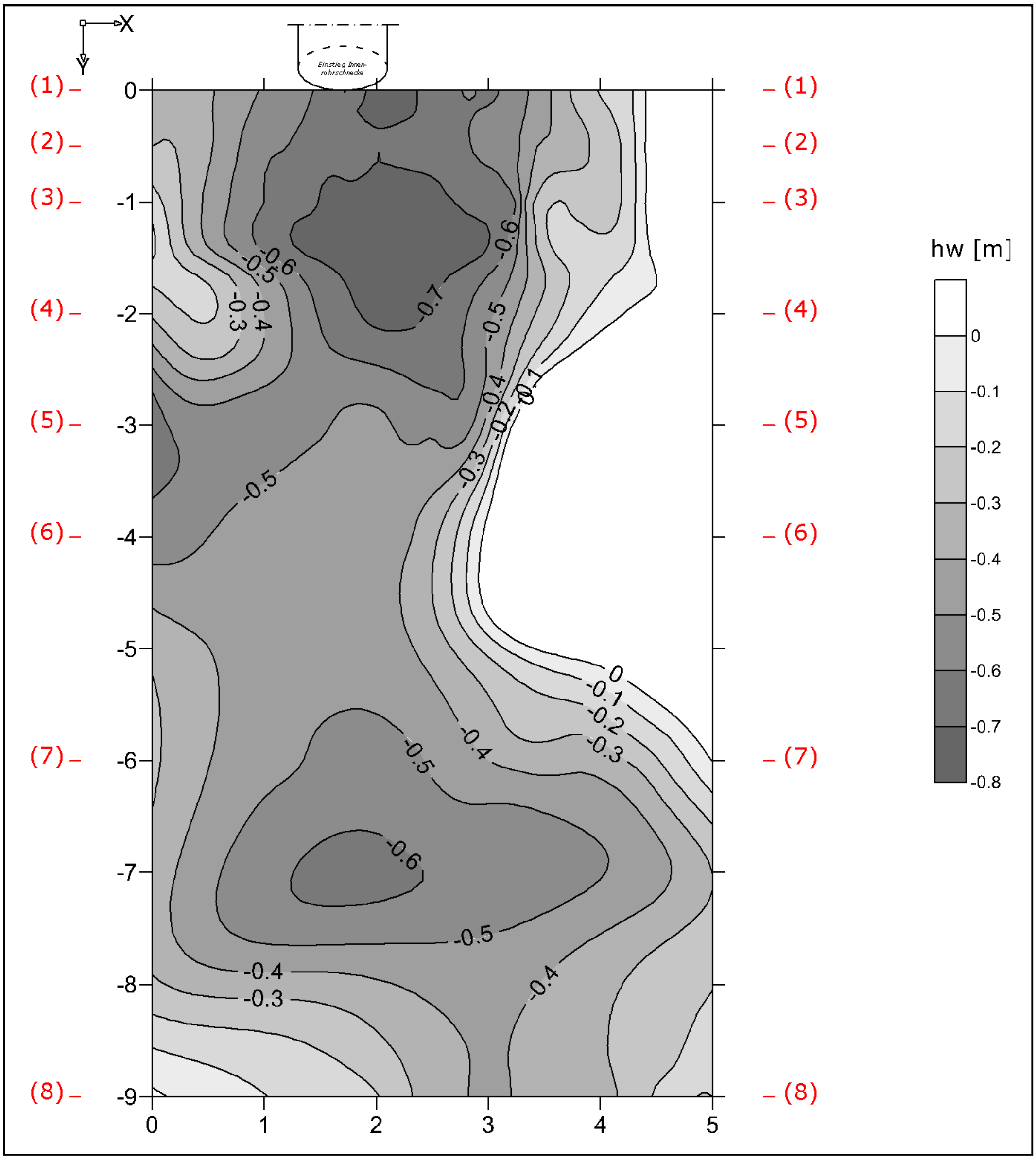

Figure 39: Modelled top view of the river bed below the water surface of the Jeßnitz River downstream of HYDROCONNECT in February 2014. The x- and y-axis are given in meters. On the x-axis, the verticals were sampled, the y-axis shows the distance to origin. As reference, the inner tube is depicted above the top view. “Einstieg Innenrohrschnecke” translates to “Entrance inner tube”. “hw [m]” stands for “water depth [m]”. The numbers in red show the situation for the different transects (ZEIRINGER, 2015).

The flow velocities for the first four transects in the tailwater of HYDROCONNECT are shown in Figure 40.

The x- and the z-axis are given in meters, where the z-axis shows the water depth for each vertical.

The maximum flow velocity with more than 0.8 m/s is reached at the outlet of the works water on the orographic left side of the inner tube at $v_{80\%}$. Water flows in the inner tube at a maximum flow velocity of less than 0.3 m/s.

At a distance of 2 m (at transect 4) from the downstream ending of the inner tube, the turbulences caused by the works water settle to moderate amounts with a maximum flow velocity of around 0.3 m.

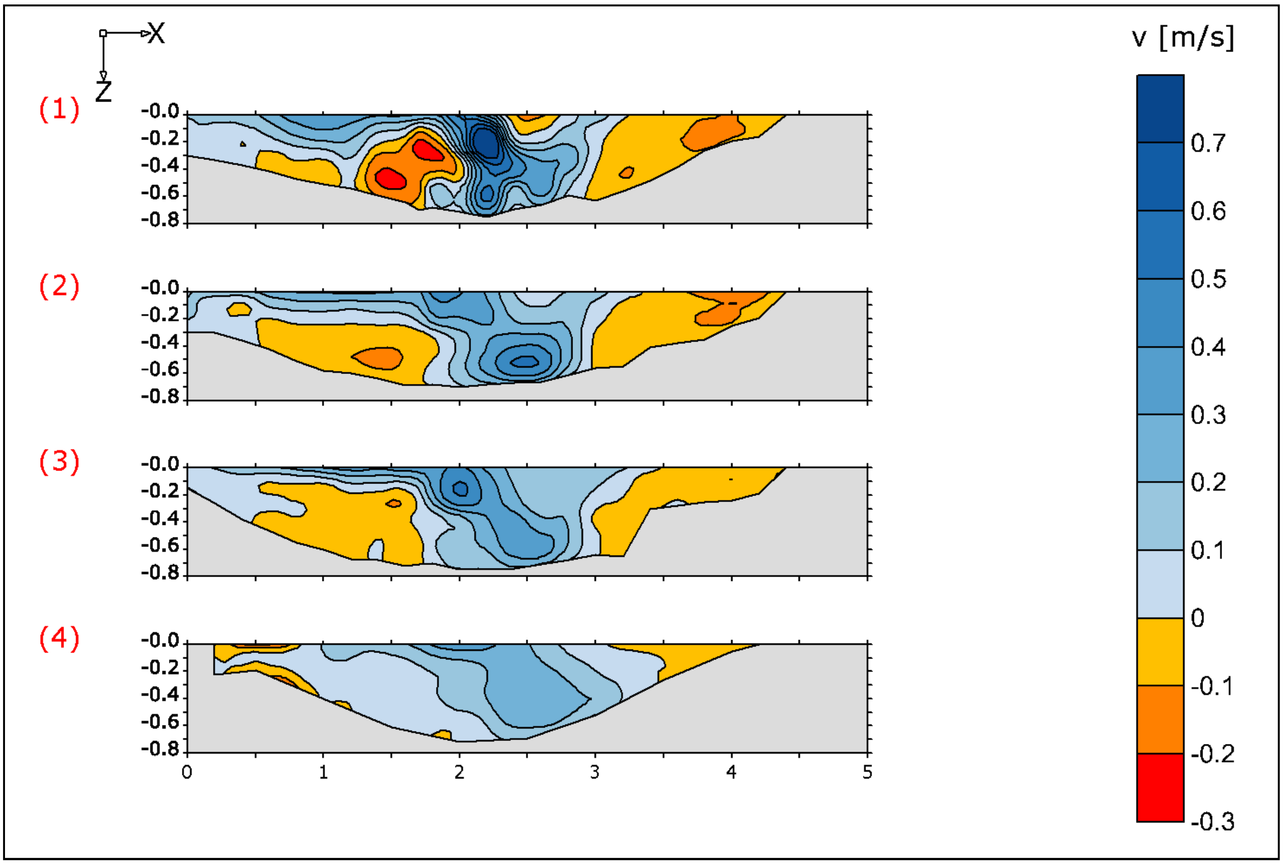

Figure 40: Flow velocities at the cross-sections. The red numbers one to four stand for the different transects in the tailwater of HYDROCONNECT at the Jeßnitz River in Lower Austria (see Figure 39 for the situation of the transects). Mapping was done in February 2014. The x- and z-axis are given in meters. On the x-axis, the verticals were sampled, the z-axis shows the water depth for each vertical. The middle of the inner tube is situated at 1.7 m on the x-axis (ZEIRINGER, 2015).

4. Discussion

Literature search

To understand the idea behind HYDROCONNECT, one must be aware of the fact that common turbine types like Pelton-, Francis- and Kaplan turbines have relatively high mortality rates for fish in comparison to hydrodynamic screws. They do not work for unharmed fish migration in most cases and never in two directions without any further constructions like bypasses. The turbine preceding fine meshed screens can filter most flotsam like woody debris, waste and/or ice which could harm the turbine, yet it cannot hold back everything, as too fine meshed screens would lead to reduced water in the turbine. Archimedean screws are better suitable for fish migration, as they cause lesser mortality than common turbines and are less likely to get damaged by flotsam due to lower rounds per minute, yet they are far from perfect in concern of injuries to fish and jamming. Furthermore, their efficiency cannot match the one of common turbine types. The downsides of common Archimedean screws are almost nullified by the HYDROCONNECT, as log or ice jams can no longer easily happen and injuries on fish do no longer occur.

Biomass calculation

The biomass calculation was done as precisely as the data allowed. More accurate results could have been gained by always doing two runs for each stretch, as in the headwater and head of reservoir only one run each was undertaken. This leads to slightly inaccurate calculations, as the second run, which is necessary for the two-catch method by SEBER & LeCREN (1967) was estimated by the amounts caught in the first run. Second runs could not have been conducted for the upstream sections due to a lack of time and resources. The received results therefore show an approximation, which is accurate enough to permit comparisons to other waterbodies.

In general, the fish density and biomass at the Jeßnitz River seem to be at an average. The good biomass results for the headwater section could be caused by the spawning season of brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*). As there is a groundsill at the top end of the headwater section, further upstream migration cannot take place and fish accumulate in this section. Water depth and flow velocity at the headwater section strengthens this assumption, as it is of preferred depth for spawning trout. In the head of reservoir, water depth of up to 1.5 m and in parts lentic (standing) water are far less favorable for trout, especially during spawning period.. This could be an explanation as to why the biomass is considerably lower in this section (112 kg/ha) than it is in the headwater section (254 kg/ha). The tailwater has suitable flow conditions for trout spawning, yet the water depth is too shallow in most cases. Still, few spawning redds could be spotted in the tailwater section.

The groundsill further downstream of HYDROCONNECT impairs fish migration to massive amounts, as it is impassable for upstream migrating brown- and rainbow trout (*Salmo trutta, Oncorhynchus mykiss*) as well as for bullhead (*Cottus gobio*). Due to this, upstream migrating fish from the Erlauf River cannot enter the tailwater habitat above the groundsill and, as a consequence, the populations in the three fished sections are very much isolated and can exchange individuals only by drifting and or swimming from upstream habitats into downstream habitats.

The weir, at which HYDROCONNECT is located, cannot be passed by upstream migrating fish when HYDROCONNECT is not in operation. It can, however, be passed by downstream migration over the spillway.

It seems as if the populations of brown trout (*Salmo trutta*), rainbow trout *(Oncorhynchus mykiss*) and bullhead (*Cottus gobio*) are self sustaining and healthy in these river stretches, as all age classes of these species could be caught by electro-fishing.

Upstream migration experiment

Considering a total stock of 446 individuals, an upstream migration of 69 individuals (15.5 %) in the time span from 8th to 23rd of November 2013 and 118 individuals (26 %) from 20th of October 2013 to 29th of April 2014 does not sound a lot, but shows that fish can and do use HYDROCONNECT for migration at their own will. Their wish to migrate was in this case mostly driven by the spawning season. In an earlier experiment in 2012, 372 individuals (185 brown trout (*Salmo trutta*) (50 %), 94 bullhead (*Cottus gobio*) (25 %), 66 rainbow trout (*Oncorhynchus mykiss*) (18 %) and 27 grayling (*Thymallus thymallus*) (7 %)) were stocked in the experiment pool while the screen was closed. Under these confined conditions, 151 individuals (41 %) (107 brown trout (*Salmo trutta*) (71 %), 9 bullhead (*Cottus gobio*) (6 %), 20 rainbow trout (*Oncorhynchus mykiss*) (13 %), 15 grayling (*Thymallus thymallus*) (10 %) and a frog went upstream unharmed (ZEIRINGER & JUNGWIRTH, 2012). The usage of HYDROCONNECT by fish as migration aid is obvious and seems to be related to crowdedness. Crowdedness, however, was not given in the upstream migration experiment conducted during this master thesis, as the fish were not kept in the pool but could spread freely. The lesser amount of upstream migrating individuals therefore seems plausible.

All tested fish species and all their life stages are able to use HYDROCONNECT, as to why the qualitative upstream migration was graded with one, meaning that all species and life stages (juvenile & adult) can migrate upstream unharmed.

The quantitative upstream migration was graded with two (to three), as brown trout (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) reached good shares of upstream migration (55 % and 36 %), the bullhead (*Cottus gobio*), which is one of the two key species in the Jeßnitz, reached only moderate shares of upstream migrations (9 %).

The tagging of only 50 % of the catch from the headwater section is a flaw in the methods, as 100 % would have been needed to really be able to distinguish between fish from the headwater and the tailwater section. The initial question, whether fish from the headwater and head of reservoir section would migrate upstream again after stocking them in the tailwater, was answered however, as several tagged individuals performed upstream migrations.

Upstream migration experiment with potamal fish species

The potamal species which were used for this experiment all adapted HYDROCONNECT very well, as all species had individuals migrating upstream at least once. With the lowest share of upstream migrations being 45 % for chub (*Squalius cephalus*) and the highest share reaching up to 100 % for barbel (*Barbus barbus*), nase (*Chondrostoma nasus*) and pike (*Esox lucius*), this experiment showed a huge success. With an overall upstream migration of 76 % it exceeds the compact upstream migration experiment for rithralic species from the year 2012 by around 35 %. This shows that HYDROCONNECT is very well used by the tested species. It has to be considered however, that the Jeßnitz River is no natural habitat for the potamal species and the stocking density in the experiment pool was high. This is why the great share of upstream migrations has to be treated with caution, as the fish could just have searched for a way to get into a more fitting habitat. As the experiment pool was blocked, the only way out of the pool was by using the inner tube of HYDROCONNECT. The same experimental setup in the Marchfeldkanal or Rußbach could yield different results, as the habitat in that case would be more fitting and the fish could stay in the experiment pool without going upstream. This can only be answered by conducting the experiment in a potamal river. However, the Hypotheses that potamal species can use HYDROCONNECT as Fish Migration Aid was proven. This was the intended outcome of the experiment.

Downstream migration experiment

The downstream migration experiment showed good results, as expected. Many fish (67 % of brown trout (*Salmo trutta*), 59 % of rainbow trout (*Oncorhynchus mykiss*) and 87 % of bullhead (*Cottus gobio*)) moved unharmed with the works water from the intake channel into the experiment pool via the outer tube of HYDROCONNECT. Several individuals even used the inner tube of HYDROCONNECT to migrate upstream afterwards. The high share of downstream migrating bullhead (*Cottus gobio*), which has very limited swimming capabilities, could have been caused by the high flow velocity of around 200 l/s and the lack of gravel bed in the intake channel. Even though there were areas with less flow on the orographic left side of the intake channel, a more structured intake channel could have resulted in less downstream migrations of this species.

As with all other experiments during this Master thesis, no scratches, bruises, loss of scales or other injuries could be detected when examining the fish after the completion of the experiment. One can therefore conclude that downstream migration for the tested fish species works very well and without any injuries. A downstream migration experiment with potamal fish species was not conducted, yet the expected results are similar to the ones found for the rithral species.

The qualitative downstream migration could be graded with one, as all tested species and life stages (juvenile & adult) could migrate downstream without any injuries. The quantitative downstream migration was graded with two, as brown trout (*Salmo trutta*), and bullhead (*Cottus gobio*) had good shares of downstream migrations (67 % and 87 %), the rainbow trout (*Oncorhynchus mykiss*) had moderate shares of downstream migrations (59 %). As the rainbow trout is no key species, this had no effect on the grading of the downstream migration.

Hydromorphology

The riverbed of the experiment pool at the Jeßnitz River is level with the entrance to the inner tube of HYDROCONNECT. This is important, as non-swimming species like the bullhead (*Cottus gobio*) could not enter the inner tube otherwise. The processed works water, which exits the outer tube at more than 0.8 m/s, serves as attraction flow for upstream migrating fish to find the entrance to the inner tube. Water that flows into the inner tube reaches flow velocities of less than 0.3 m/s. At no point in time fish are sucked into the inner tube with such force, that they are unable to turn around. As several individuals of different tested species used HYDROCONNECT for upstream migration not only once, but several times, one can draw the conclusion that the fish are not scared or deterred by the process. Video analysis showed that the fish slowly approach the turbine and investigate it. In some occasions it seemed like they enjoyed the turbulences caused by the turbine by swimming in and out several times before the migration or simply staying in the area of the entrance to the inner tube.

General discussion

HYDROCONNECT was originally designed as residual flow turbine to upgrade existing run-of-river powerplants. One possible consequence for hydro-powerplant operators using HYDROCONNECT could therefore be to dotate more water to the residual stretch, as the residual flow is no longer lost for power generation. This would result in more available habitat for all the prevalent species.

Another possible area of usage for HYDROCONNECT is the upgrading of existing ground sills or other transversal structures to recreate longitudinal connectivity, which is essential for fish communities.

Upstream migrations of all key species in the Jeßnitz River happened during the whole period of operation from October 2013 to April 2014, even though several environmental influences occurred during the operation of HYDROCONNECT.

Construction work at a bridge next to the groundsill downstream of HYDROCONNECT possibly enabled upstream migrations of fish for some days, as the groundsill was partly stripped down during that phase. However, this is an assumption, as upstream migrations into the tailwater section of HYDROCONNECT are elusive.

The experiment pool and its adjacent tailwater section were anthropogenic changed two times during the experiment phase to optimize flow conditions. The first adaptation happened on the seventh of November 2013, one day prior to the start of the monitoring, as the experiment pool was changed by high water flows after rainfall for two consecutive days. The second adaptation was necessary to prepare the experiment pool for the upstream migration experiment with potamal fish species, as a screen was now required to keep the fish in the pool. On the 23rd of November 2013, one day after the adaptation of the experiment pool, a flood event happened due to which HYDROCONNECT had to be shut down for several hours. Interestingly, four of the total ten bullhead (*Cottus gobio*) migrated upstream on that day, when HYDROCONNECT was back in operation. The flood event obviously altered the connection between the ending of the inner tube and the river bed in favor of the bullhead (*Cottus gobio*).

Gravel extraction in the headwater of HYDROCONNECT caused the water to be very turbid for half the day of 21st of November 2013. However, a significant impact was not noticeable, as upstream migrations fluctuated by several individuals per day regularly (two rainbow trout (*Oncorhynchus mykiss*) on 20th of November 2013, two upstream migrating rainbow trout (*Oncorhynchus mykiss*) and two brown trout (*Salmo trutta*) on 21st of November 2013).

Of further interest would be the fish behavior at different rounds per minute, as all experiments were done with 18 to 20 rpm. From the 20th of December 2013 to the tenth of February 2014, HYDROCONNECT operated at 13 rounds per minute. In that time, twelve brown trout (*Salmo trutta*) and two rainbow trout (*Oncorhynchus mykiss*) migrated upstream. That is 14 individuals over the course of around six weeks. Higher or even lesser rounds per minute would probably yield different results. An assumption is that higher rounds per minute lead to increased upstream migrations, as the attraction flow, caused by the works water, is also higher.

Another field of interest would be to test HYDROCONNECT at different sites, for example a potamal river, to have an increased range of species in their natural habitat for the testing which would yield more accurate results.

The monitoring showed that all hypotheses mentioned in the introduction hold true: All tested fish species adapt HYDROCONNECT for the type of migration which they are tested for and the majority of age classes of the tested fish species use it while not being hurt or even killed in any way.

As many of Europe’s transversal structures in rivers are obsolete, general efforts should go into reconsidering whether each structure is still needed or can be deconstructed. If a transversal structure is still needed, HYDROCONNECT can provide a solution in terms of river connectivity and fish migration.

5. References

ALBRECHT, W., 2013: Oral communication on the advantages of HYDROCONNECT.

ANDRITZ-ATRO, 2014: Hydrodynamic screw turbines. Last visited on 17.12.2014: http://www.andritz.com/no-index/pf-detail?productid=8775.

FISHTEK, 2007: Fish Monitoring and Live Fish Trials, Archimedes Screw Turbine, River Dart- Phase 1 Report: Live fish trials, smolts, leading edge assessment, disorientation study, outflow monitoring. Moretonhampstead, 2007.

ICPR, 2004: Auswirkungen von Wasserkraftanlagen in den Rheinzuflüssen auf den Wanderfischabstieg. Vortrag bei der 70. Plenarsitzung der Internationalen Kommission zum Schutz des Rhein, 8./9. Juli 2004, Bern.

LARINIER M & TRAVADE F. 2002. Downstream migration: Problems and facilities. *Bull. Fr.* Pêche Piscic. 364: 181-207.

LASHOFER, A., HAWLE, W., KALTENBERGER, F., PELIKAN, B., 2013: Die Wasserkraftschnecke – Praxis, Prüfstand und Potential, Österreichische Wasser- und Abfallwirtschaft 65 (9-10), 2013.

LASHOFER, A., KALTENBERGER, F., PELIKAN, B., 2011: Wie gut bewährt sich die Wasserkraftschnecke in der Praxis? WasserWirtschaft 8, 2011.

SCHMALZ, W., 2010: Untersuchungen zum Fischabstieg und Kontrolle möglicher Fischschäden durch die Wasserkraftschnecke an der Wasserkraftanlage Walkmühle an der Werra in Meiningen – Abschlussbericht. Breitenbach, 2010.

SCHMUTZ, S., 2011: Human impacts in riverine landscapes. Lecture at the University of Natural Resources and Life Sciences, 2011, unpublished.

SEBER, G. A. F., and Le CREN, E. D., 1967: Estimating population parameters from catches large relative to the population. Journal of Animal Ecology 36: 631-643.

SPÄH, H., 2001: Fischereibiologisches Gutachten zur Fischverträglichkeit der patentgeschützten Wasserkraftschnecke der Ritz-Atro Pumpwerksbau GmbH, Bielefeld, 2001.

NÖGIS, 2014: Report Wasserkörper Jeßnitz_01 (SB), available at http://atlas.noe.gv.at/webgisatlas/%28S%28po3gguhkzeq35qlc1xh1523g%29%29/init.aspx?karte=atlas_gst , last visited 13.10.2014.

OLESON, J. P., 2008: Handbook of Engineering and Technology in the Classical World, New York: Oxford University Press, 2008.

WFD, 2000: Directive 2000/60/EC of the European Parliament and the Council establishing a framework for the Community action in the field of water policy. Official Journal OJ L 327, published by the European Parliament on 22nd of December 2000.

ZEIRINGER, B. & JUNGWIRTH, M., 2012: Fischökologisches Monitoring bzw. Begleitforschung an der Wasserkraftschnecke mit integriertem Fischaufstieg am Standort KW Jeßnitz während des Probebetriebs. University of Natural Resources and Applied Life Sciences, Vienna, 2012.

6. Annex

Table 4: Transect one of eight to depict the hydromorphology downstream of HYDROCONNECT in the Jeßnitz River in Lower Austria. All transects were assessed on 10.02.2014. Point of origin is at the orographic right bank, 0 m downstream the outlet of the inner screw.

Transect 1, orogr. right side, distance to origin: 0 m																								
Vertical	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sample point [m]	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.7	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4
Water depth [m]	0.3	0.33	0.37	0.41	0.47	0.51	0.54	0.59	0.64	0.7	0.68	0.71	0.75	0.69	0.66	0.59	0.62	0.56	0.48	0.38	0.26	0.19	0.16	0.0
$V_{100\%}$ [m/s]	0.105	0.125	0.135	0.246	0.362	0.372	0.354	0.304	0.31	0.301	0.272	0.51	0.278	-0.08	-0.109	0.047	0.147	0.019	-0.051	-0.057	-0.069	-0.116	-0.031	0.0
$V_{80\%}$ [m/s]	0.091	0.094	0.1	0.169	0.263	0.306	0.254	0.108	0.041	-0.145	-0.041	0.358	0.873	0.048	0.022	0.13	0.052	-0.045	-0.073	-0.071	-0.122	-0.108	-0.052	0.0
$V_{40\%}$ [m/s]	0.082	0.086	-0.007	0.021	0.046	0.023	0.096	-0.16	-0.149	0.272	-0.111	-0.066	0.462	0.476	0.331	0.272	0.006	-0.083	-0.089	-0.094	-0.117	-0.116	-0.067	0.0
$V_{20\%}$ [m/s]	0.078	0.017	0.083	-0.076	-0.02	-0.089	0.03	-0.216	-0.203	-0.141	0.135	0.108	0.549	0.159	0.393	0.143	-0.024	-0.105	-0.08	-0.065	-0.15	-0.129	-0.093	0.0

Table 5: Transect two of eight to depict the hydromorphology downstream of HYDROCONNECT in the Jeßnitz River in Lower Austria. All transects were assessed on 10.02.2014. Point of origin is at the orographic right bank, 0.5 m downstream the outlet of the inner screw.

Transect 2, orogr. right side, distance to origin: -0.5 m																								
Vertical	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sample point [m]	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.7	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4
Water depth [m]	-0.3	-0.3	-0.36	-0.42	-0.51	-0.58	-0.6	-0.64	-0.69	-0.69	-0.68	-0.7	-0.68	-0.67	-0.66	-0.61	-0.56	-0.55	-0.41	-0.38	-0.35	-0.25	-0.19	0.0
$V_{100\%}$ [m/s]	0.087	0.171	0.176	0.247	0.306	0.318	0.323	0.317	0.305	0.278	0.43	0.407	0.285	0.097	0.038	0.106	0.136	0.036	-0.017	-0.079	-0.138	-0.139	-0.139	0.0
$V_{80\%}$ [m/s]	0.105	0.062	0.015	0.136	0.148	0.137	0.114	0.127	0.131	0.184	0.328	0.327	0.327	0.157	0.115	0.167	0.073	-0.024	-0.013	-0.057	-0.087	-0.108	-0.115	0.0
$V_{40\%}$ [m/s]	0.131	0.028	0.014	-0.034	-0.043	-0.064	-0.064	-0.088	-0.087	-0.091	-0.034	0.126	0.305	0.398	0.392	0.23	-0.016	-0.036	-0.099	-0.065	-0.117	-0.105	-0.064	0.0
$V_{20\%}$ [m/s]	0.066	0.013	0.051	-0.032	-0.056	-0.084	-0.1	-0.114	-0.087	-0.017	0.014	0.168	0.349	0.509	0.488	0.231	-0.022	-0.074	-0.081	-0.076	-0.083	-0.121	-0.048	0.0

Table 6: Transect three of eight to depict the hydromorphology downstream of HYDROCONNECT in the Jeßnitz River in Lower Austria. All transects were assessed on 10.02.2014. Point of origin is at the orographic right bank, 1 m downstream the outlet of the inner screw.

Transect 3, orogr. right side, distance to origin: -1 m																								
Vertical	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sample point [m]	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.7	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4
Water depth [m]	-0.15	-0.26	-0.38	-0.46	-0.55	-0.6	-0.67	-0.68	-0.72	-0.71	-0.7	-0.75	-0.75	-0.74	-0.71	-0.68	-0.64	-0.65	-0.3	-0.2	-0.25	-0.24	-0.19	0.0
$V_{100\%}$ [m/s]	0.081	0.105	0.173	0.191	0.225	0.3	0.351	0.322	0.357	0.351	0.344	0.418	0.278	0.171	0.117	0.167	0.167	0.108	0.042	-0.084	-0.099	-0.013	-0.08	0.0
$V_{80\%}$ [m/s]	0.076	0.06	0.068	0.01	0.01	-0.011	0.067	0.059	0.031	0.111	0.323	0.516	0.363	0.2	0.122	0.186	0.108	0.034	-0.038	-0.017	-0.082	-0.094	-0.01	0.0
$V_{40\%}$ [m/s]	0.041	0.05	0.018	0.027	0.009	-0.016	-0.061	-0.065	-0.012	0.012	0.043	0.111	0.271	0.372	0.245	0.195	-0.019	-0.028	-0.087	-0.065	-0.066	-0.078	-0.067	0.0
$V_{20\%}$ [m/s]	0.006	0.019	0.017	-0.028	-0.031	-0.025	-0.043	0.005	-0.057	-0.031	0.086	0.187	0.203	0.356	0.389	0.199	0.021	-0.072	-0.055	-0.072	-0.091	-0.09	-0.029	0.0

Table 7: Transect four of eight to depict the hydromorphology downstream of HYDROCONNECT in the Jeßnitz River in Lower Austria. All transects were assessed on 10.02.2014. Point of origin is at the orographic right bank, 2 m downstream the outlet of the inner screw.

Transect 4, orogr. right side, distance to origin: -2 m										
Vertical	1	2	3	4	5	6	7	8	9	10
Sample point [m]	0.2	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.2
Water depth [m]	-0.22	-0.19	-0.4	-0.61	-0.72	-0.69	-0.52	-0.26	-0.05	0.0
$V_{100\%}$ [m/s]	0,002	-0,26	0,108	0,166	0,378	0,206	0,023	-0,048	-0,08	0.0
$V_{80\%}$ [m/s]	-0,01	-0,01	0,098	0,068	0,164	0,224	0,069	-0,016	-0,07	0.0
$V_{40\%}$ [m/s]	0,01	0,001	0,058	0,031	0,149	0,295	0,129	0,003	-0,06	0.0
$V_{20\%}$ [m/s]	0,003	-0,02	0,017	0,051	0,017	0,249	0,192	-0,011	-0,05	0.0

Table 8: Transect five of eight to depict the hydromorphology downstream of HYDROCONNECT in the Jeßnitz River in Lower Austria. All transects were assessed on 10.02.2014. Point of origin is at the orographic right bank, 3 m downstream the outlet of the inner screw.

Transect 5, orogr. right side, distance to origin: -3 m						
Vertical	1	2	3	4	5	6
Sample point [m]	0.0	1.4	1.9	2.4	2.9	3.2
Water depth [m]	-0,52	-0,5	-0,45	-0,5	-0,44	0
$V_{100\%}$ [m/s]	0.05	0.095	0.313	0.319	0.171	0.0
$V_{80\%}$ [m/s]	0.105	0.12	0.31	0.325	0.247	0.0
$V_{40\%}$ [m/s]	0.046	0.107	0.303	0.358	0.335	0.0
$V_{20\%}$ [m/s]	0.04	0.016	0.326	0.319	0.241	0.0

Table 9: Transect six of eight to depict the hydromorphology downstream of HYDROCONNECT in the Jeßnitz River in Lower Austria. All transects were assessed on 10.02.2014. Point of origin is at the orographic right bank, 4 m downstream the outlet of the inner screw.

Transect 6, orogr. right side, distance to origin: -4 m					
Vertical	1	2	3	4	5
Sample point [m]	0.9	1.4	1.9	2.4	2.9
Water depth [m]	-0,42	-0,38	-0,4	-0,33	0.0
$V_{100\%}$ [m/s]	0.021	0.355	0.451	0.552	0.0
$V_{80\%}$ [m/s]	0.113	0.373	0.491	0.591	0.0
$V_{40\%}$ [m/s]	0.05	0.333	0.399	0.561	0.0
$V_{20\%}$ [m/s]	0.003	0.268	0.226	0.5	0.0

Table 10: Transect seven of eight to depict the hydromorphology downstream of HYDROCONNECT in the Jeßnitz River in Lower Austria. All transects were assessed on 10.02.2014. Point of origin is at the orographic right bank, 6 m downstream the outlet of the inner screw.

Transect 7, orogr. right side, distance to origin: -6 m										
Vertical	1	2	3	4	5	6	7	8	9	10
Sample point [m]	0.2	0.7	1.2	1.7	2.2	2.7	3.2	3.7	4.2	4.7
Water depth [m]	-0,2	-0,3	-0,35	-0,41	-0,4	-0,38	-0,24	-0,24	-0,18	0.0
$V_{100\%}$ [m/s]	-0.099	-0.153	0.041	0.547	1026	0.391	0.123	0.027	0.022	0.0
$V_{80\%}$ [m/s]	-0.168	-0.173	-0.021	0.369	0.886	0.459	0.07	0.015	0.004	0.0
$V_{40\%}$ [m/s]	-0.164	-0.188	-0.065	0.186	0.484	0.424	0.121	0.0	-0.017	0.0
$V_{20\%}$ [m/s]	-0.114	-0.061	0.039	0.277	0.186	0.217	0.034	-0.013	0.001	0.0

Table 11: Transect eight of eight to depict the hydromorphology downstream of HYDROCONNECT in the Jeßnitz River in Lower Austria. All transects were assessed on 10.02.2014. Point of origin is at the orographic right bank, 9 m downstream the outlet of the inner screw.

Transect 8, orogr. right side, distance to origin: -9 m																
Vertical	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sample point [m]	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.1
Water depth [m]	0.0	-0.13	-0.24	-0.15	-0.13	0.0	-0.05	-0.02	-0.06	-0.06	-0.18	0.0	0.0	-0.25	-0.07	0.0
$V_{100\%}$ [m/s]	0.0	1374	1016	0.74	0.666	0.0	0.02	0.173	0.314	0.903	0.977	0.0	0.0	0.714	0.438	0.0
$V_{80\%}$ [m/s]	0.0	1362	1054	0.566	0.889	0.0	0.017	0.14705	0.2669	0.76755	0.83045	0.0	0.0	0.469	0.3723	0.0
$V_{40\%}$ [m/s]	0.0	1119	0.978	0.558	0.884	0.0	0.014	0.1211	0.2198	0.6321	0.6839	0.0	0.0	0.212	0.3066	0.0
$V_{20\%}$ [m/s]	0.0	1117	0.547	0.653	0.771	0.0	0.012	0.1038	0.1884	0.5418	0.5862	0.0	0.0	0.207	0.2628	0.0

Table 12: Grading the upstream migration of prevalent species at the Jeßnitz River. Key species are shown in black.

Criteria	*Fish species*	*all*	*adult*	*juvenile*	*Grading*
Qualitative upstream migration *(Species and life stages)*	brown trout *(Salmo trutta)*	✓	✓	✓	**I → fully functional** (all species and life stages (juvenile/adult) can migrate upstream unharmed)
	rainbow trout *(Oncorhynchus mykiss)*	✓	✓	✓	
	bullhead *(Cottus gobio)*	✓	✓	✓	
		Grading			
Quantitative upstream migration *(amount of upstream migrating species, short distance migrants)*	brown trout *(Salmo trutta)*	II			**II (- *III*) → functional** (many individuals who want to migrate upstream can do so unharmed)
	rainbow trout *(Oncorhynchus mykiss)*	II			
	bullhead *(Cottus gobio)*	III			
Total grading					**II Functional**

Table 13: Grading the downstream migration of prevalent species at the Jeßnitz River. Key species are shown in black.

Criteria	*Fish species*	*all*	*adult*	*juvenile*	*Grading*
Qualitative downstream migration *(Species and life stages)*	brown trout *(Salmo trutta)*	✓	✓	✓	**I → fully functional** (all species and life stages (juvenile/adult) can migrate downstream unharmed)
	rainbow trout *(Oncorhynchus mykiss)*	✓	✓	✓	
	bullhead *(Cottus gobio)*	✓	✓	✓	
		Grading			
Quantitative downstream migration *(amount of downstream migrating species, short distance migrants)*	brown trout *(Salmo trutta)*	II			**II → functional** (many individuals who want to migrate upstream can do so unharmed)
	rainbow trout *(Oncorhynchus mykiss)*	III			
	bullhead *(Cottus gobio)*	II			
Total grading					**II** **Functional**