UNIVERSITÄT FÜR BODENKULTUR WIEN
University of Natural Resources and Life Sciences, Vienna

Master Thesis

Salmonid Movement: Effects of a drawdown flushing on the movement behavior of fish in the River Möll

Submitted by

Roman BURTSCHER, BSc

in the framework of the Master programme

Applied Limnology

in partial fulfilment of the requirements for the academic degree

MSc

Vienna, October 2022

Supervisor:

Univ.Prof. Dipl.-Ing. Dr.nat. techn. Stefan Schmutz

Institute of Hydrobiology and Aquatic Ecosystem Management

Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

Vienna, 25.10.2022 Roman BURTSCHER (manu propria)

Acknowledgments

Co-Supervisor: DDipl.Ing. Dr. Kurt Pinter

Team (untitled): Alex Auhser, Stefan Auer, Maria Bräuner, Bettina Grün, Meinrad Burgschwaiger, Andreas Cosma, Benjamin Droop, Felix Erhard, Katharina Fraunbaum, Simon Führer, Michael Gallowitsch, Marina Golja, Paul Grabner, Michael Grohmann, Urban Hammerschmid, Thomas Hasler, Daniel Hayes, Johannes Hofer, Stefan Kaltschik, Erwin Lautsch, Jakob Neuburg, Thomas Neudorfer, Tristan Maurer, Paul Meulenbroek, Stefan Metzger, Jamie Lee Morgan, Jonathan Pazmandy, Truong Quoc Phu, Pablo Rauch, Panchan Ruamruedee, Michael Schöfbenker, Philipp Schubert, Leonard Sonten, Valentin Sturmberger, Günther Unfer, Christian Witt, Thomas Wöhrer und Leonardo Zoltan.

Table of Content

1 ABSTRACT:

Sediment-management in alpine hydropower reservoirs is challenging. Operators must find solutions to get rid of the alluvial deposit to preserve reservoir storage, at the same time the negative effects of a drawdown flushing on the living environment in downstream river stretches have to be kept to a minimum. To provide a scientific explanation of the acute impact of a drawdown flushing on the downstream freshwater ecosystem, individual fish movement was investigated in two river sections of the River Möll, Carinthia, Austria. In this mark-recapture study (MR) all together 6 978 salmonids (age 1+ onwards) were marked with passive integrated transponder (PIT) tags and observed for more than a year. Movement variables like 'turnover-rate', 'individual displacement' and 'proportion of sedentary individuals' were assessed for brown trout, grayling and rainbow trout. Salmonid movement was restricted during summer in both river sections. Within the study sections the flood including a drawdown flushing in October 2018 led to enhanced mean movement (365 m/Ind.) than the flood event itself (198 m/Ind.). Findings regarding the two size classes (< 201 mm and > 200 mm) were limited. Recolonization behavior showed species-specific differences. After displacement, in August 2019 more than 80 % of recaptured graylings and brown trout returned to formerly occupied habitats in the control section, while recolonization movement was restricted for rainbow trout (57%). Most investigated fish were missing after the drawdown flushing in the residual flow section. Since it remained unclear, where the tagged individuals stayed, the study design should be optimized: additional application of telemetry techniques, enhanced electrofishing effort immediately after the flushing event, extension of the impacted study section or continuous marking throughout the investigation period is recommended for future investigations with regard to the effect of a drawdown flushing on salmonid movement.

2 INTRODUCTION:

Movement of animals is a key process in nature and has fundamental influence on population dynamics (Nathan et al., 2008). Fish move to reduce predation risk, find habitats that optimize food intake and growth (also Gowan and Fausch, 2002), avoid competition with dominant fish and seek shelter during periods of discharge shifts (Railsback et al., 1999).

Heggenes et al., (2007) define movement as *a simple and flexible strategy for fish to adapt to the relatively rapid and frequent temporal and spatial environmental changes in most temperate streams (e.g. spatial habitat heterogeneity, water flow, light, temperature, water chemistry, predation and competition).*

The debate about movements of stream fishes was discussed controversial and numerous studies have been carried out since the 1950s (Young, 2011), when the home range concept in riverine fish ecology came up from early mark-recapture studies (Crook, 2004). For decades, the opinion was held that adult resident stream salmonids show high site fidelity and practically spend their entire life within a small section (20-50 m) of the river (Gerking, 1959), particularly during nonmigratory periods (Rodriguez, 2002). Gowan et al. (1994) called this theory of sedentary behavior the Restricted-Movement Paradigm (RMP) and criticized the methodological approach, especially the spatial extent of mark-recapture (MR) studies supporting the RMP. Individuals who leave the study area after the marking would not be represented sufficiently (Lucas and Baras, 2001). Although the recapture rate was low, conclusions were based only on recaptured individuals (Gowan et al., 1994). Further studies challenged the tenets of the paradigm as well and suggest that the majority of a population is sedentary and a small fraction exhibits some degree of mobility (Harcup et al., 1984; Heggenes, 1988a; Heggenes et al., 1991; also Stott, 1967), even though mobility shows seasonal dependency (Gresswell and Hendricks, 2007). Even more recent studies observed restricted movement during summer (nonmigratory period), as ~ 80 % of recaptured trout stayed within 100 m from point of first capture (Gresswell and Hendricks, 2007; Aparicio et al., 2018). In addition the discussion arises, how far an individual has to move to be considered as mobile (Gerking, 1959; Crook, 2004). Therefore, it is important to distinguish between migratory and nonmigratory periods and consequently between large- and small-scale movements. Short-term movements within small areas take place to enhance foraging opportunities or minimize predation risk whereas long distance movements serve as an option to reach new habitats, to react on environmental changes or to complete life history (Booth et al., 2013). There might be no need for long distance migrations throughout the life history, if suitable habitats for spawning, nurseries and for adult growth occur in close proximity in a stream (Solomon and Templeton, 1976; Schrank and Rahel, 2004; Palm et al., 2009). On the other hand movement distances will be high, if the required habitats for survival and reproduction are located far apart (Schlosser, 1995). This implies that home range size shows high dependency of habitat heterogeneity and might explain why movement patterns can differ between taxa and streams (also within stream sections) (Rodriguez, 2002), as well as between life-history stages (Lucas and Baras, 2001). An individual moves downstream from hatchery areas to nursery areas and again downstream to areas of adult growth, shows sedentary behavior from being 1 year old to maturity (also Gerking, 1959) and undertakes downstream movements following upstream spawning migrations (Solomon and Templeton, 1976). As a result of increased energy demands, larger fish tend to move farther than smaller individuals, especially fast growing trout occupy larger areas within the stream network (Young, 1994, 2011), and sedentary fish may stay smaller than putative mobile individuals (reviewed by Rasmussen and Belk, 2017). The observations of Young support the thesis, that animal movement increases with body size (Peters, 1983).

Migration is directed rather than arbitrary movement from one habitat to another with seasonal periodicity and includes a high share of the population (Northcote, 1978). Since spawning migration can be related to large-scale movement it is not the key objective of this movement study at River Möll even though it finds consideration. Other than in context of spawning migration, in fish movement studies the term ‘homing’ refers to the return of an individual to a formerly occupied habitat even though a comparable habitat is available elsewhere (Gerking, 1959). Homing behavior was observed after experimentally displacement of salmonids in several studies (Harcup et al., 1984; Halvorsen and Stabell, 1990; Armstrong and Herbert, 2005). Another study detected increased movements of experimentally displaced juvenile brown trout (Höjesjö et al., 2015), but homing could not be determined. Crook (2004) observed homing respectively strong site fidelity as the majority of translocated carp and golden perch returned to their point of first capture. At the same time some individuals exhibited fidelity to restricted home ranges in other stream sections and thus he suggests a post release mobility may be followed by restricted movement (home range shift).

Movement behavior is environmentally induced (Olsson et al., 2006). Discharge-changes as floods may influence the movement behavior of fish assemblages (Booth et al., 2013) and high flow velocities as well as enhanced sediment transport can lead to downstream displacement of individuals, especially if the morphological structure does not provide shelter (Heggenes, 1988b; Ward et al., 2003). Morphological complex reaches loose less fish following floods than hydraulically simple stream sections in small rivers (Pearsons et al., 1992), also in larger channels morphological structure like groynes serve as refuge for trout (Ribi et al., 2014). As long as the local habitat parameters are not changed greatly by a flood, the adverse impact on the fish community will be little (also Gerking, 1959), but if the geomorphological state is altered substantially by high flows, displaced individuals may not return to former occupied habitats (McEwan and Joy, 2013). Another environmental factor is food availability. When food levels are low, trout become migrants (Olsson et al., 2006). If growth opportunities are little, local as well as large-scale movements may enhance.

The impact of temporarily increased discharges on fish are examined in divers studies, e.g. in laboratory (Chun et al., 2011), by snorkeling (Pearsons et al., 1992; Thompson et al., 2011) or at small spatial and temporal scale (Heggenes, 1988b; Bell et al., 2001; Boavida et al., 2016). The investigation designs often focus on young individuals and point out the importance of morphological structure especially for juveniles, whose swimming abilities are low. Off-channel habitats like small tributaries or alcoves protect juvenile fish against floods (Bell et al., 2001). Larger fish with better swimming performances may be less affected by higher discharges in terms of longitudinal displacement (reviewed by Young et al., 2011). Moreover, home range sizes as well as seasonal movements increase significantly in hydropeaking reaches in relation to hydraulically undisturbed reaches (Rocaspana et al., 2019).

The effect of high flows in combination with sediment release from a reservoir and therefore high suspended solid concentrations (SSC) were quite rarely investigated in movement studies. Bergstedt and Bergersen (1997) observed enhanced average movement of fish (average movement 4,3 km) below a dam at Wind River, Wyoming, after a sediment sluicing operation (SSC-peak: 18.000 mg/l). Fish living above the dam only moved 1,8 km on average and therefore they attributed the increased movement downstream to the sluicing operation. In difference to a drawdown flushing, sluicing operations serve to prevent deposition of incoming sediment caused by a flood rather than to remove already deposited material (Kondolf et al., 2014). The drawdown flushing at Verbois dam at River Rhone (mean SSC: 11.000 mg/l over 278 h) also led to increased, unnatural movements below the dam, despite a drop of abundance and biomass (Grimardias et al., 2017).

The ecological impacts of anthropogenic activities in rivers and streams like the production of hydroelectricity is widely well known (Benejam et al., 2016). Among other impacts, the construction of hydropower reservoirs hinders the transport of sediments by rivers and leads to sediment trapping (Kondolf, 1995). Drawdown flushings (sensu Kondolf et al., 2014) serve as a common measure, to maintain and recover the storage capacity of reservoirs above a dam (Crosa et al., 2009). Thereby, deposited sediments, coarse material as well as fine sediments, are remobilized and transported downstream through low-level gates of the dam (Kondolf et al., 2014). Remobilized sediments may lead to extensive damage of the biota below reservoirs (Schmutz, 2003). The extent of the impact on the organisms in the downstream river section is basically depending on the hydrological conditions in the river during such an operation. If performed during low or base flow, the adverse effect of a drawdown flushing may be catastrophic due to high suspended sediment concentration (SSC), whereas during high flows (heavy dilution of suspended sediments) the harm of a drawdown flushing may be minimal (Grimardias et al., 2017).

The term suspended sediments or suspended solids (analytical methods differ*) refers to the mass [mg] or concentration [mg L^{-1}] of inorganic and organic matter, which is held in the water column of a stream, river, lake or reservoir by turbulence* (Bilotta and Brazier, 2008). Beside bedload transport, the transport of suspended sediments is considered as the major sediment transport mechanism in a river system. The silt and clay-sized particles transport nutrients, mineral and organic matter, metals as well as impurities through the channel system and serve as a measure for hillslope erosion (Everest et al., 1987). The impact of suspended sediments on the living environment are reviewed by (Newcombe and Macdonald, 1991):

Salmonid fisheries can be affected by inert sediment (1) acting directly on free-living fish, either by killing them or by reducing their growth rate or resistance to disease, or both; (2) interfering with the development of eggs and larvae; ***(3) modifying natural movements and migrations of fish****; (4) reducing the abundance of food organisms available to the fish; and (5) reducing the efficiency of methods used for catching fish.*

Beside the concentration of suspended sediments, the adverse impact on aquatic biota is also dependent of the duration of exposure of such an operation (Newcombe and Macdonald, 1991).

Suspended sediments have both negative and positive effects on fish populations and occur under natural conditions. Fine sediments may have essential importance for aquatic ecosystems and serve for example as primary source of food and energy. The SSC varies spatially and temporally depending on seasonal flow patterns or for instance by occurrence of catastrophic events like mudslides. The negative effect of increased sediment loads on fish may vary among other things with SSC, duration and timing of exposure and are dependent on the life-history stage of the individuals (review by Kemp et al., 2011).

Several studies observed the acute effect of enhanced fine sediments loads released from reservoirs on fish assemblages in downstream reaches. Brown trout populations below the Valgrosina reservoir (Northern Italy) showed severe decreases of abundance (reduction of 73 %) and biomass (66 %) after a drawdown flushing, especially juvenile individuals were affected heavily (Crosa et al., 2009). A few years later at Valgrosina reservoir a density loss of brown trout up to 70 % was noticed again (Espa et al., 2013). A species depending mortality rate of adult individuals of 60 % was observed after a drawdown flushing at Verbois reservoir (River Rhône), where brown trout seems to be more sensitive to such an operation than both barbel and chub (Grimardias et al., 2017). In a study at River Salzach only 1.3‰ of marked fish (6 out of more than 5.000 Ind.) were recaptured after flushing the reservoir of the hydroelectric power plant Urstein near Salzburg (Austria) (Petz-Glechner et al., 2005). At Yellow River (China) investigations show severe ecological impacts of reservoir sediment flushing, where gills of deceased fish were damaged and clogged with fine sediments (Baoligao et al., 2016).

This master thesis is part of a larger study concerning the effect of a drawdown flushing. The main study is funded by the Verbund Hydro Power AG to receive knowledge about the acute impact of a drawdown flushing at River Möll (Carinthia, Austria) on the fish assemblage living downstream of the reservoir Rottau.

The Verbund-powerplant “Malta Hauptstufe” is located at River Möll and in the course of the drawdown flushing (reservoir Rottau) in October 2015 thousands of fish died. Local fishermen accused the Verbund Hydro Power AG (operator) for killing the biota in the residual flow section below the reservoir and claimed compensation. In reaction to the accusations the operators decided to back a project financially, which provides scientific explanation of the impact of a drawdown flushing on the downstream fish assemblage at the reservoir Rottau. The Institute of Hydrobiology and Aquatic Ecosystem Management, University of Natural Resources and Life Sciences, Vienna (BOKU) was commissioned by the operator to develop an appropriate research design. To ensure more environmentally compatible conditions for following operations, the provincial government imposed restrictions. One of the restrictions refers to the discharge, whereas the flushing of the reservoir Rottau is only permitted, if at least a one-year flood (HQ1) occurs in the River Möll.

Under consideration of the ministerial guidelines the main study examined fish assemblages in two river sections at the River Möll for more than a year. In this mark-recapture study fish were caught and initially tagged with passive integrated transponder (PIT) tags and recaptured again and again throughout the study period. The development of the fish population in the residual flow section (below reservoir Rottau) was compared with the development of the fish population in the control section (reference site ~30 km upstream, where the hydrological regime is largely unaffected) in terms of tag-rate, displacement of individuals, biomass and abundance. Marking of fish with passive integrated transponder tags is frequently used in mark-recapture movement studies. It allows long-term monitoring of high numbers of individuals at low costs within small ecosystems (Zydlewski et al., 2001, 2006), and displacement distances can be determined accurately (Rodríguez, 2010).

Thus, in case of a flood event at River Möll, the fish assemblage in the residual flow section may additionally be affected by the drawdown flushing, while fish in the control section are only faced with the flood event itself. The design is comparable in its principles to a BACI (Before-After-Control-Impact; Underwood, 1992) study, where the control (C) and the possibly impacted (I) sections are sampled before (B) and after (A) the occurrence of an impact (e.g. a drawdown flushing), repeating the samplings temporally and independent from each other both before the impact starts and again afterwards.

The results of the mark-recapture study show a strong decrease of fish abundance (79 %) and biomass (66 %; from 172 kg/ha in May 2018 to 58 kg/ha in December 2018) following a flood including a drawdown flushing in October 2018 in the residual flow section, while the fish assemblage in the control section was almost not affected by the flood event (reduction of abundance 4 %; while biomass even increased from 151 kg/ha in August 2018 to 179 kg/ha in December 2018) (Pinter et al., 2021).

This master thesis deals with salmonid movement in detail. Every tagged and recaptured fish provides information about its individual displacement from the point of first capture - the “home stretch” (Rodriguez, 2002). The aim is to (a) describe the individual movement behavior of brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*) and european grayling (*Thymallus thymallus*) before the drawdown flushing (b) display displacement of fish caused by the drawdown flushing and (c) analyze post displacement recolonization movements.

Summarizing, the home range concept during nonmigratory periods says that the main part of a fish population shows stationary behavior, exhibiting diel or short-term movements within the home range. A little fraction of the assemblage - so called strays (sensu Gerking, 1959) - undertakes longer movements seeking for new habitats or shelter, or having higher demands concerning food uptake. The degree of mobility is dependent on the morphological state, the hydraulic condition and the food supply of the river section, the species, the length, and the life-history-stage of an individual, the predation pressure or shows seasonal variation.

The available data set is evaluated with frequently used movement-parameters to provide appropriate statements regarding movement of fish in the River Möll. Variables like ‘turnover-rate’ (e.g. Rodríguez, 2002; Schrank and Rahel, 2006; Booth et al., 2013), ‘individual displacement’ (e.g. Rodríguez, 2002; Schrank and Rahel, 2006; Aparicio et al., 2018) and ‘proportion of sedentary individuals’ (e.g. Rodríguez, 2002; Young, 2011; Radinger and Wolter, 2014) display the movement patterns of salmonids and describe the movement behavior development in the residual flow section (RFS) and the control section (CS).

3 RESEARCH QUESTIONS and HYPOTHESIS:

Over the years, a lot of research has been carried out at the River Möll by the University of Natural Resources and Life Sciences, Vienna (BOKU). The huge fishing effort and the financial outlay for this study, however, are unique. The fish stock assessment before and after the drawdown flushing in October 2018 showed that the event led to a sharp decrease in biomass and abundance in the residual flow section (Pinter et al., 2021).

A large data set of two fish populations is available, which allows investigations concerning individual movement in two river sections, which differ hydrologically, over a period of more than a year. Beside salmonid movements during nonmigratory periods, there is a certain interest regarding the displacement of fish due to high discharges. However, the focus is on the impact of the drawdown flushing, since only few movement studies addressed the effect of a drawdown flushing for a substantial proportion of the fish assemblage.

The high potential for local adaption indicates, that individual (also intra-specific) variations in movement is the rule for trout (Heggenes et al., 2007). This gives rise to the question, how the population dynamics and fish movement patterns look like in the River Möll (hyporhithral - grayling region). Is the home range concept detectable? What is the share of the mobile fraction? Do constant discharges in the RFS influence fish movement more than undisturbed discharges in the CS, are there variations between species and life-history-stages? Is longitudinal displacement noticeable after both a flood including a drawdown flushing and a flood event itself? Is it possible to determine recolonization movements? All these thoughts lead to following research questions and hypothesis:

RMP - Restricted Movement Paradigm:

Are there differences between the residual flow section and the control section in terms of summer movement pattern (nonmigratory period, from May 2018 until October 2018)?

Hypothesis 1: There are no differences in summer movement patterns between the two sections.

Drawdown Flushing:

Is it possible to display the proven, adverse environmental impact of a drawdown flushing (Pinter et al., 2021) with fish movement data?

Hypothesis 2: Downstream displacement of fish is higher in the residual flow section (flood including a drawdown flushing) than in the control section (flood only).

Species and Life-history Dependency:

Are there fish species-specific differences in movement behavior? Do certain fish species show more sensitivity to a drawdown flushing? Do results differ between life-history stages?

Hypothesis 3: Movement patterns differ between species.

Hypothesis 4: Juvenile fish are more affected by the drawdown flushing than adult fish.

4 METHODS

Since this master thesis is part of a larger study, the hydrological and biological aspects as well as the methods described below are limited to features essential to the here presented behavioral study. The detailed descriptions of the

- fish sampling procedure
- calculation of biomass and abundance
- calculation of growth rate
- statistical analysis of tagging ratio

are not part of this master thesis and can be found in the "Fischökologische Studie Rottau 2018/19" (Pinter et al., 2021).

Further details concerning the calculations of the fish stock can be found in the Bachelor Thesis of Michael Grohmann and Thomas Wöhrer (2020).

4.1 Study area

The study area is located in the Mölltal (Carinthia) between Möllbrücke and Stall and separates into two sections: The residual flow section below the reservoir Rottau (RFS) and the free-flowing control section about 30 km upstream the hydropower-plant near the village Stall im Mölltal (CS). Both sections belong to the bioregion "Unvergletscherte Zentralalpen" (B); its biocoenotic region is corresponding to „Hyporhithral groß" (Haunschmid et al. 2016). The fish fauna is dominated by brown trout (S*almo trutta*), rainbow trout (*Oncorhynchus mykiss*) and european grayling (*Thymallus thymallus*) as well as the bullhead (*cottus gobio*).
The data analysis focuses on the three species: brown trout, rainbow trout and grayling. These species occur in high numbers and deliver adequate data to answer the research questions and hypothesis.

The Möll rises at about 2 000 meter above sea level (m ASL) as a glacial stream from the Großglockner. The 1 105 km² catchment area of the Möll is located in the Hohe Tauern in the central area of the Eastern Alps (Egger et al., 2003). The river flows after 90 km at around 550 m ASL at Möllbrücke into the River Drava (Drau). In relation to other Alpine areas, the Mölltal (with almost 1 000 mm of annual precipitation) counts as an inner-Alpine dry valley.

From a geological perspective the catchment is determined by metamorphic rocks such as Grünschiefer, Glimmerschiefer and Schiefergneiss. Due to the energy industry and the related lack of glacial components, the actual runoff condition can be classified as a moderate nival runoff regime (Brunnbauer, 1995).

Since the 1950s the entire river has been changed in its hydrological regime due to hydraulic-engineering measures. Especially through the serious narrowing of the riverbed and the riverbank stabilizations, the river mostly lost its dynamics and structural/morphological diversity. Before the river straightening, the tributaries caused extensive furcation areas (Petutschnigg et al., 1998) in the lower reaches of the River Möll because of their strong bed load. Today, most of the larger side streams are derived for the use of hydropower, in total there are ten hydropower plants in the Möll catchment. The human impacts like impoundments, residual flow, hydropeaking and in some cases total diversions considerably impair the ecological functionality of the river.

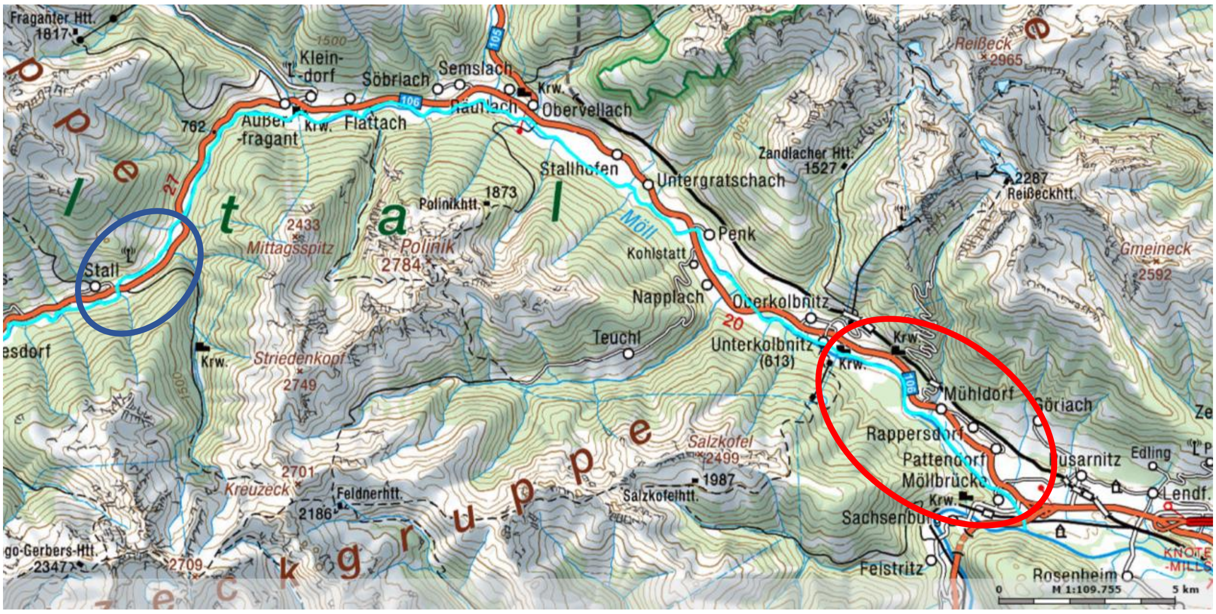


Figure 1: Overview map (Source: KAGIS, ÖK500; Office of the Carinthian Provincial Government). The study area is divided into two river sections at River Möll: the residual flow section (RFS) below the hydropower plant (red ellipse) and the control section (CS) 30 km upstream, near the village Stall im Mölltal (blue ellipse).

4.1.1 Residual flow section (RFS)

The Verbund AG hydropower plant “Malta-Hauptstufe” (Rottau) is located at River Möll between Mühldorf and Kolbnitz at river kilometer (km) 5,50. The pumped-storage powerplant has the most efficient turbine of the power plant group Malta-Reißeck, it delivers energy supply for more than 140 thousand inhabitants. The reservoir with the volumetric capacity of 500 000 m^3 was built between 1971 and 1979.

In addition to the pumped storage powerplant, the reservoir Rottau feeds a diversion powerplant, its reflux happens in Möllbrücke into the River Drava. A discharge of about 5 m^3/s (equals one fifth of the mean-flow conditions of the river in this area – gauging station Kolbnitz a. d. Tauernbahn, HZB-number 212399) is leaded to a propeller type turbine and further into the residual flow section between the reservoir dam and the river mouth of the River Möll (Corresponding water gauge: Möllbrücke, HZB-number 212407; see Figure 5).

The section has a total length of 2 670 m, it is classified as a 6th order stream (Wimmer and Moog, 1994), and starts at the reflux of the residual water turbine close to the low-level outlets of the weir. According to the River Basin Management Plan 2015 the section (corresponding to the waterbody 900930001) is assessed with the “good potential”. Reason for this is the poor hydro-morphological component with its altered flow-conditions and disturbed sediment regime.

The study site is divided into 24 stretches (average length ~111 m), its mean width is about 24,5 m, and mean depth about 0,75 m. The fish assemblage is dominated by rainbow trout.

Marking of fish started close to the weir at stretch nr. 1 (ID 1) and ended in stretch nr. 23 (ID 23) downstream the “Winterbrücke” (see Figure 2). One additional stretch (ID 24), which has been investigated for several years by BOKU University, is located at the “Eisenbahnbrücke Lurnfeld” at km 0,45. All recaptures of all stretches are considered in the results of the study.

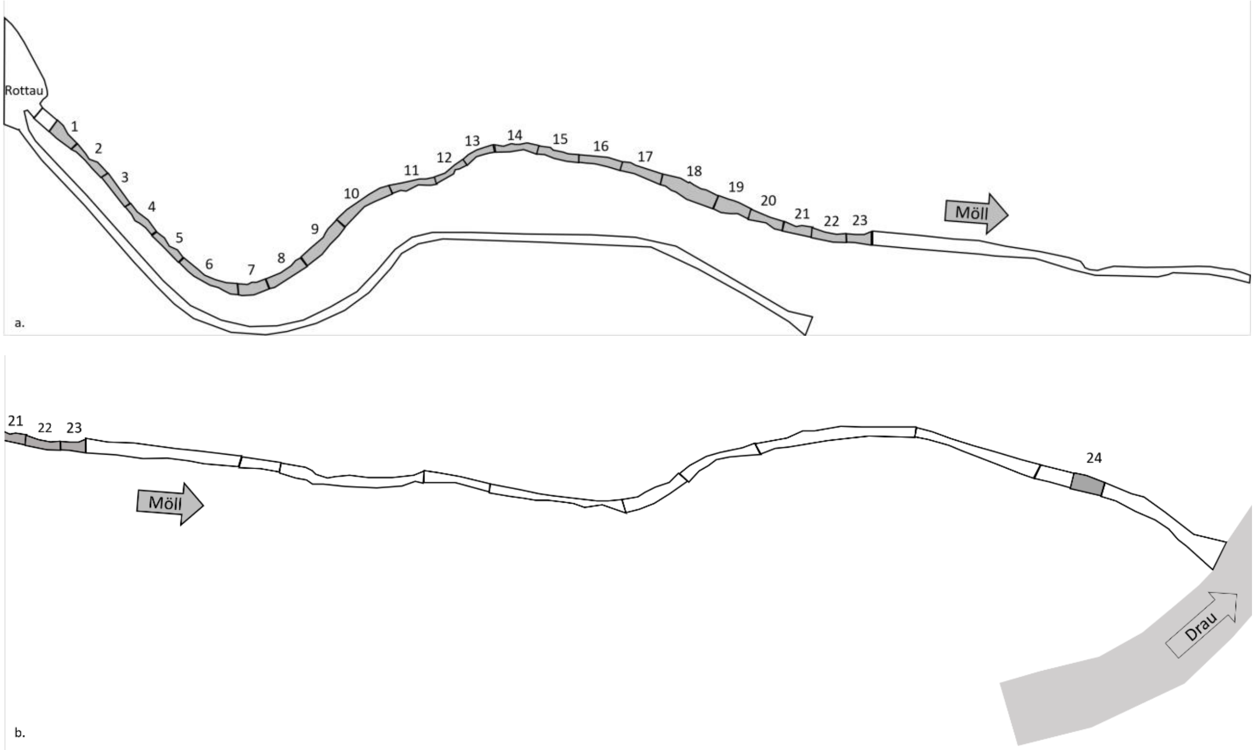


Figure 2: Schematic illustration of the residual flow section (RFS). a.: core investigation area starting close to the reservoir Rottau (stretch ID 1 - 23). Below the investigation stretches the watercourse of the diverted reach is pictured. b.: estuary area of the River Möll into the River Drava (Drau) and stretch ID 24.

4.1.2 Control Section (CS)

The control section is located about 1,5 km upstream of reservoir Gößnitz and reaches from the state road bridge close to Pußtratten (B106 Mölltalstraße) downstream to the junction of the Wöllabach and the River Möll. The section, classified as a 5th order stream (Wimmer and Moog, 1994), is split up in 16 stretches with an average length of ~127,5 m. Marking started in the most downstream stretch (ID 101) and ended close to Pußtratten in stretch ID 116 (see Figure 3).

The 2 040 m long river section shows hydraulic-engineering alterations, the meandering watercourse is replaced by a straightened one. The mean width of the section is about 25,5 m, mean depth about 0,75 m and the fish assemblage is dominated by brown trout. Due to construction of groins and other structures over the last years, the morphological state of the river section is considerably improved. Additionally, following investigations in 2006 concerning hydropeaking, the clogged/silted riverbed of the section was reconstructed and improved (Honsig-Erlenburg and Lorenz, 2006). The CS is part of the waterbody "900790073" and listed in the River Basin Management Plan 2015 with "good condition". The hydrological regime in this section is largely undisturbed.

The corresponding water gauge to this reach is in Winklern (HZB-number 212373). Several little streams enter the River Möll between Winklern and the study area. This results in slightly higher discharges in the control section than shown in the hydrographs (e.g. Figure 5), the mean-flow discharge is ~7,8 m³/s at the gauging station Winklern.

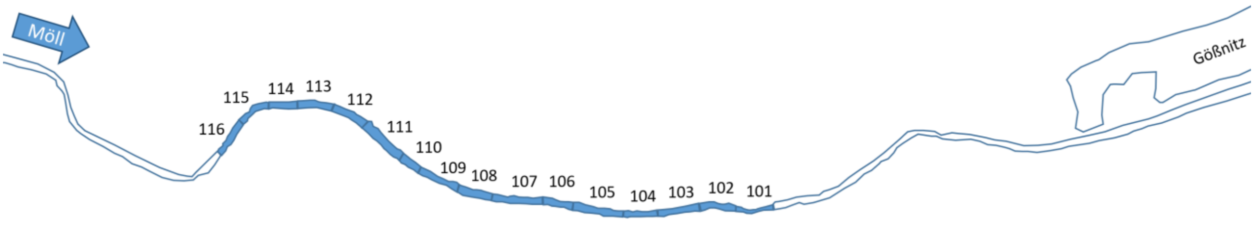
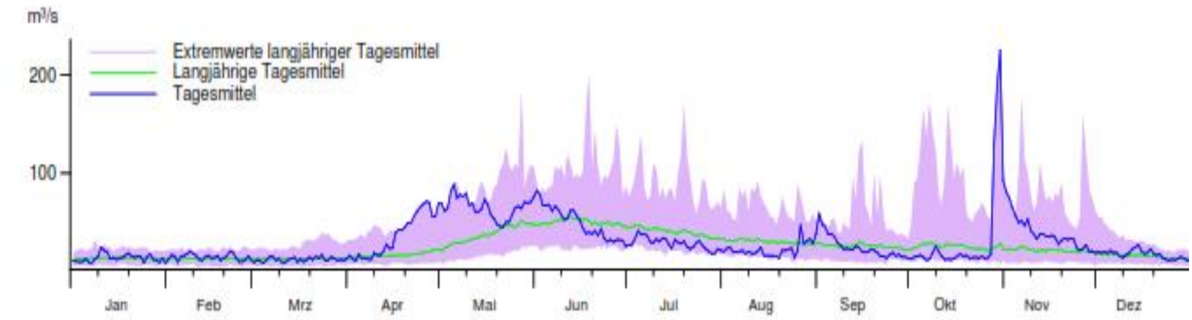


Figure 3: Schematic illustration of the control section (CS). The investigated river stretches (ID 101 - 116) are located about 1,5 km upstream of reservoir Gößnitz - the hydrological regime of the River Möll is largely unaffected upstream the reservoir.

4.2 Hydrology during the study period

The hydrological conditions at River Möll are classified as a moderate nival runoff regime (Brunnbauer, 1995), the discharge is dominated by snowfall and snow melting in the catchment below the glaciated summit region. From december until april, runoff is low, during summer and autumn the daily mean discharge increases. Heavy rainfalls in combination with snow melt can lead to steep runoff peaks.

In the beginning of 2018 runoff was uneventful, in spring slightly enhanced discharges were recorded. During summer, discharge was relatively low with exception of a little rise in the end of August. A long-lasting bad weather situation in the end of October led to flooding and several mudslides in the Möll catchment. In 2019 low flow conditions were followed by high discharges in June.



Reihe	2013 - 2017											
	Mittlere Monatsmittel in m³/s (MQ), l/s*km² (Mq), bzw. -summen in mm (h_A)											
MQ	15.5	14.1	15.8	22.9	40.6	53.7	40.4	35.9	29.3	22.4	24.5	16.3
Mq	16.7	15.2	17.0	24.7	43.8	57.9	43.5	38.7	31.6	24.1	26.4	17.6
h_A	45	37	46	64	117	150	117	104	82	65	68	47

Figure 4: Extract from the hydrographic yearbook of Austria 2018, discharge measures at gauging station Kolbnitz a. d. Tauernbahn, HZB-number 212399. The blue line shows the daily mean discharge of 2018, the green line represents the long-term daily average mean discharge and the pink range displays the long-term extreme values of the daily mean discharge.

During the investigation period (May 2018-August 2019), two considerable flood events (including a drawdown flushing) took place at River Möll:

28.10.2018 – 31.10.2018 (see Figure 4)

11.06.2019 – 14.06.2019

This study focuses mainly on the impact of the event in October 2018, the second flood is mentioned here for the sake of completeness (Figure 7; Figure 8).

At Winklern (CS) River Möll has a mean discharge of 7,8 m³/s; due to the water diversion at reservoir Rottau, the RFS (water gauge Möllbrücke) has a mean discharge (MQ) of 5 m³/s.

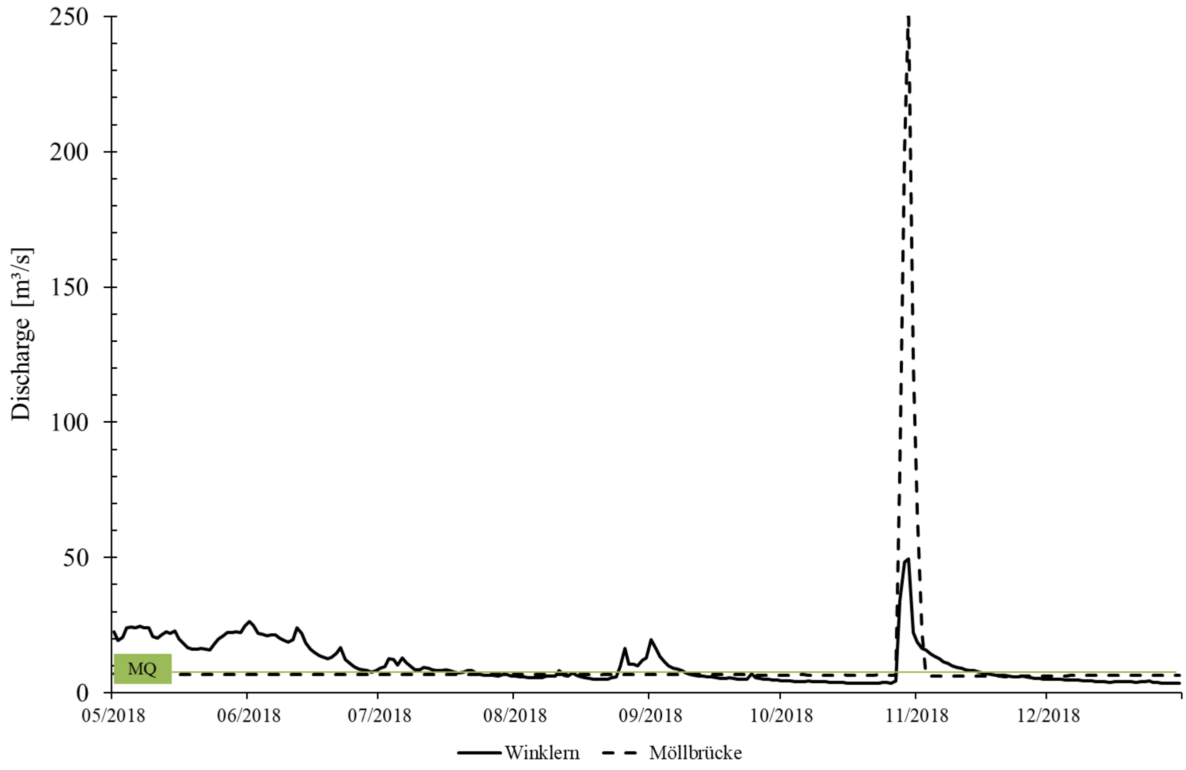


Figure 5: Hydrographs of the corresponding water gauges Winklern (CS; HZB-number 212373) and Möllbrücke (RFS; HZB-number 212407) from May 2018 until December 2018 (daily mean discharge). (Source: Hydrographischer Dienst Land Kärnten).

Figure 5 shows the daily mean discharge from May 2018 until January 2019 at the study-relevant gauging stations Winklern and Möllbrücke and the discharge peak in both investigation sections in the end of October.

The bad weather conditions led to discharges of 187 m³/s (HQ20) in the control section on October 29, 2018, see Figure 6. The rainfalls in combination with the drawdown flushing at reservoir Rottau resulted in even higher discharges: the water gauge at Möllbrücke measured a discharge of 280 m³/s on October 28, 2018, while on October 29, 2018, the discharge reached its peak of 395 m³/s, this corresponds to a HQ12 (Figure 6).

According to the flood statistics, a HQ12-discharge occurs once in 12 years (return period of a discharge). Even though the return period of the flood was lower in the control section, the runoff was by far higher in the residual flow section.

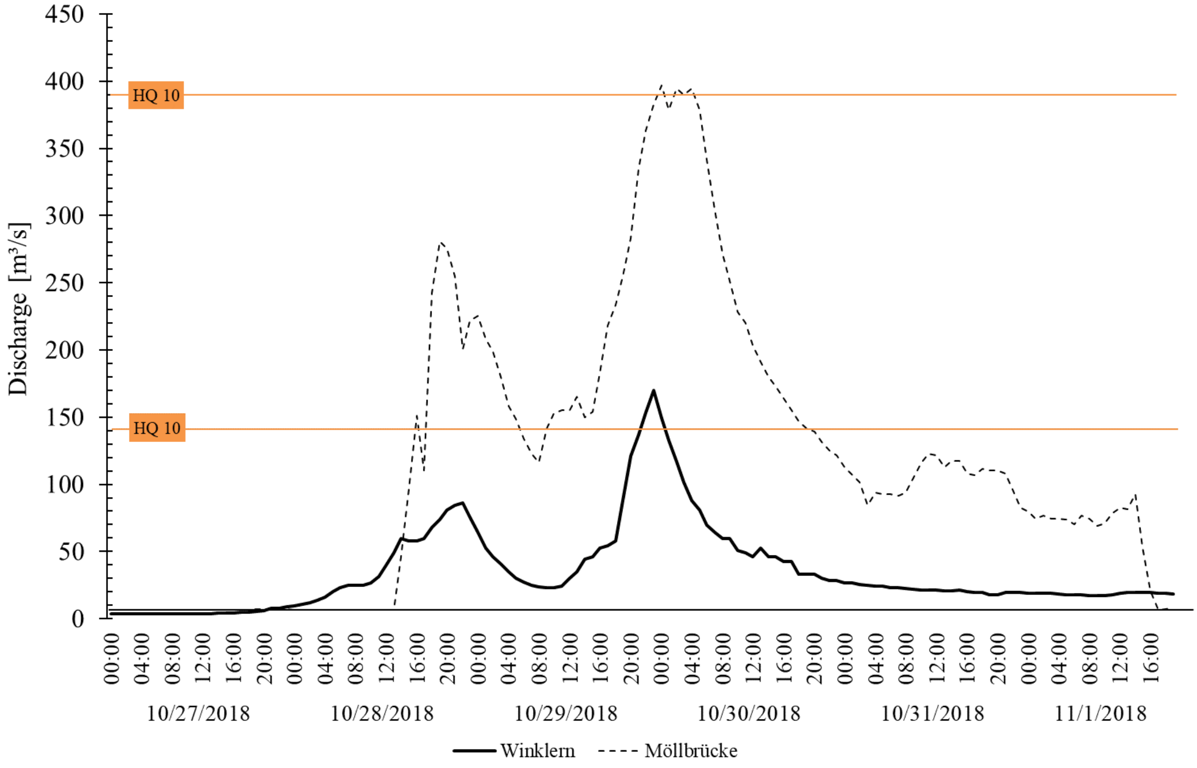


Figure 6: Hydrographs of the corresponding water gauges Winklern (CS; HZB-number 212373) and Möllbrücke (RFS; HZB-number 212407) during the flood and the drawdown flushing in October 2018 (hourly maximum value).

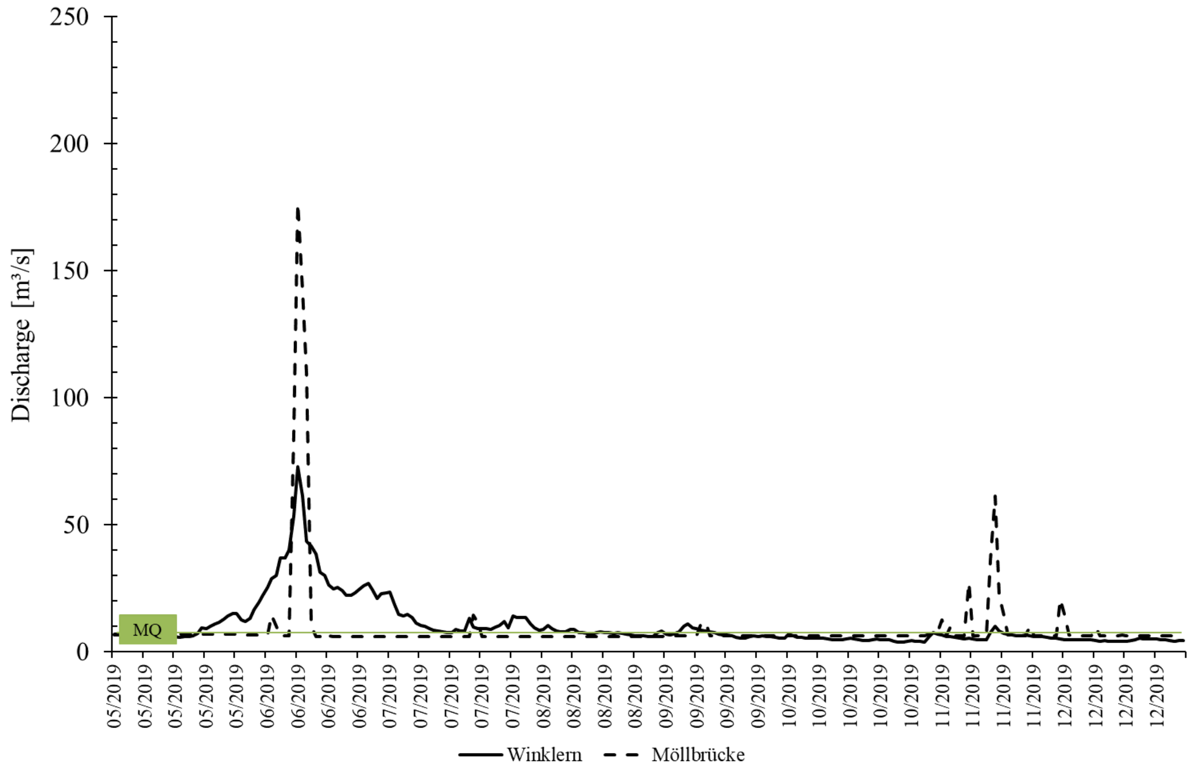


Figure 7: Hydrographs of the corresponding water gauges Winklern (CS; HZB-number 212373) and Möllbrücke (RFS; HZB-number 212407) from May 2019 until December 2019 (daily mean value).

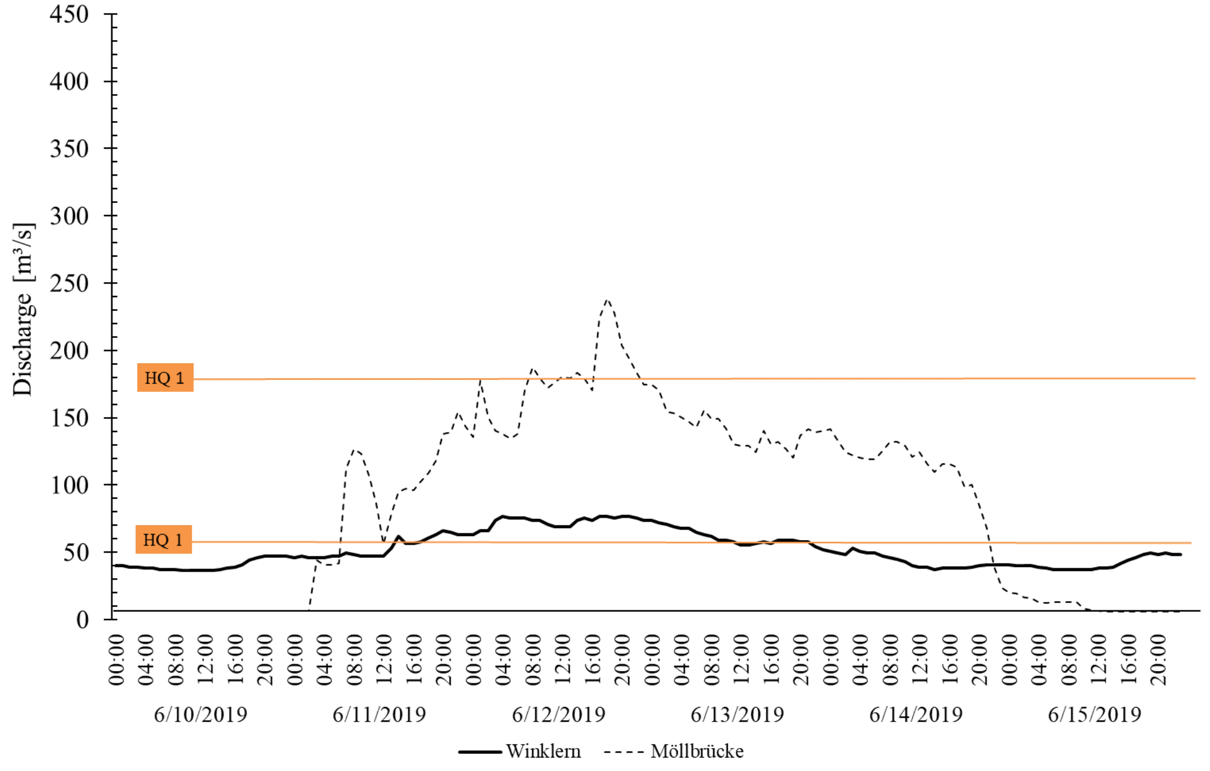


Figure 8: Hydrographs of the corresponding water gauges Winklern (CS; HZB-number 212373) and Möllbrücke (RFS; HZB-number 212407) during the flood and the drawdown flushing in June 2019 (hourly maximum value).

4.3 Fish sampling and tagging design

Electrofishing is the most frequently used method to survey fish populations in shallow freshwaters (Peter and Erb, 1996; Lucas and Baras, 2001).

In this study, quantitative fish sampling generally followed the “Leitfaden zur Erhebung der Biologischen Qualitätselemente Teil A – Fische” (Haunschmid et al., 2016) - the Austrian standard for quantitative fish sampling developed for the implementation of the Water Framework Directive (WFD). But, the study design (monitoring of tag -rate) required further electrofishing effort. Instead of sampling only a few characteristic stretches in a river section, fish were sampled continuously over a length of more than two kilometers in both river sections. Each section was divided into juxtaposed stretches of approximately equal length, block nets at the upstream and the downstream end of each stretch were installed to impede fish escapement.

Figure 9: Electrofishing in the residual flow section in May 2018. In difference to the standard method, block nets were installed at the upstream and the downstream end of each stretch.

Fish were sampled at least in two runs (removal method) by wading upstream with constant direct-current (cDC) backpack-electrofisher (1,5 Hz, 300-500 V). Constant DC is the less harmful current type for fish, at the same time it provides the highest documented catch efficiency (Peter and Erb, 1996). One anode was used per 4 m river width. To determine the length the upper and the lower waypoint of every stretch was marked with a handheld GPS-device, in addition mean river width was measured with a laser distance meter.

Figure 10: Each person handling an anode is followed by another person, who catches the stunned fish with a dipnet. At the very back, people (carrying the buckets) collect fish from the dipnets and take care of them.

Tagging of fish only took place at the qualitative sampling days in May 2018 and August 2018. In May, 19 stretches in the residual flow section were sampled by a team of about 20 people beginning below the reflux of the residual flow turbine. In August, the fish assemblage of the control section (stretch ID 101-116) was investigated, furthermore the remaining stretches (ID 20-24) in the residual flow section were completed.

Collected fish were determined by species, measured to the nearest millimeter, and marked with 12 mm passive integrated transponder (PIT)-tags (see Figure 11):

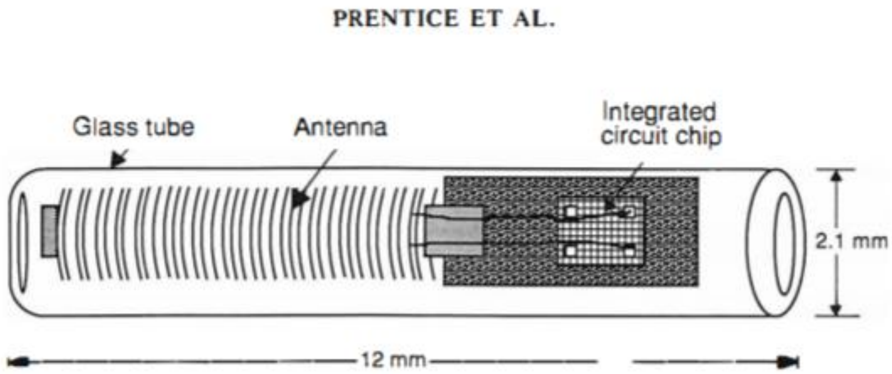


Figure 11: This figure shows a typical PIT-tag. A single tag weighs about 0.1 g and the integrated chip in the small glass cylinder owns an unique alpha numeric code (Prentice et al, 1990).

Passive integrated transponders are interrogated with the field of an induction coil, which energizes and causes a tag to retransmit its code to the reader. Since PITs contain no power source, their life is theoretically infinite, and because their identity is electronically coded, they enable a fast and reliable identification of individual fish with minimum handling (Lucas and Baras, 2001).

Small fish from 85 mm to 120 mm were tagged into the peritoneal cavity by hand (left picture in Figure 13). Larger individuals were marked intermuscular behind the dorsal fin with a PIT-tag injector (see Figure 12, right picture Figure 14). Only grayling (*thymallus thymallus*) larger than 120 mm were marked, as smaller individuals tended to be more sensitive to tagging than the other study species. Once implanted, fish could recover in instream cages before they were released in the stretch where they were caught. If the incision has healed (3-15 days) it is very unlikely that fish loose a PIT-tag (Lucas and Baras, 2001).

Figure 12: PIT-Tag injector with exchangeable needle (Source:www.oregonrfid.com).

Figure 13: Tagging action: Small fish were marked by abdominal incision (left picture); for fish > 120 mm – PIT-tags were implanted into the musculature behind the dorsal fin (right picture).

Handheld reading devices (Figure 14) were used for registration of marked individuals. A tag detector contains an internal memory, additionally every record can be transferred into an Excel-sheet via USB-connection with a laptop. The PIT-tags as well as the tag detector are manufactured by Oregon RFID, Portland OR. Since the detection of PIT-tags relies on inductive coupling, beside of handheld devices also remote detection antennae can be used to record tagged individuals (Lucas and Baras, 2001). Therefore, a remote detection antenna was installed in the vertical slot fish pass at the weir Rottau (see Figure 15). If a tagged fish swims through the fish pass, the antenna receives the transmitted code from the tag and stores every record time stamped in a file. (Castro-Santos et al., 1996). Thus, all marked fish exiting the residual flow section in upstream direction were registered.

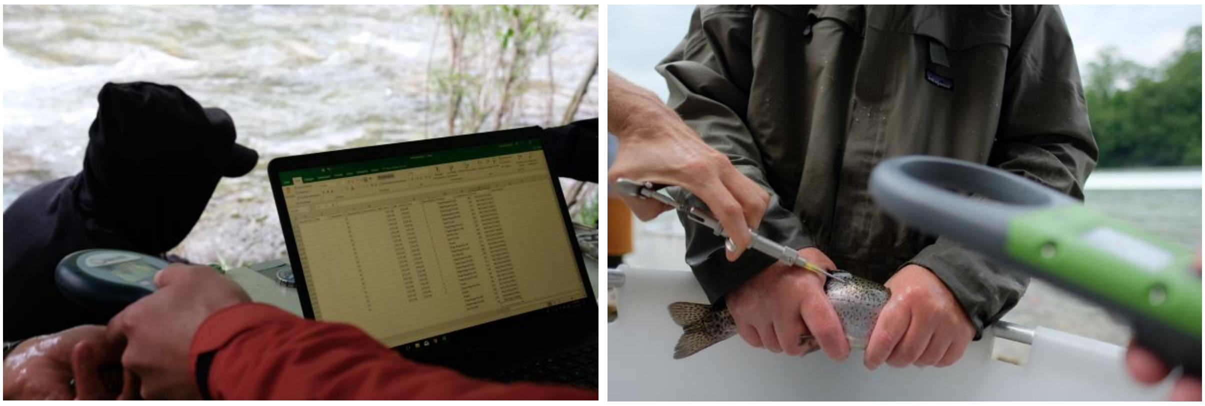


Figure 14: The handheld reading device transfers every record via USB-connection into an Excel-sheet (left picture); tagging and registration of a rainbow trout with a handheld tag detector (right picture, source: A. Pesendorfer).

Figure 15: A remote detection antenna was installed in the vertical slot at reservoir Rottau (picture source: Pablo Rauch).

During the observation period from May 2018 until August 2019, in total 15 quantitative and 17 qualitative sampling days took place. Furthermore, to keep track of the fish populations, qualitative samplings – like spot checks (single pass electrofishing) – were carried out once a month. The timeline of the PIT-tag study is shown in Figure 16:

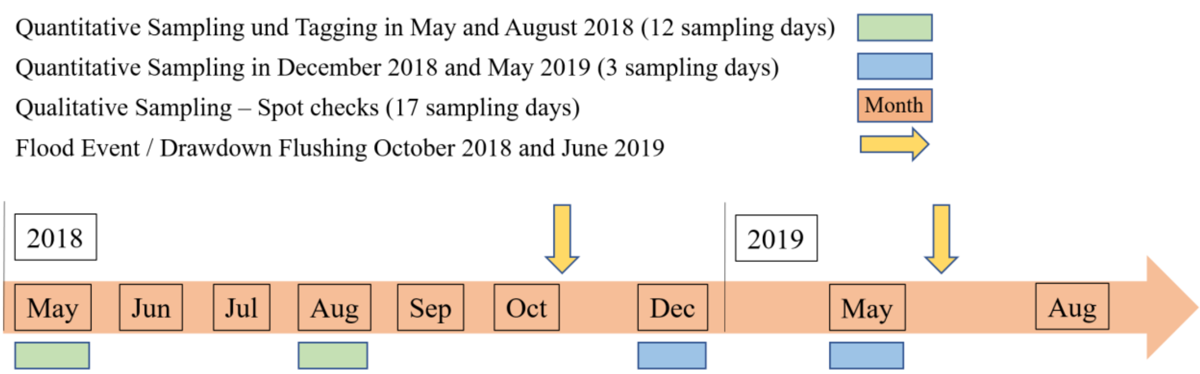


Figure 16: Timeline PIT-tag study. The two separated fish populations were monitored for more than a year.

The first spot check was taken one day after the marking in May 2018. Therefore, small teams of at least 4 persons were formed and fish were sampled in randomly chosen river stretches within the investigation area(s). Two people handled an anode, one person collected the fish with a dipnet and another one took care of the fish sample (this approach is valid for all qualitative samplings throughout the study). As soon as 30 to 50 fish were caught, each fish was determined by species, the total length was measured, and each fish was checked for a PIT-tag using a handheld reader. Finally, the sample-stretch was staked out with GPS-points. The goal was to sample at least 300 individuals for every qualitative sampling event per study section. The locations of the sampling stretches varied every month and were later assigned to the stretches defined during the quantitative samplings for further calculations (see 4.4).

The spot checks in August 2018 were completed by electrofishing from the boat in downstream direction between stretch ID 23 and stretch ID 24 in the residual flow section. This additional fishing effort delivered information, whether fish have left the investigation section or not.

The sampling days in December 2018 were of particular importance. To obtain more information about the effect of the flood in the CS and the effect of the flood including a drawdown flushing in the RFS on the respective fish assemblage - beside the spot checks - two additional quantitative sampling days (see Figure 16) were carried out in characteristic river stretches of the sections. Further spot checks in upstream (only CS; wading) and downstream (by boat) areas of the two investigation sections were performed to acquire information about potential displacements or movements of individuals due to the event. In the RFS the spot checks downstream reached to the river mouth and even further into the River Drava. In the CS the additional spot checks beyond the investigation area took place about 1 km upstream the control section and downstream until reservoir Gößnitz. This enhanced electrofishing effort resulted in higher numbers of recaptured fish.

A large accumulation of fish was observed in the stilling basin of the weir Rottau in February and March 2019. Local fishermen caught the fish by rod and checked them for PIT-tags.
In May 2019 additional quantitative fish stock assessment in 5 characteristic stretches of the residual flow section were performed again to get information about the degree of recolonization movements. After the flood event in June 2019 (including another drawdown flushing in the RFS), one final qualitative sampling (spot checks) took place in both sections in August 2019.

4.4 Data collection

Generally, the investigation design of the larger study was chosen to monitor the development of the tag-rate within the study sections. Since fish movement analysis requires recaptures, the available dataset was suitable for the present master thesis.

Data for the analysis was gathered in the course of the spot checks, the quantitative samplings, the additional fishing effort beyond the investigation sections and the fishing by rod. Furthermore, tagged fish were recorded by the remote detection antenna in the fish pass at the weir.

In particular, the monthly updates (spot checks) delivered information on:

- Development of the ratio between tagged and untagged individuals (tag-rate)
- Growth-rate of every recaptured fish
- Individual movement behavior within and beyond the sections (site fidelity)
- Species- and life-history- dependent differences in movement behavior

Frequently used fish movement variables like 'turnover-rate', 'individual displacement' and the 'proportion of sedentary individuals' were chosen to answer the research questions. All variables are suitable to describe fish movement during nonmigratory periods as well as the effect of the drawdown flushing in October 2018. The settings of the variables and the respective tests for significance are described in the section given below.

For data analysis and the calculation of the movement variables, however, the data from the antenna, the fishing effort in the River Drava and the fishing by rod close to the weir was not considered. In the discussion the whole dataset finds consideration though.

4.5 Data analysis

The stretch of first capture, in which an individual was initially tagged, was termed as the home stretch (HS). Movement of an individual was measured between the stretch of recapture (SoR). and the HS.

Typically, PIT-tag studies (treating the degree of mobility) investigate predefined stretches again and yet again (e.g. Aparicio et al., 2018). Due to factors like river size, the large temporal and spatial scale and limited human resources, the qualitative samplings (periodic interval ~ 4 weeks) were taken in randomly chosen stretches within the investigation sections. Every sampling-stretch received an upper and a lower waypoint (GPS), the resulting midpoint was then assigned to the stretches of first capture (ID 1-24 in the residual flow section, ID 101-115 in the control section).

It was possible that individuals were recaptured more than once, but all recaptures were referred to the home stretch.

Further, two length categories were defined for the data analysis. Fish larger than 200 mm and smaller than 201 mm were considered separately. The split arises from the recaptures of December 2018 after the drawdown flushing. Therefore, it was possible to describe the response of juvenile rainbow trout to the impact of the drawdown flushing event with almost sufficient recaptures.

4.5.1 Proportion of Sedentary Individuals (P):

The proportion of sedentary individuals describes the movement behavior of the fish assemblage within the study section. P ranges from 0.00 (no sedentary individuals) to 1.00 (exclusively sedentary individuals) and is calculated as the ratio between the count of sedentary individuals $n_{sedentary}$ (sum of $p_{sedentary}$) and all individuals of a sample (n_{total}).

Salmonids were classified as sedentary, if an individual was recaptured within its home stretch or in the adjacent one, irrelevant up- or downstream (average stretch-length ~ 117 m). Consequently, an individual was considered as sedentary as long as it was recaptured within a home range (corridor) of about 300 m. All other recaptures were assigned to the mobile share:

$$ID_{SoR} - ID_{HS} = p \qquad -1 \geq p_{sedentary} \leq +1$$

$$-1 < p_{mobile} > +1$$

$$n_{sedentary} = \sum p_{sedentary}$$

$$P = n_{sedentary}/n_{total} \qquad 0 \leq P \leq +1$$

For example, one individual was tagged in May 2018 in the RFS in stretch ID 12, in June 2018 the same individual was recaptured in stretch ID 8 → ID_{SoR} - ID_{HS} = 8 - 12 = -4 → mobile individual (p_{mobile}). Another PIT-tagged brown trout (alpha numeric code: 982126053539688) was marked in stretch ID 113 (CS) and recaptured two months later in ID 113 → ID_{SoR} - ID_{HS} = 113 - 113 = 0 →sedentary individual ($p_{sedentary}$).

P was calculated for every sampling event separately and pooled during summer 2018 in each section (RFS - May, June, July, August, September and October; CS – August, September and October). To ensure comparability between the two sections, P was pooled in the residual flow section additionally from August 2018 until October 2018 (summer movement / pre-monitoring).

Significance check:

The test for statistical significance is performed using the calculation of ODDS RATIOS. For this purpose, P during nonmigratory period ($P_{aug\text{-}oct\_18}$, pre-monitoring) is related to P after the flood/flushing event (P_{dec_18}, post-monitoring) for each fish species in each section (ODDS).

[1] $ODDS^{aug\text{-}oct\_18} = n_{sedentary\_aug\text{-}oct\_18} / n_{total\_aug\text{-}oct\_18}$ and

$ODDS^{dec\_18} = n_{sedentary\_dec18} / n_{total\_dec\_18}$

or $ODDS^{aug\text{-}oct\_18} = P_{aug\text{-}oct\_18}$ and $ODDS^{dec\_18} = P_{dec\_18}$

after that, another ratio is calculated between the ODDS, the Odds Ratio (OR):

[2] $OR = ODDS^{aug\text{-}oct\_18} / ODDS^{dec\_18}$; $(0 \leq OR \leq +\infty)$

or $OR = P_{aug\text{-}oct\_18} / P_{dec\_18}$

In order to make the results more transparent, OR is transformed into Q

[3] $Q = (OR - 1)/(OR + 1)$; $(-1 \leq Q \leq +1)$

To test the significance of recolonization movements, P_{Dec_18} (post-monitoring) is related to the proportion of sedentary individuals of summer 2019 (P_{Aug_19}), again for each fish species in both sections.

Q = 0 means a homogeneous development between the two sampling events, +1 signals a total heterogeneity, indicating that the sedentary share of the population is massively reduced. A complete alteration between the samplings is also given if Q results in -1, stating a massive rise of the sedentary proportion.

The odds ratio (OR), its standard error and 95 % confidence interval were calculated via https://www.medcalc.org/calc/odds_ratio.php according to (Altman et al., 1991). The software calculated the significance threshold (p_{sig}-value) according to (Sheskin, 2004).

4.5.2 Individual Displacement (D)

D was measured from the midpoint of the SoR to the midpoint of the HS (Aparicio et al., 2018). Therefore, all gathered midpoints were transferred to GIS to define the distance (km) of each midpoint from the river mouth. The subtraction of the corresponding river kilometer results in the distance from the point of first capture – the individual displacement.

$$KM_{Midpoint\_SoR} - KM_{Midpoint\_HS} = D$$

Positive values were assigned to upstream movements and negative values to downstream movements (Crook, 2004; Aparicio et al., 2018):

The results of all recaptures are displayed in boxplots. The arithmetic mean of every sample is marked with a “X”, 50 % of all values are within the box, the line divides the sample in two parts (median). The whiskers (antennae) map the minimum and maximum value, with exception of statistical outliers (circles).

Additionally with regard to P, mean movement was calculated for both sedentary and mobile individuals during each sampling event.

Significance check:

To check the results of D for significance, median movement as well as the confidence intervals were determined for each sampling event within the investigation area. A significant change is given if the whiskers of two consecutive samples do not overlap. Fish recaptured either one day after the marking procedure or recaptured outside the study section, did not find consideration.

4.5.3 Turnover rate (T)

Turnover rate is defined as the proportion of individuals moving out of home section over the study period (Rodríguez, 2002).

The turnover rate was calculated as the 1 minus the proportion of marked individuals (tag-rate) in each section during each sampling event (Rodriguez, 2002; Schrank and Rahel, 2006):

$$T = 1 – [\text{tag-rate}]$$

T can be high, if emigrating tagged fish are replaced by unmarked fish. In difference to other movement studies, T was calculated on section level instead of habitat level (pool, run, riffle).

Since the share of sedentary proportion (P) delivers information whether fish stay within a certain river stretch (small scale), the turnover rate describes the willingness of individuals to leave either the residual flow section or the control section in both upstream and downstream direction (large scale).

For the calculations of T it was important to consider fish growth. Fish, which were too small during tagging periods in May 2018 (RFS) and August 2018 (RFS + CS) could have grown into the relevant size classes over time and thus been counted as unmarked (Schrank and Rahel, 2006). Therefore, the growth rate of the fish assemblages at River Möll in 2018 was calculated (Pinter et al., 2021) to avoid this methodological error. As a result, it was possible to eliminate fish during each sampling event, that could have grown into the markable length category. For the evaluation of T, no distinction was made neither between species nor size classes.

Significance check:

Fish move due to several reasons (see Railsback et al., 1999; Heggenes et al., 2007). This leads to an increasing turnover rate over time and this rise can be expected as relatively constant. Therefore, an abrupt change in turnover rate may exemplify certain alterations in the stream section or within the population.

During the project "Fischökologische Studie Rottau 2018/19" the IHG (Institut für Hydrobiologie und Gewässermanagement - BOKU Wien) developed a regression model. This model is based on the tag-rate of the samples until October 2018 and predicts the development of the tag-rate. If the forecast and the observation are comparable after the flood/flushing event, enhanced discharges do not have any impact on the tagged fish populations. Otherwise, there is an impact, especially if the observed tag-rates are outside the confidence intervals of the predicted tag-rate (significant change, see Figure 49, Figure 50) (Pinter et al., 2021).

5 RESULTS

5.1 Marking Effort

The two study sections ensure comparability in numbers of marked individuals and section length (see Figure 17). In this mark recapture study, in total 6 978 fish (age 1+ onwards) were PIT-tagged, from that 3 579 in the residual flow section with a total length of about 2,7 km and consisting of 24 stretches (average length ~111 m). During the quantitative samplings in May (Stretch ID 1-19) and August 2018 (Stretch ID 20-24) 2 668 rainbow trout, 552 brown trout and 359 graylings were marked (see Table 1).

Figure 17: Fishing and tagging effort in the two study sections.

Table 1: Number of tagged individuals per stretch und species in the residual flow section.

Residual Flow Section						
		Count of tagged Individuals [n]				
Stretch ID	**Length [m]**	**Rainbow Trout**	**Brown Trout**	**Grayling**	**Total**	**Ind./100m**
1	85	38	1	15	54	64
2	115	88	1	8	97	84
3	97	92	4	16	112	115
4	100	87	8	11	106	106
5	108	154	19	15	188	174
6	172	179	7	26	212	123
7	75	143	25	8	176	235
8	120	152	36	12	200	167
9	140	182	23	13	218	156
10	160	184	34	34	252	158
11	130	196	40	26	262	202
12	90	100	15	5	120	133
13	94	125	31	7	163	173
14	110	123	33	4	160	145
15	116	126	28	5	159	137
16	112	119	23	14	156	139
17	120	99	12	38	149	124
18	145	149	62	11	222	153
19	109	158	31	17	206	189
20	120	62	26	18	106	88
21	76	56	25	21	102	134
22	99	20	20	9	49	49
23	68	8	22	3	33	49
24	100	28	26	23	77	77
Total	**2 661**	**2 668**	**552**	**359**	**3 579**	**Ø 134**

Figure 18 shows the species distribution below the reservoir. The residual flow section is dominated by rainbow trout (~75 % of the population), followed by brown trout (15 %) and grayling (10 %).

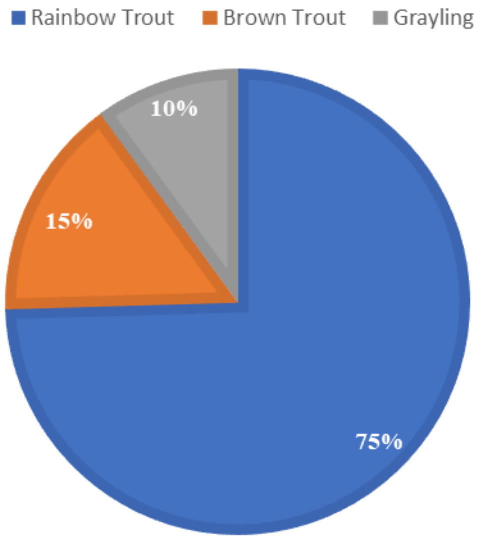


Figure 18: Species distribution in the residual flow section.

The overall number of individuals per 100 m comes to 151, whereas in the RFS the number of fish was slightly lower with 134/100 m compared to 167/100 m in the CS.

In the control section 16 stretches (average length ~128 m, total length ~2,0 km) were examined in August 2018 and 3 399 individuals were marked, from that 1 677 brown trout, 904 rainbow trout and 818 graylings (see Table 2).

Table 2: Number of tagged individuals per stretch und species in the control section.

Control Section						
		Count of tagged Individuals [n]				
Stretch ID	**Length [m]**	**Rainbow Trout**	**Brown Trout**	**Grayling**	**Total**	**Ind./100m**
101	128	5	18	22	45	35
102	120	43	89	56	188	157
103	143	49	103	55	207	145
104	118	40	56	42	138	117
105	172	65	77	39	181	105
106	102	51	63	30	144	141
107	175	76	110	48	234	134
108	118	88	125	57	270	229
109	148	41	82	44	167	113
110	77	40	50	32	122	158
111	160	97	221	102	420	263
112	127	50	105	75	230	181
113	121	82	169	79	330	273
114	95	60	158	64	282	297
115	111	68	152	31	251	226
116	125	49	99	42	190	152
Total	**2 040**	**904**	**1 677**	**818**	**3 399**	**Ø 167**

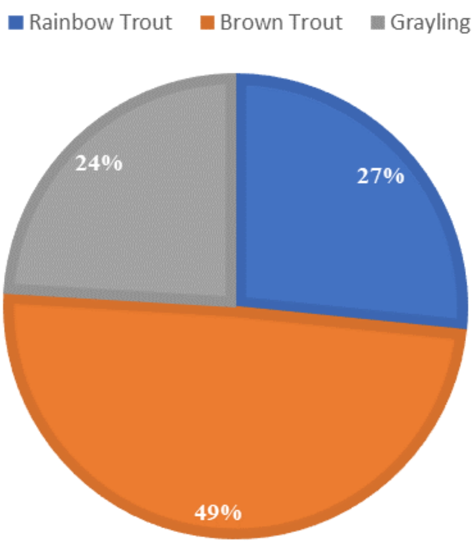


Figure 19: Species distribution in the control section.

While brown trout makes up only 15 % of the fish population in the RFS, it occurs most frequent in the control section (~50 %). The share of grayling and rainbow trout is nearly at the same level (see Figure 19).

Table 3: Count of recaptured fish and total recaptures throughout the study period in comparison between both study sections.

Section	Species	4x	3x	2x	1x	Total fish	Total recaptures
RFS							
	Rainbow trout	3	23	106	546	678	839
	Brown trout		5	19	92	116	145
	Grayling		4	12	44	60	80
	Total	**3**	**32**	**137**	**682**	**854**	**1 064**
CS							
	Rainbow trout	2	6	55	287	350	423
	Brown trout		8	82	440	530	628
	Grayling	1	3	46	187	237	292
	Total	**3**	**17**	**183**	**914**	**1 117**	**1 343**

All movement calculations and assumptions below are based on recaptures. In Table 3 all recaptures from both study sections are confronted, some fish were recaptured more than once. Single individuals were caught up to 4 times, therefore the count of total recaptures is higher than the count of recaptured fish. Before the drawdown flushing event, on average 145 tagged individuals were caught during each spot check in the residual flow section. Despite enhanced electrofishing effort after the event, the number of recaptures decreased after the sediment release from the reservoir (see Table 5). On the contrary, in the control section numerous marked individuals were recaptured after the flood in December 2018. Even during the spot checks in August 2019, a high number of caught fish still carried a PIT-tag (see Table 7).

5.1.1 Length-Frequency-Diagrams

The length-frequency-diagrams (LFD) give information about the population structure of the fish assemblages. Fish length is plotted on the x-axis, the frequency (n) of the corresponding length class is pictured on the y-axis. The black bars show all tagged individuals, the white bars show unmarked fish.

5.1.1.1 LFD residual flow section

The LFD of rainbow trout in the RFS shows a good age structure with many individuals in the small length classes, several adult rainbow trout occur as well (see Figure 20). The population structure of brown trout is good as well (Figure 21), only in the case of grayling (Figure 22) the juvenile part of the population is under-represented.

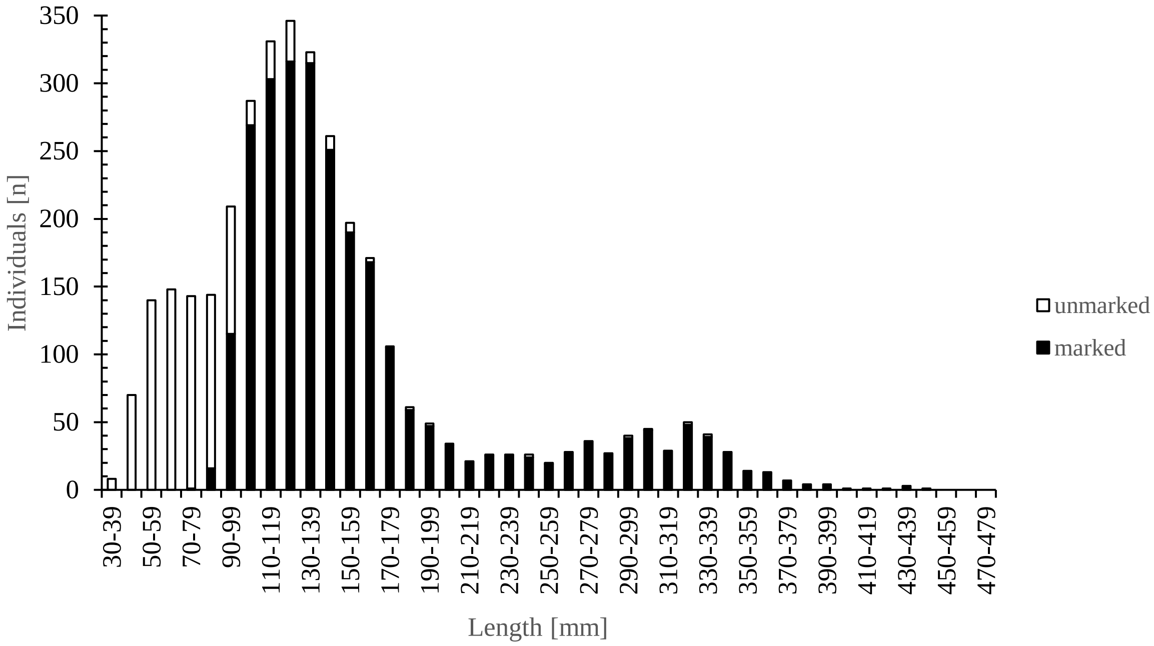


Figure 20: Length-Frequency-Diagram of rainbow trout in May 2018 and August 2018 (pooled) (n_{marked} = 2 668; $n_{unmarked}$ = 852)

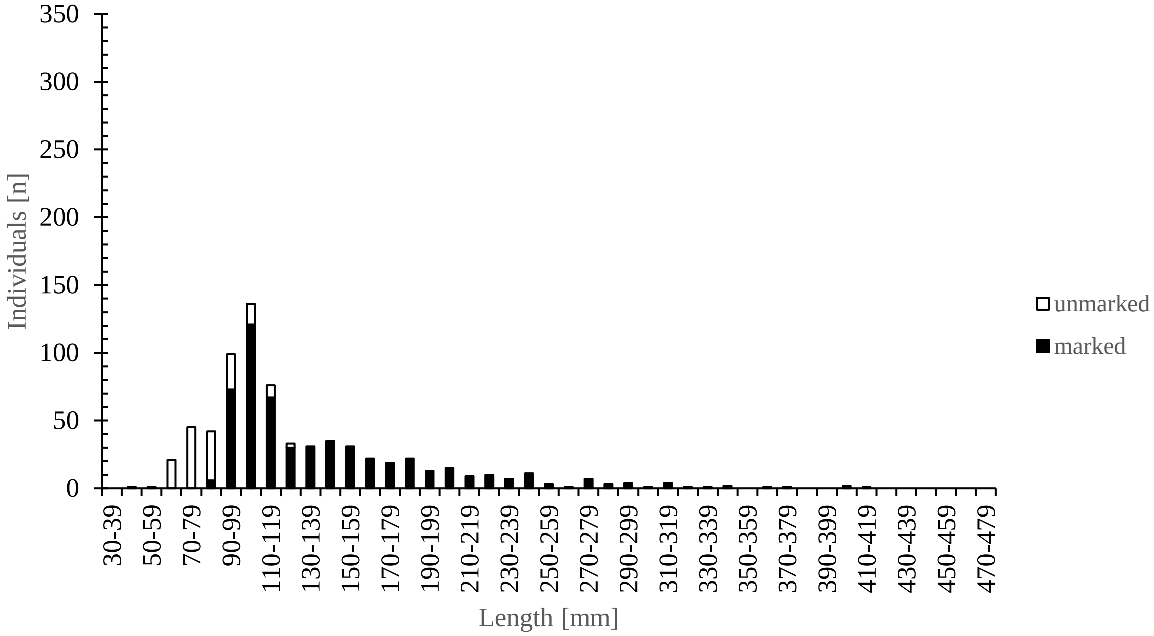


Figure 21: Length-Frequency-Diagram of brown trout in May 2018 and August 2018 (pooled) (n_{marked} = 552; $n_{unmarked}$ = 159)

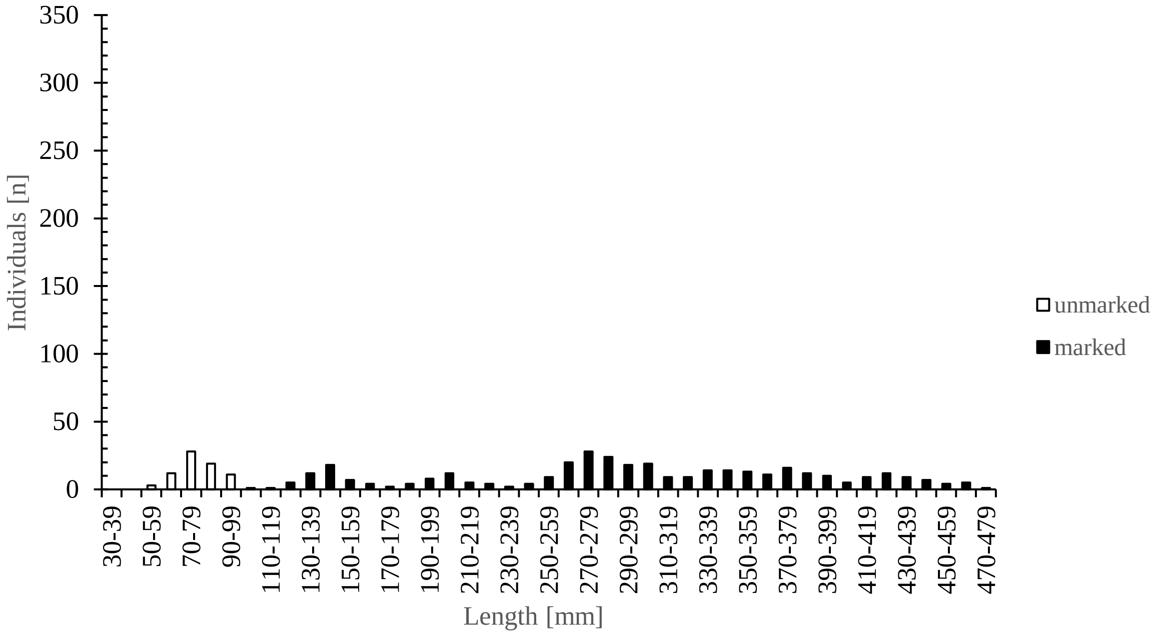


Figure 22: Length-Frequency-Diagram of grayling in May 2018 and August 2018 (pooled) (n_{marked} = 359; $n_{unmarked}$ = 82)

5.1.1.2 LFD control section

The population structure is in good shape for all study species in the CS in August 2018. The length-frequency-diagrams below show an underrepresentation of the age group "young of the year" (individuals < 100 mm). This can be explained by the methodological design of the study, since only individuals larger than 85 mm were tagged (smaller fish were consciously not caught during the electrofishing).

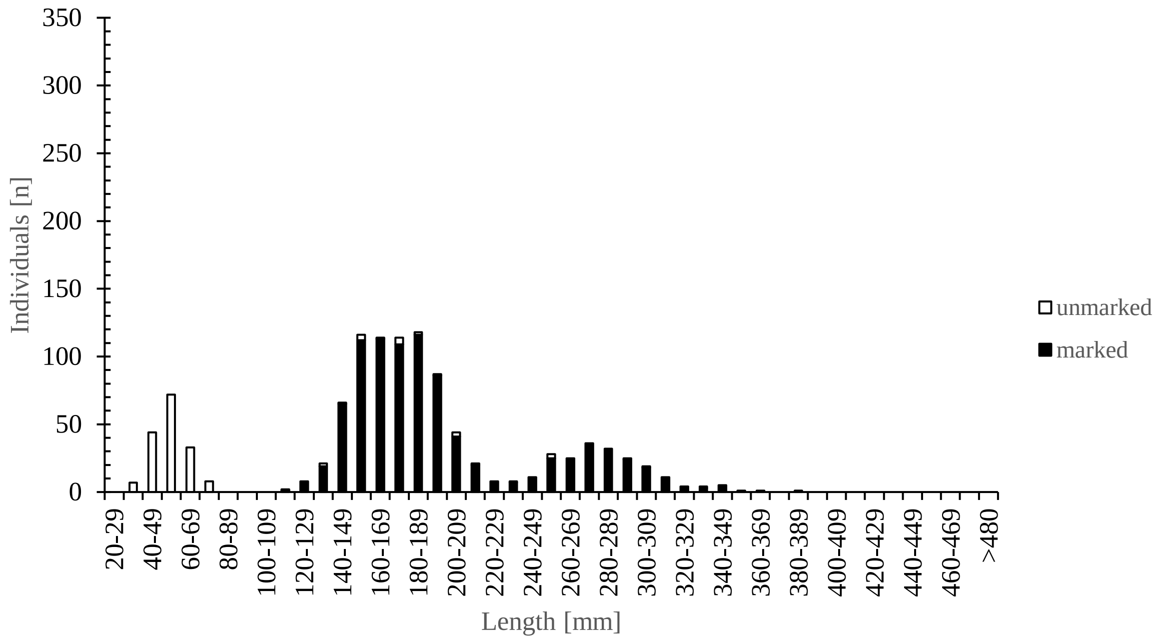


Figure 23: Length-Frequency-Diagram of rainbow trout in the CS in August 2018 (n_{marked} = 904; $n_{unmarked}$ = 192)

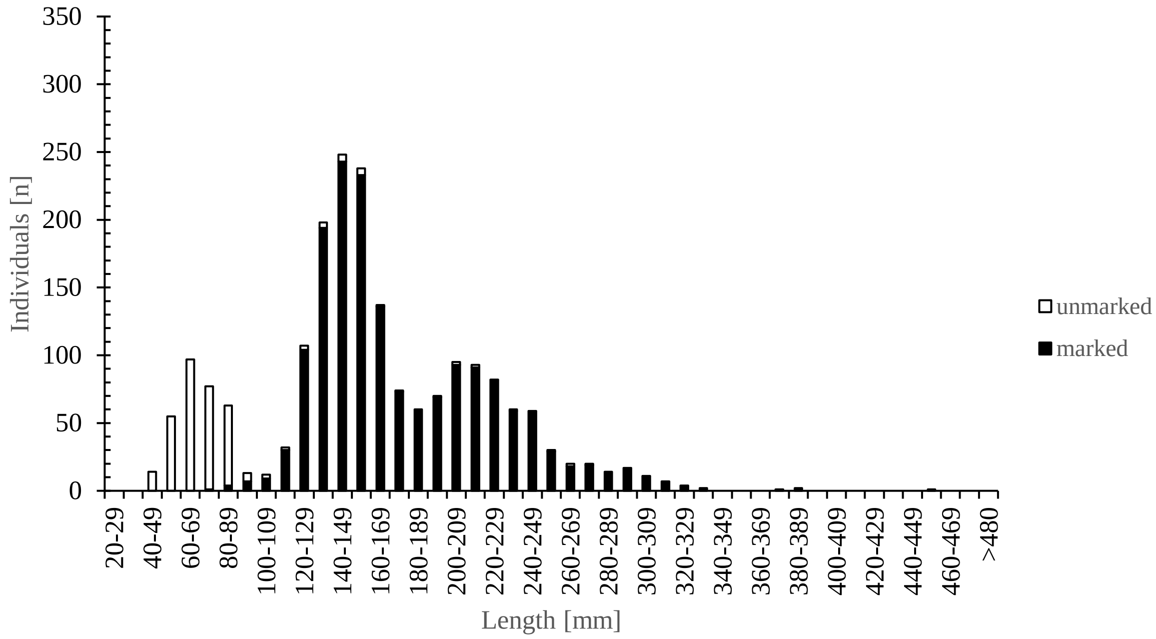


Figure 24: Length-Frequency-Diagram of brown trout in the CS in August 2018 (n_{marked} = 1 677; $n_{unmarked}$ = 341)

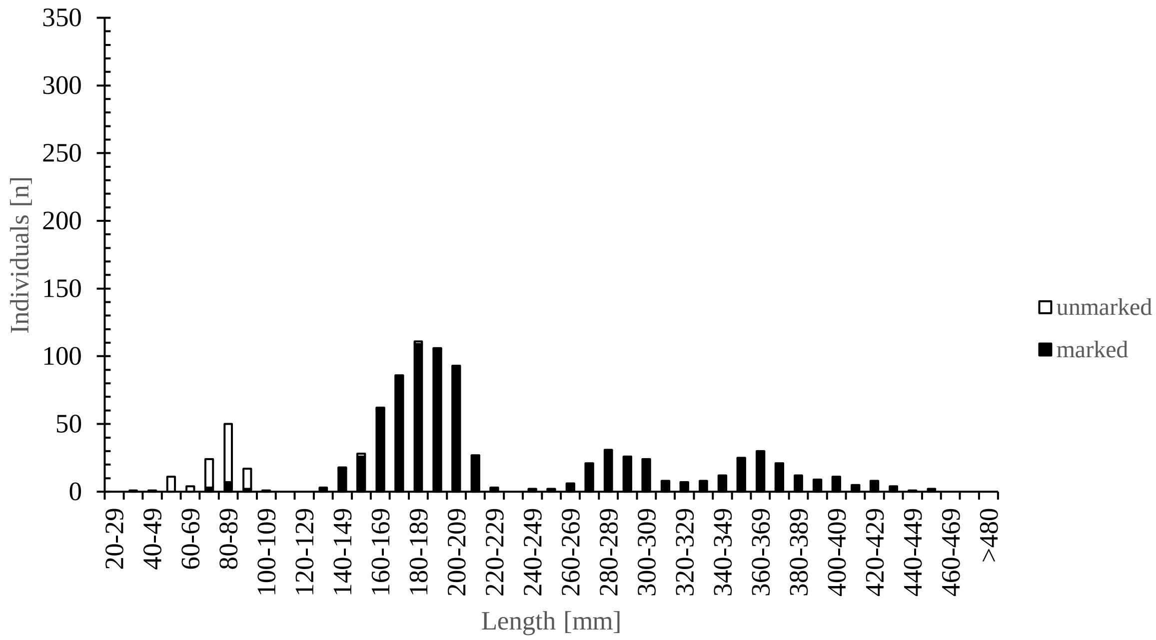


Figure 25: Length-Frequency-Diagram of grayling in the CS in August 2018 (n_{marked} = 818; $n_{unmarked}$ = 103)

5.2 Proportion of Sedentary Individuals (P)

5.2.1 Residual Flow Section

Fish movement in the RFS was restricted during summer. A high share of detected fish stayed within the stretch of first capture or the neighboring one (home range). Between May 2018 and October 2018, 868 salmonids were recaptured, from that 85 % were assigned as sedentary (see Table 4, $P_{may\text{-}oct\_18} = 0.85$)

Table 4: Recaptured fish in the RFS, pooled from May 2018 until October 2018 and from August 2018 until October 2018. (RBT = rainbow trout; BT = brown trout; G = grayling).

Section	Period of time	Species	n	Sedentary Ind.	Mobile Ind.	P
Residual Flow Section	May until October 2018	RBT	694	593	101	0,85
		BT	108	97	11	0,90
		G	66	51	15	0,77
		Salmonids	868	741	127	0,85
		RBT (>200)	355	307	48	0,86
		RBT (<201)	339	286	53	0,84
	August until October 2018	RBT	356	312	44	0,88
		BT	67	61	6	0,91
		G	32	25	7	0,78
		Salmonids	455	398	57	0,87
		RBT (>200)	233	213	20	0,91
		RBT (<201)	123	99	24	0,80

The analysis on species level shows a high preference of brown trout to stay local (P = 0.90). While P of rainbow trout was equal to all salmonids, grayling showed a slightly higher readiness to move (P = 0.77).

Due to low recaptures of brown trout and grayling throughout the study in the residual flow section, only the two size classes of rainbow trout were compared. Fish smaller than 201 mm showed very similar movement behavior as fish larger than 200 mm (84 % and 86 % behaved sedentary) in summer 2018.

After the drawdown flushing, P of salmonids dropped from 0.86 to 0.47 (October 2018 to December 2018, see Table 5). Therefore, more than 50 % of all recaptures were caught beyond their home range. The sampling of December 2018 was dominated by marked rainbow trout (n = 59), while only 14 tagged brown trout and 3 tagged graylings were caught.

In consideration of low recaptures of brown trout and grayling (see Table 5) Figure 26 shows P for all three species. Until October 2018 P developed very similar for brown trout and rainbow trout, after the drawdown flushing the development changed. P_{BT} (brown trout) first dropped to 0.64 in December 2018 and then constantly increased to 0.86 in August 2019. On the contrary only about 40 % of recaptured rainbow trout were caught in its former habitats after the flushing.

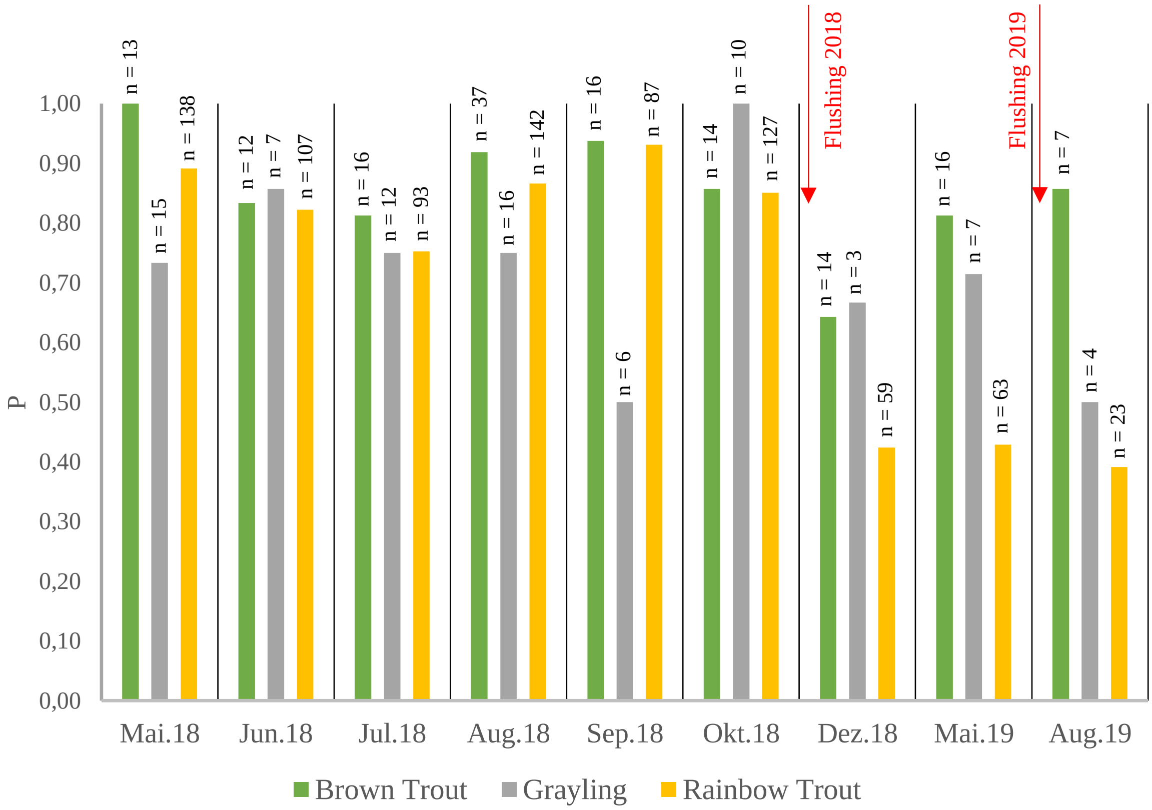


Figure 26: Proportion of sedentary individuals (P) in the residual flow section during the whole study period. n_{may18} *=166,* n_{june18} *=126;* n_{july18} *=121;* $n_{august18}$ *=195;* $n_{september18}$ *=109;* $n_{october18}$ *=151;* $n_{december18}$ *=76;* n_{may19} *=86;* $n_{august19}$ *=34.*

Due to high growth of juvenile rainbow trout and low recaptures after the flushing anyway, it is difficult to describe differences in movement behavior between the age groups. Still, in December 2018 46 % of rainbow trout smaller than 201 mm (n = 13, P = 0.46) were found within their home range, when P was 0.41 for larger rainbow trout (n = 46; see Table 5).

Table 5: P in the RFS during the whole study period.

Section	Month	Species	n	Sedentary Ind.	Mobile Ind.	P
Residual Flow Section	MAY 2018	Salmonids	166	147	19	**0,89**
		RBT	138	123	15	**0,89**
		RBT >200	43	36	7	0,84
		RBT <201	95	87	8	0,92
		BT (All)	13	13	0	**1,00**
		G (>200)	15	11	4	**0,73**
	JUNE 2018	Salmonids	126	104	22	**0,83**
		RBT	107	88	19	**0,82**
		RBT >200	37	27	10	0,73
		RBT <201	70	61	9	0,87
		BT (All)	12	10	2	**0,83**
		G (>200)	7	6	1	**0,86**
	JULY 2018	Salmonids	121	92	29	**0,76**
		RBT	93	70	23	**0,75**
		RBT >200	42	31	11	0,74
		RBT <201	51	39	12	0,76
		BT (All)	16	13	3	**0,81**
		G (>200)	12	9	3	**0,75**
	AUGUST 2018	Salmonids	195	169	26	**0,87**
		RBT	142	123	19	**0,87**
		RBT >200	63	57	6	0,90
		RBT <201	79	66	13	0,84
		BT (All)	37	34	3	**0,92**
		G (>200)	16	12	4	**0,75**
	SEPTEMBER 2018	Salmonids	109	99	10	**0,91**
		RBT	87	81	6	**0,93**
		RBT >200	66	65	1	0,98
		RBT <201	21	16	5	0,76
		BT (All)	16	15	1	**0,94**
		G (>200)	6	3	3	**0,50**
	OCTOBER 2018	Salmonids	151	130	21	**0,86**
		RBT	127	108	19	**0,85**
		RBT >200	104	91	13	0,88
		RBT <201	23	17	6	0,74
		BT (All)	14	12	2	**0,86**
		G (>200)	10	10	0	**1,00**
	→	FLOOD INCLUDING A DRAWDOWN FLUSHING				
	DECEMBER 2018	Salmonids	76	36	40	**0,47**
		RBT	59	25	34	**0,42**
		RBT >200	46	19	27	0,41
		RBT <201	13	6	7	0,46
		BT (All)	14	9	5	**0,64**
		G (>200)	3	2	1	**0,67**
	MAY 2019	Salmonids	86	45	41	**0,52**
		RBT	63	27	36	**0,43**
		RBT >200	59	24	35	0,41
		RBT <201	4	3	1	0,75
		BT (All)	16	13	3	**0,81**
		G (>200)	7	5	2	**0,71**
	→	FLOOD INCLUDING A DRAWDOWN FLUSHING				
	AUGUST 2019	Salmonids	34	17	17	**0,50**
		RBT (>200)	23	9	14	**0,39**
		BT (All)	7	6	1	**0,86**
		G (>200)	4	2	2	**0,50**

5.2.2 Control Section

Regarding summer movement patterns (nonmigratory period from August 2018 until October 2018) in the CS the results of P show highly sedentary movement behavior of salmonids. From 661 recaptures, 88 % were assigned to the sedentary fraction of the fish assemblage (see Table 6). On species level rainbow trout and brown trout behaved similar, grayling shows comparatively less site fidelity (P = 0.83).

Table 6: Recaptured fish in the CS, pooled from August 2018 until October 2018. (RBT = rainbow trout; BT = brown trout; G = grayling).

Section	Period of time	Species	n	Sedentary Ind.	Mobile Ind.	P
Control Section	August until October 2018	RBT	188	165	23	0,88
		BT	341	307	34	0,90
		G	132	110	22	0,83
		Salmonids	661	582	79	0,88
		RBT (>200)	84	73	11	0,87
		RBT (<201)	104	92	12	0,88
		BT (>200)	118	109	9	0,92
		BT (<201)	223	198	25	0,89
		G (>200)	92	78	14	0,85
		G (<201)	40	32	8	0,80

In September 2018 and October 2018 more than 90 % of recaptured individuals were found within their home range. Therefore, salmonids showed even higher site fidelity than in the sampling after the marking procedure in August 2018 (see Figure 27). In view of the two size classes, no notable differences in P were ascertainable during the nonmigratory period.

The flood event (HQ20) in the end of October 2018 led to enhanced movement. The proportion of sedentary individuals dropped to 0.66 during the spot checks in December 2018.

Grayling and rainbow trout were affected more by the flood event than brown trout. While P_{BT} was reduced from 0.92 (October 2018) to 0.72, P_{RBT} decreased by 0.28 and P_{G} by 0.26 (see Table 7).

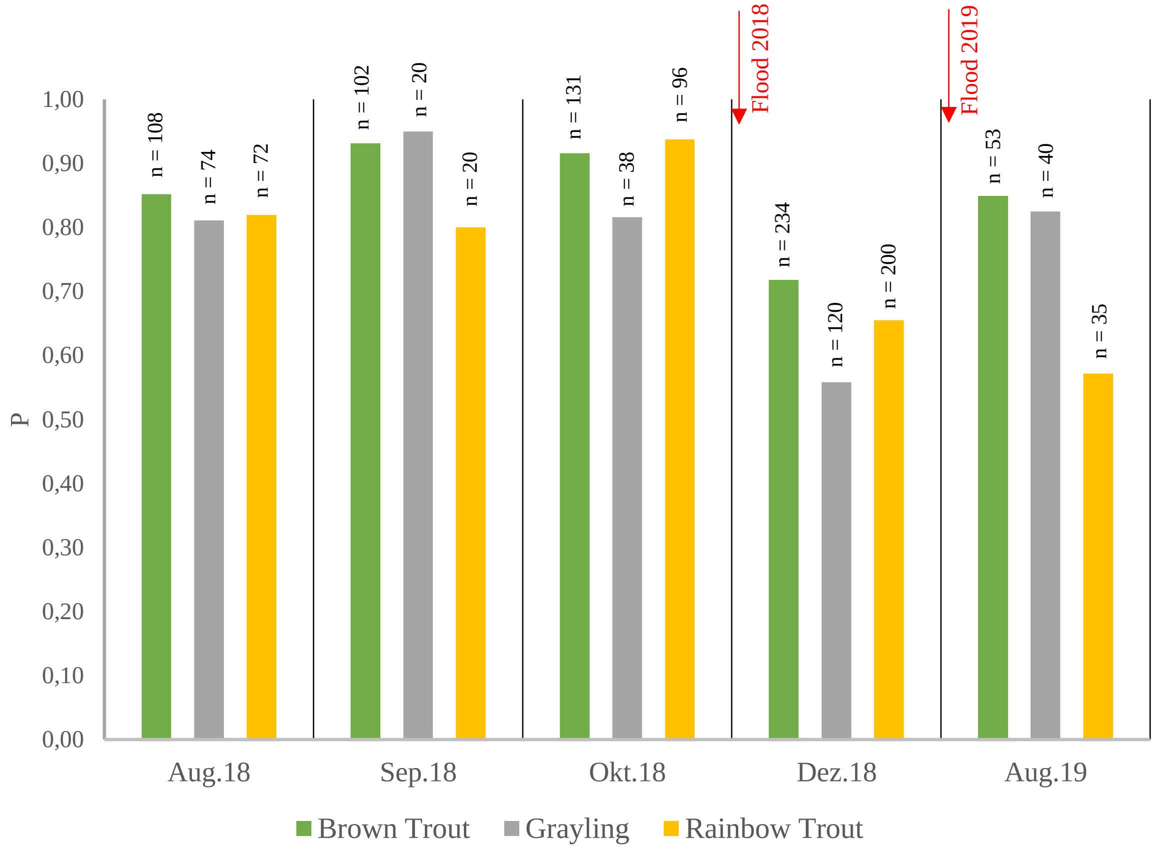


Figure 27: Proportion of sedentary individuals (P) in the control section from August 2018 and August 2019. $n_{august18}$ =254, $n_{september18}$ =142; $n_{october18}$ =265; $n_{december18}$ =554; $n_{august19}$ =128.

Eight months later, in August 2019, after the second flood event (HQ1), P of salmonids increased to 0.77 (see also Table 7). Especially brown trout and grayling tended to return to the stretch of first capture or the neighboring stretch (BT 85 %, G 83 %), while only 57 % of recaptured rainbow trout occupied former habitats.

After the flood event it seems, that individuals > 200 m show stronger recolonization movements than smaller fish. $P_{BT > 200\ mm}$ recovers from 0.72 in December 2018 to 0.91 in August 2019, while $P_{BT < 201mm}$ remains the same. Furthermore, in August 2019 all three recaptured individuals of rainbow trout smaller 201 mm were caught beyond their home range.

Table 7: P in the CS during August 2018 and August 2019.

Section	Month	Species	n	Sedentary Ind.	Mobile Ind.	P
Control Section	AUGUST 2018	Salmonids	254	211	43	**0.83**
		RBT	72	59	13	**0.82**
		RBT >200	20	14	6	0.70
		RBT <201	52	45	7	0.87
		BT	108	92	16	**0.85**
		BT>200	30	25	5	0.83
		BT<201	78	67	11	0.86
		G	74	60	14	**0.81**
		G>200	46	36	10	0.78
		G<201	28	24	4	0.86
	SEPTEMBER 2018	Salmonids	142	130	12	**0.92**
		RBT	20	16	4	**0.80**
		RBT>200	6	5	1	0.83
		RBT<201	14	11	3	0.79
		BT	102	95	7	**0.93**
		BT>200	36	36	0	1.00
		BT<201	66	59	7	0.89
		G	20	19	1	**0.95**
		G>200	14	14	0	1.00
		G<201	6	5	1	0.83
	OCTOBER 2018	Salmonids	265	241	24	**0.91**
		RBT	96	90	6	**0.94**
		RBT >200	58	54	4	0.93
		RBT <201	38	36	2	0.95
		BT	131	120	11	**0.92**
		BT>200	52	48	4	0.92
		BT<201	79	72	7	0.91
		G	38	31	7	**0.82**
		G>200	32	28	4	0.88
		G<201	6	3	3	0.50
	→	FLOOD - HQ20				
	DECEMBER 2018	Salmonids	554	366	188	**0.66**
		RBT	200	131	69	**0.66**
		RBT >200	131	88	43	0.67
		RBT <201	69	43	26	0.62
		BT	234	168	66	**0.72**
		BT>200	96	69	27	0.72
		BT<201	138	99	39	0.72
		G	120	67	53	**0.56**
		G>200	113	64	49	0.57
		G<201	7	3	4	0.43
	→	FLOOD - HQ1				
	AUGUST 2019	Salmonids	128	98	30	**0.77**
		RBT	35	20	15	**0.57**
		RBT >200	32	20	12	0.63
		RBT <201	3	0	3	0.00
		BT	53	45	8	**0.85**
		BT>200	35	32	3	0.91
		BT<201	18	13	5	0.72
		G (>201)	40	33	7	**0.83**

5.2.3 Comparison of the two sites

As already described in 5.2.1 and 5.2.2 the proportion of sedentary individuals was very high in both river sections until October 2018. The flood in the CS as well as the flood including a drawdown flushing in the RFS led to a dislocation of both fish assemblages, when P_{RFS} decreased under 0.50 in December 2018 (P_{CS} = 0.66). While salmonids showed tendencies to recolonization movements in the control section, P stayed close to 0.50 during samplings in May 2019 and August 2019 in the RFS.

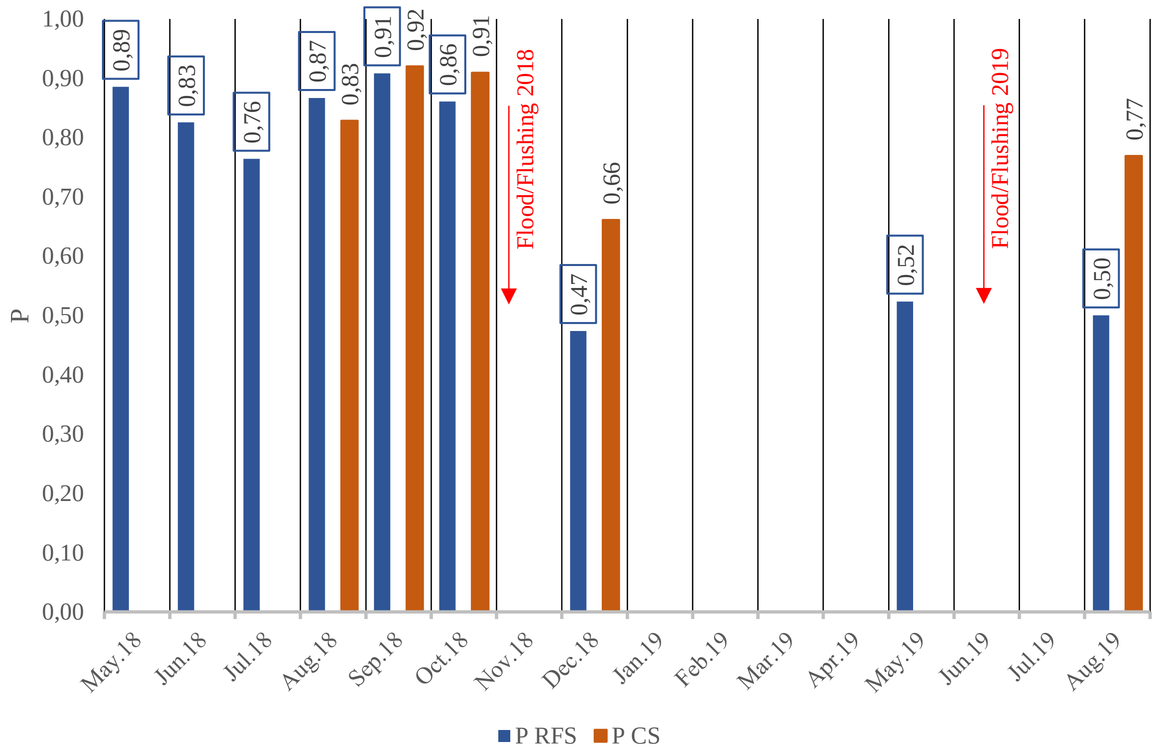


Figure 28: Proportion of sedentary individuals (P) of salmonids from May 2018 until August 2019 in the residual flow section (n_{may18} = 166; n_{june18} =126; n_{july18} =121; $n_{august18}$ =195; $n_{september18}$ =109; $n_{october18}$ =151; $n_{december18}$ =76; n_{may19} =86; $n_{august19}$ =34) and the control section ($n_{august18}$ =254; $n_{september18}$ =142; $n_{october18}$ =265; $n_{december18}$ =554; $n_{august19}$ =128).

A precise view on the development of P on species level is shown in Figure 29. In October 2018, the proportion of sedentary individuals was over 0.80 for all study species. The flood event occurred 180 days after the first day of the study in May 2018.

Rainbow trout showed more reaction on enhanced discharges than brown trout and left its home ranges to a larger extent. While brown trout was able to recolonize its former habitats (in both sections more than 80 % of all recaptures in August 2019), P_{RBT} remained the same or even decreased over time.

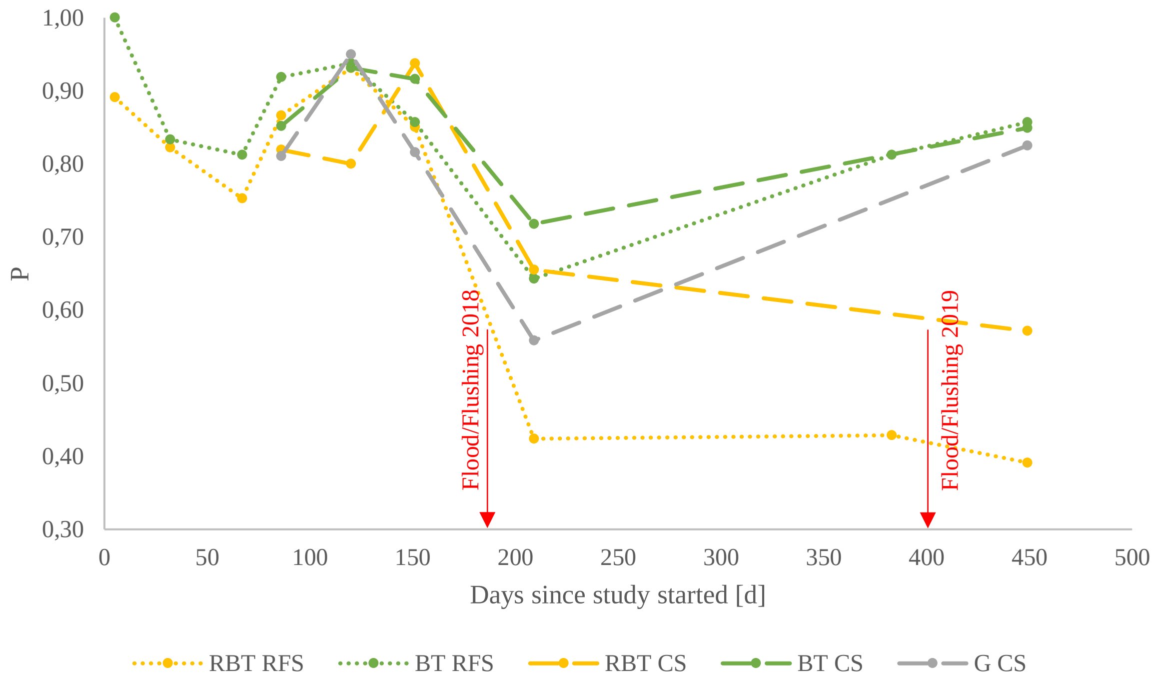


Figure 29: Comparison of P since the very first day of the study in May 2018. The dotted lines show the development of P of rainbow trout (RBT) and brown trout (BT) in the residual flow section, the dashed lines of RBT, BT and G (grayling) in the control section.

Due to the large share of rainbow trout in the samples of December 2018, May 2019 and August 2019 in the residual flow section, P_{RFS} did not recover and stayed close to 0.50 (Figure 28).

Because of low recaptures of grayling in the RFS after the drawdown flushing ($n_{december2018} = 3$; $n_{may2019} = 7$; $n_{august2019} = 4$), it was not considered in Figure 29. In the CS, 44 % of recaptured graylings left their home range after the flood event ($n_{december2018} = 120$, $P_G = 0.56$) but showed – like brown trout – enhanced recolonization-movements into the area of first capture in August 2019 ($P_G = 0.83$; $n_{august2019} = 40$).

5.2.4 Check for significance

The proportion of sedentary individuals (P) was tested for significant behavioral changes of salmonids in both study sections. The ODD ratio of all study species was compared between:

- P during nonmigratory period (pooled from August 2018 until October 2018)
- P after the flood/drawdown flushing (December 2018)
- P in August 2019 in terms of recolonization movement analysis

Q would equal 0, if the development of P was homogeneous. If Q equals or exceeds ± 0.2, the change between two observations was statistical significant (Sachs, 1992). Statistical significance was also given, when p_{sig} was < 0,05. The sample size is decisive for the set of the confidence intervals, if it is small the range of the whiskers is wider since the sample loses on explanatory power.

Table 8: Result table of species-specific analysis according to the proportion of sedentary individuals (a,b,c,d). OR = ODDS RATIO; Q = ODDS RATIO transformed to Q; uGR = lower barrier confidence intervals, oGR = upper barrier confidence intervals. Significance level α = 0,05. Statistically significant cells are highlighted in red.

	Pre-monitoring		Post-monitoring										
	sed (n)	total (n)	sed (n)	total (n)					uGr	oGR	p_{sig}	uGr	oGR
Species - Section	***a***	***b***	***c***	***d***	***Odds1 (P_{pre})***	***Odds2 (P_{post})***	***OR***	***Q***	***OR***			Q	
RBT - RFS	312	356	25	59	0.88	0.42	2.07	0.348	1.265	3.382	0.004	0.117	0.544
RBT - CS	165	188	131	200	0.88	0.66	1.34	0.145	0.989	1.816	0.059	-0.006	0.290
BT - RFS	61	67	9	14	0.91	0.64	1.42	0.172	0.572	3.506	0.452	-0.272	0.556
BT - CS	307	341	168	234	0.90	0.72	1.25	0.113	0.976	1.612	0.077	-0.012	0.234
G - CS	110	132	67	120	0.83	0.56	1.49	0.198	1.009	2.208	0.045	0.004	0.377
	Post-monitoring		Summer 2019										
	sed (n)	total (n)	sed (n)	total (n)					uGr	oGR	p_{sig}	uGr	oGR
Species - Section	***a***	***b***	***c***	***d***	***Odds2 (P_{post})***	***Odds3 ($P_{recol.}$)***	***OR***	***Q***	***OR***			Q	
RBT - RFS	25	59	9	23	0.42	0.39	1.08	0.040	0.440	2.667	0.863	-0.389	0.455
RBT - CS	131	200	20	35	0.66	0.57	1.15	0.068	0.634	2.072	0.651	-0.224	0.349
BT - RFS	9	14	6	7	0.64	0.86	0.75	-0.143	0.190	2.966	0.682	-0.681	0.496
BT - CS	168	234	45	53	0.72	0.85	0.85	-0.084	0.542	1.318	0.459	-0.297	0.137
G - CS	67	120	33	40	0.56	0.83	0.68	-0.193	0.391	1.172	0.164	-0.438	0.079

The proportion of sedentary individuals during nonmigratory period ($P_{aug-oct\_18}$, pre-monitoring) is related to P after the flood/flushing event (P_{dec_18}, post-monitoring) in Figure 30. Statistical significant observations were made for rainbow trout in the residual flow section, when Q resulted in 0.348 and p in 0.004. Apart from that, only grayling in the CS experienced a significant change (p_{sig} = 0.045). In the control section, the development of P for RBT showed a very clear trend as well with p_{sig} = 0.059, but significance was not given (see Table 8).

The decline of P for brown trout in the RFS was strong (ODD1 = 0,91; ODD2 = 0,64), but the development was not statistically significant (p = 0.452). Between the species no significant difference was observed, since all confidence intervals are overlapping. Q shows exclusively positive values, this means that P was reduced for all species after the flood/drawdown flushing.

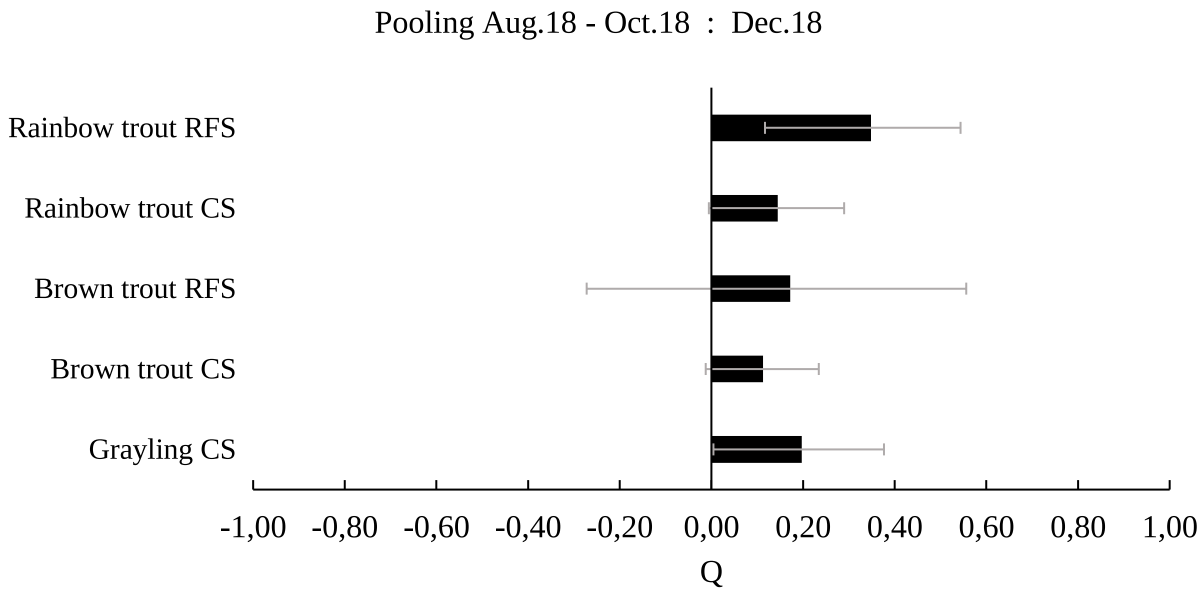


Figure 30: Development of P between pre-monitoring ($P_{aug-oct\_18}$) and post-monitoring (P_{dec_18}) for all study species in both study sections.

Regarding the two size classes, Figure 31 shows the development of rainbow trout between pre-monitoring and post-monitoring in both study sections. While individuals larger than 200 mm left their home range to a larger extend in the residual flow section, RBT < 201 mm in the control section were more affected by the flood than the larger individuals. Q in the RFS was > 0.2 for both size classes (significant change), in the CS Q was < 0.2 for larger as well as for smaller individuals. Significant differences between the size classes were not observed.

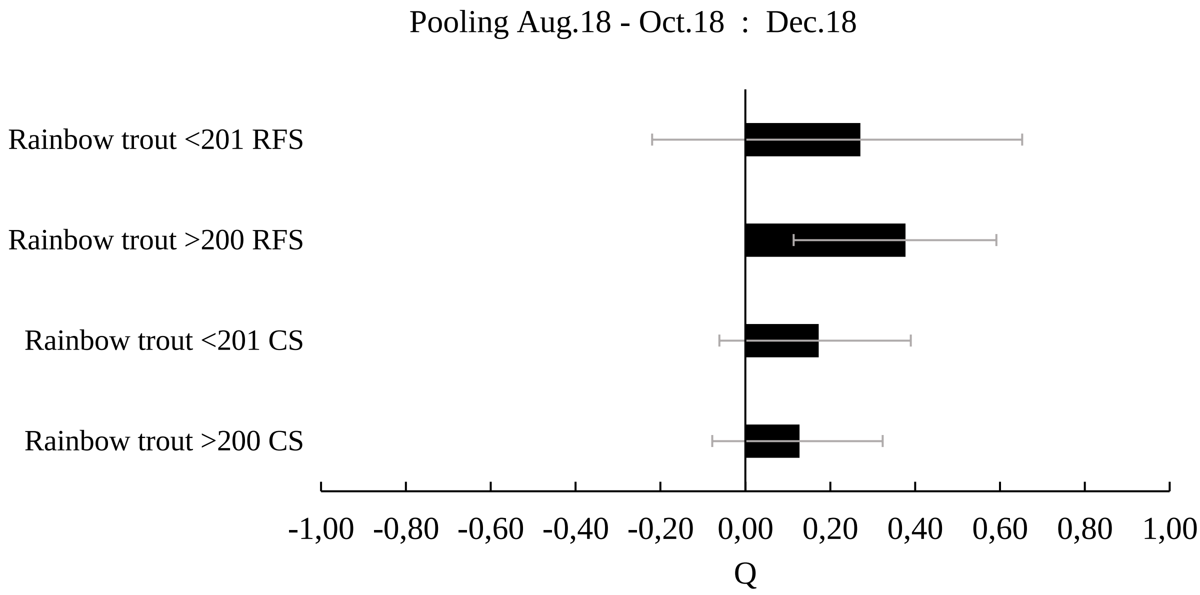


Figure 31: Development of P between pre-monitoring ($P_{aug-oct\_18}$) and post-monitoring (P_{dec_18}) for rainbow trout in view of the two size classes in both study sections.

With regard to recolonization movements, Q resulted in slightly positive values for RBT, whereas for brown trout and grayling the values were negative. While the ODDS of rainbow trout showed low heterogeneity between December 2018 and August 2019, the development of grayling was nearly significant (Q = -0,193). The contrary trend between the species is shown in Figure 32 and Table 8, brown trout and grayling returned to former occupied habitats in difference to rainbow trout, but due to the overlapping confidence intervals the development was not significantly different between the species.

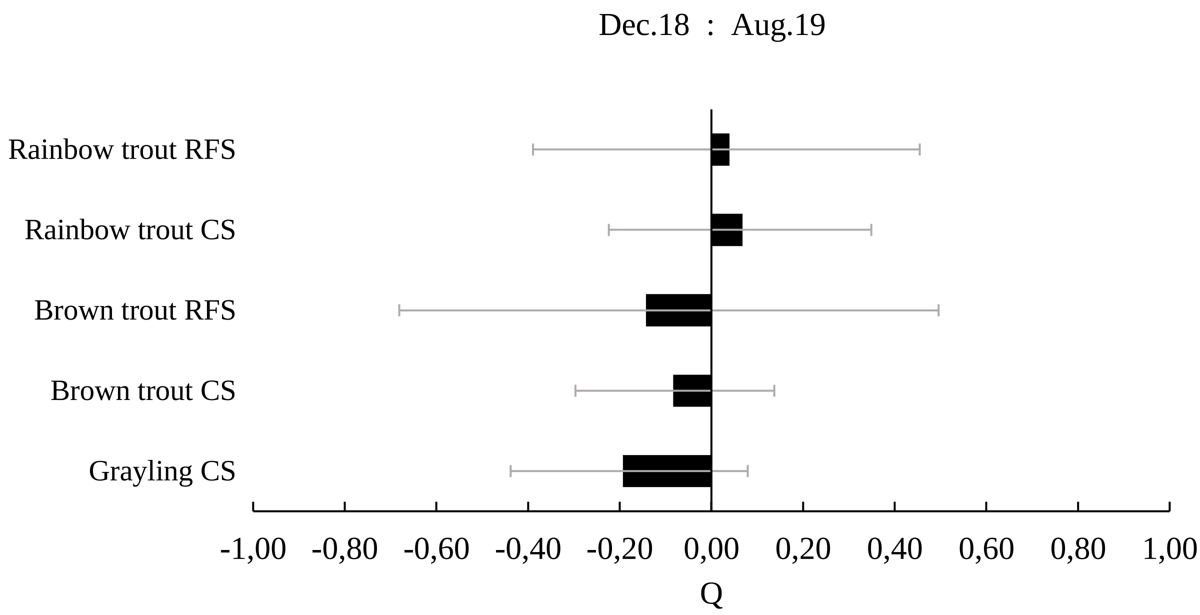


Figure 32: Development of P between post-monitoring (P_{dec_18}) and August 2019 (P_{aug_19}) for all study species in both study sections

5.2.5 Behavior of mobile fraction

This chapter focuses on the mobile fraction of the fish in the control section (undisturbed hydrological conditions). Do individuals leave their home range in upstream or downstream direction? How do they react to enhanced natural discharges?

Figure 33 shows the upstream moving share of the mobile proportion of the fish assemblage. In August 2018, 36 % of 43 individuals left in upstream direction, in September 2018 all study species moved mainly up the river (more than 70 %). In October 2018 again more than 60 % of mobile fish were recaptured in upstream regions of their home range.

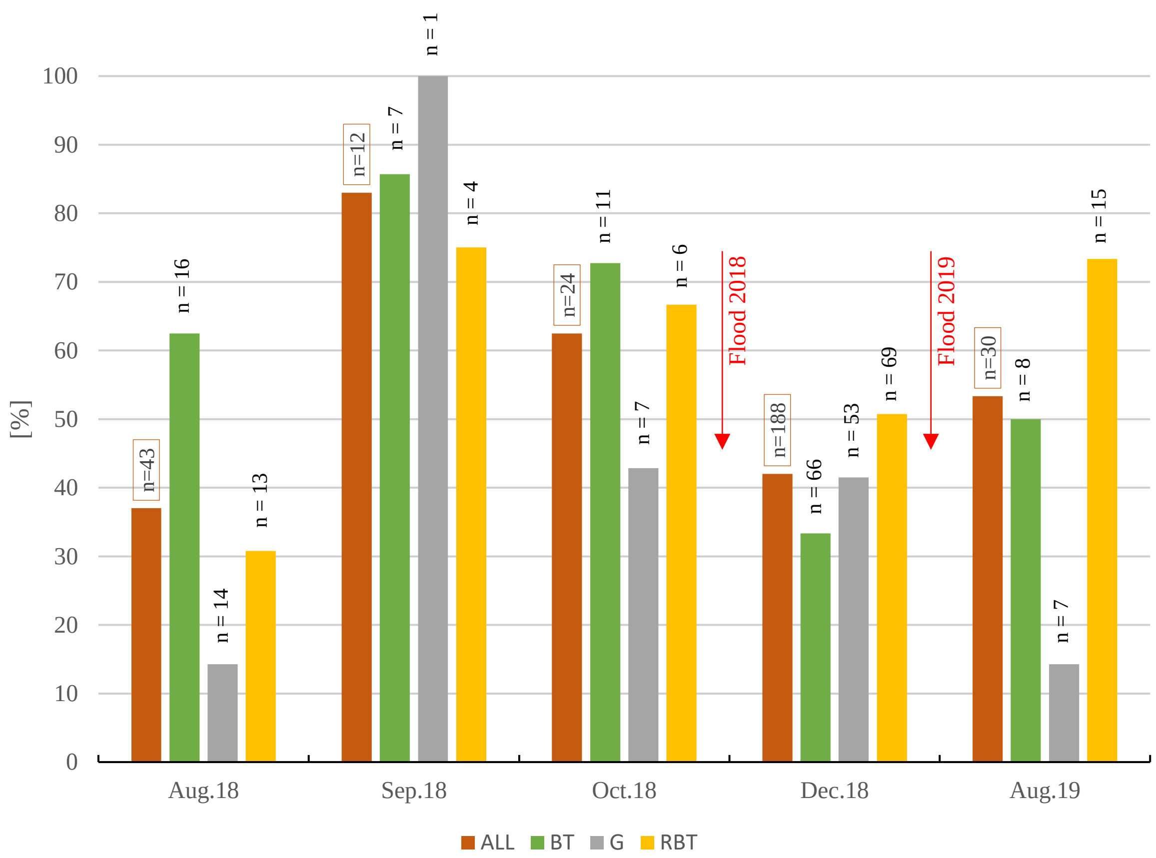


Figure 33: Share of upstream moving individuals of the mobile fraction in the control section.

After the HQ20-Flood the bars in December 2018 display that the greater share of the mobile fraction left in downstream direction. On the last day of the field study in August 2018 about 50 % of mobile salmonids moved up the river.

On species level, especially after enhanced discharges (December 2018 and August 2019), mobile rainbow trout tended more to upstream movement than the other two study species.

5.2.5.1 Comparison of mobile rainbow trout between both study sites

Before November 2018, the number of mobile rainbow trout was low, ranging between 4 and 23 individuals (see Figure 34). In the RFS, with exception of June 2018 at least 50 % of all mobile fish moved upstream. The mobile component of rainbow trout preferred downstream movement only in August 2018 in the CS.

After the flood event in December 2018, the ratio was quite balanced between upstream moving fish and the downstream moving fish in both sections (RFS 44 %, CS 51 %). Due to the higher number of recaptures the explanatory power of the sampling in December is higher than for the other sampling events.

While the comparison between May 2018 and May 2019 shows comparable results, the findings between August 2018 and August 2019 vary strongly.

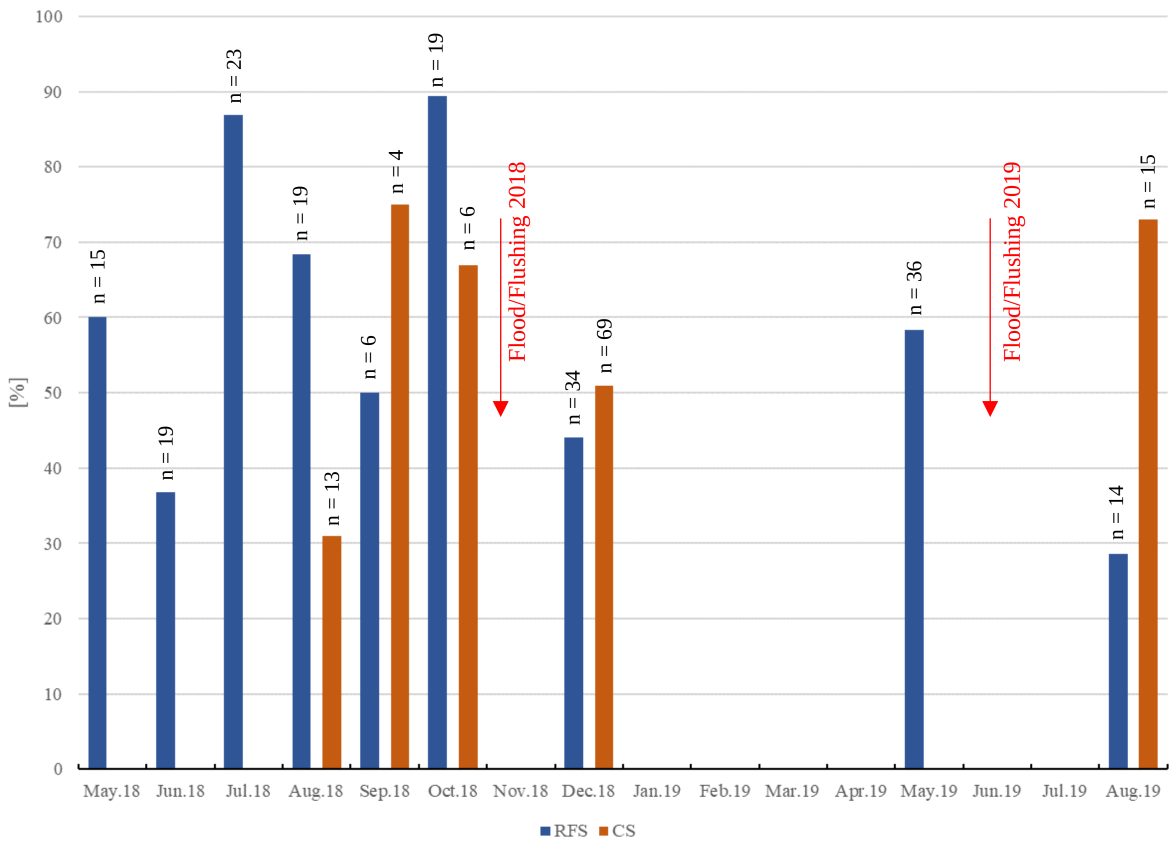


Figure 34: The mobile fraction of recaptured rainbow trout and its willingness to leave its home range in upstream direction in comparison between the two study sections.

5.3 Individual Displacement (D)

From May 2018 until August 2019 2 407 salmonids were recaptured. In total more than 400 000 m of individual displacement was measured, therefore every recaptured fish moved on average 178 m. Movement distances up to 2 000 m were covered by single individuals within the study sections in upstream as well as in downstream direction.

During nonmigratory period (between June 2018 and October 2018) mean movement ranged from 60 m in September in the CS to 169 m in July in the RFS (see Table 9 and Table 10). After the drawdown flushing /flood in December 2018, mean movement increased within the residual flow section (stretch ID1 – ID23) to 365 m, within the control section (stretch ID101 – ID116) mean movement remained below 200 m. Therefore, the flood including the drawdown in flushing in the end of October 2018 led to a noticeable displacement of individuals in the residual flow section, while the fish assemblage in the control section was less severely affected by the flood itself.

Table 9: Individual movement of salmonids in the RFS.

Month	n Recapatures	∑ Movement [m]	Mean Movement [m/Ind.]
May 2018	166	15 917	96
June 2018	126	18 141	144
July 2018	121	20 441	169
August 2018 (ALL)	195	23 962	123
August 2018 (ID1 - ID23)	194	20 883	108
September 2018	109	12 015	110
October 2018	151	21 132	140
December 2018 (ALL)	76	56 236	740
December 2018 (ID1 - ID23)	67	24 477	**365**
May 2019	86	30 621	356
August 2019	34	13 220	389
Total	1064	211 685	199
Total (ID1-ID23)	1054	176 847	**168**

Table 10: Individual movement of salmonids in the CS.

Month	n Recapatures	∑ Movement [m]	Mean Movement [m/Ind.]
August 2018	254	28 747	113
September 2018	142	8 513	60
October 2018	265	25 288	95
December 2018 (ALL)	554	133 988	242
December 2018 (ID101 - ID116)	532	105 372	**198**
August 2019	128	20 007	156
Total	1343	216 543	161
Total (ID101 - ID116)	1321	187 927	**142**

In August 2018 and December 2018 additional fish samplings beyond the core study sites took place. The gathered data of nine rainbow trout and one grayling in the RFS as well as the 22 salmonids (8 RBT, 6 BT, 8 G) in the CS did not find consideration in the calculations and boxplots of the parameter individual displacement (D) in chapter 5.3.1 and 5.3.2. Those 32 excluded fish (moved up to 4 750 m, on average 1 983 m) are considered in Table 9 and Table 10 (row August 2018 (ALL); row December 2018 (ALL)).

5.3.1 Residual Flow Section

The analysis of the parameter “individual displacement D” shows predominantly sedentary behavior of recaptured fish during summer (between May 2018 and October 2018) in the residual flow section. Individual displacement data of all together 1 054 recaptures are displayed in the boxplots below. After the drawdown flushing event in December 2018, the shape of the boxplots is altered in contrast to the boxplots during summer 2018.

For brown trout, the count of recaptured individuals was low, but still there is a clearly visible difference between the data of December 2018 and the data of other sampling events (the spot check in August 2019 is less meaningful due to low data basis; n=6). The strongly developed sedentary behavior was disrupted by the flood including the drawdown flushing. While 9 of 14 recaptured fish were found close to their home stretch, 5 individuals were caught around 500 to 1.700 m downstream of their marking stretch. Five months later in May 2019 the shape of the boxplot is similar to the ones before the event (see Figure 35). Due to low recaptures it was not possible to make reliable assertions regarding statistical significance of the observations. The confidence intervals in Figure 36 cover long distances and overlap at all consecutive sampling events.

Regarding rainbow trout, movement during June 2018 deviates significantly from the following months. Apart from that, the situation was comparable with brown trout. After consistent results during the nonmigratory period, the drawdown flushing caused strong displacement of individuals (see Figure 37). After the recovery phase (spot check May 2019), the second flushing affected the fish assemblage again. Despite enhanced mean movement, it was not possible to derive significant changes regarding individual displacements within the 23 stretches (see overlapping whiskers in Figure 38)

D for grayling is plotted only for the seek of completeness, since the number of recaptures was too low again. The boxplots (Figure 39) as well as the confidence intervals (Figure 40) show a big range of variation.

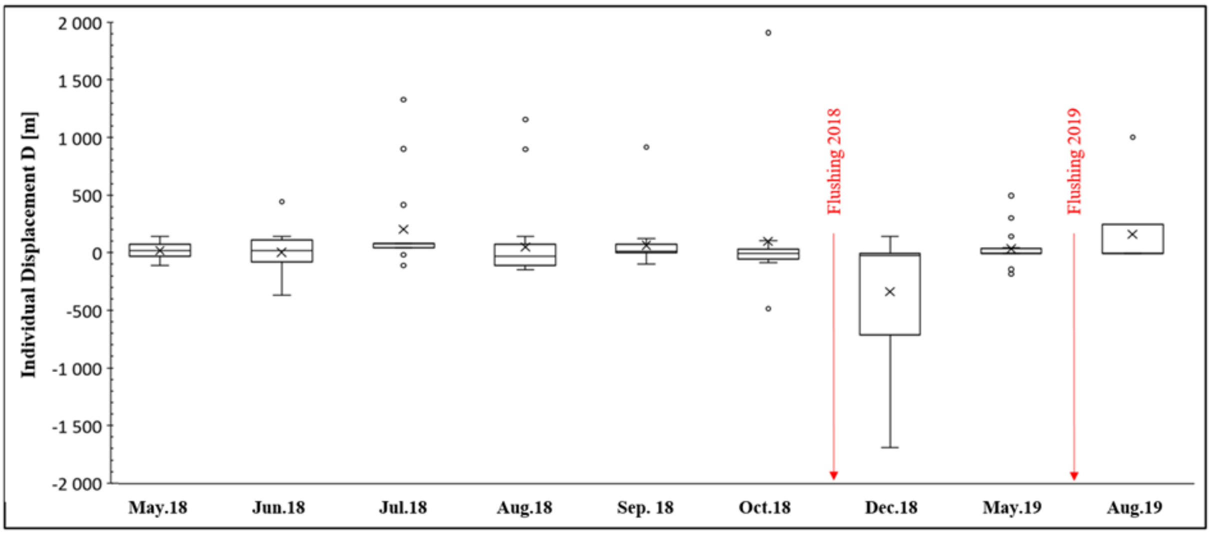


Figure 35: Individual displacement of brown trout in the residual flow section from May 2018 until August 2019. $n_{may18}=13$; $n_{june18}=12$; $n_{july18}=16$; $n_{august18}=26$; $n_{september18}=16$; $n_{october18}=14$; $n_{december18}=14$; $n_{may19}=16$; $n_{august19}=6$.

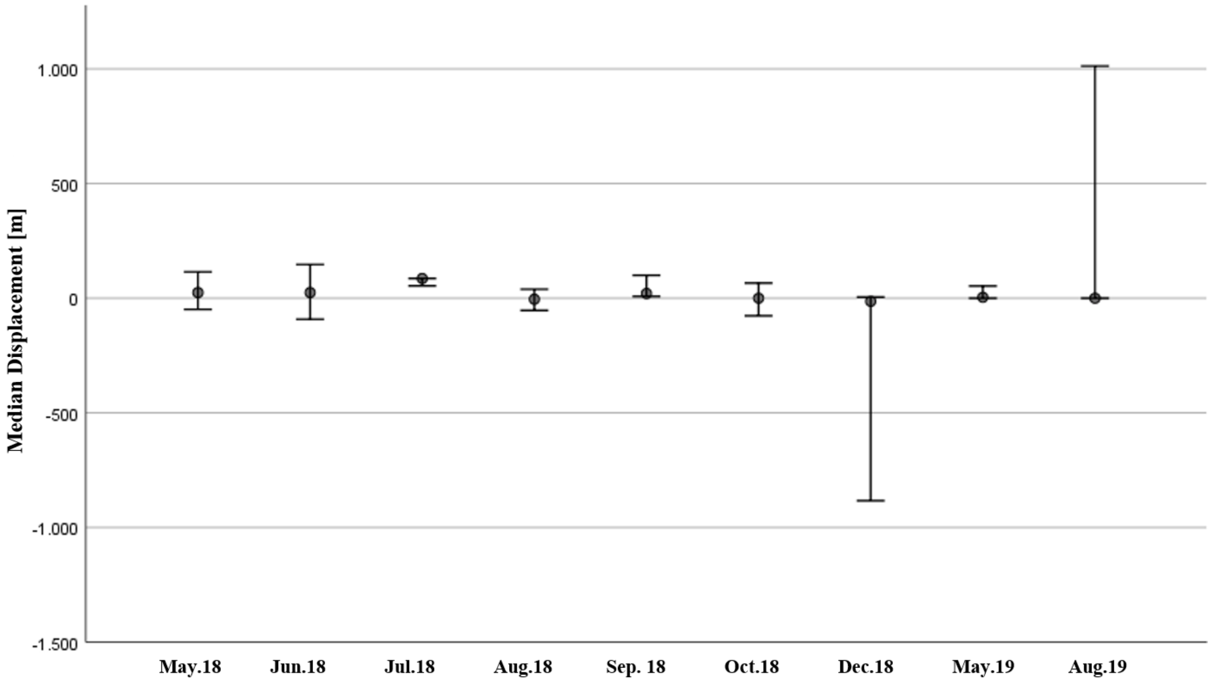


Figure 36: Median displacement and confidence intervals of movement of brown trout in the residual flow section from May 2018 until August 2019. $n_{may18}=13$; $n_{june18}=12$; $n_{july18}=16$; $n_{august18}=26$; $n_{september18}=16$; $n_{october18}=14$; $n_{december18}=14$; $n_{may19}=16$; $n_{august19}=6$.

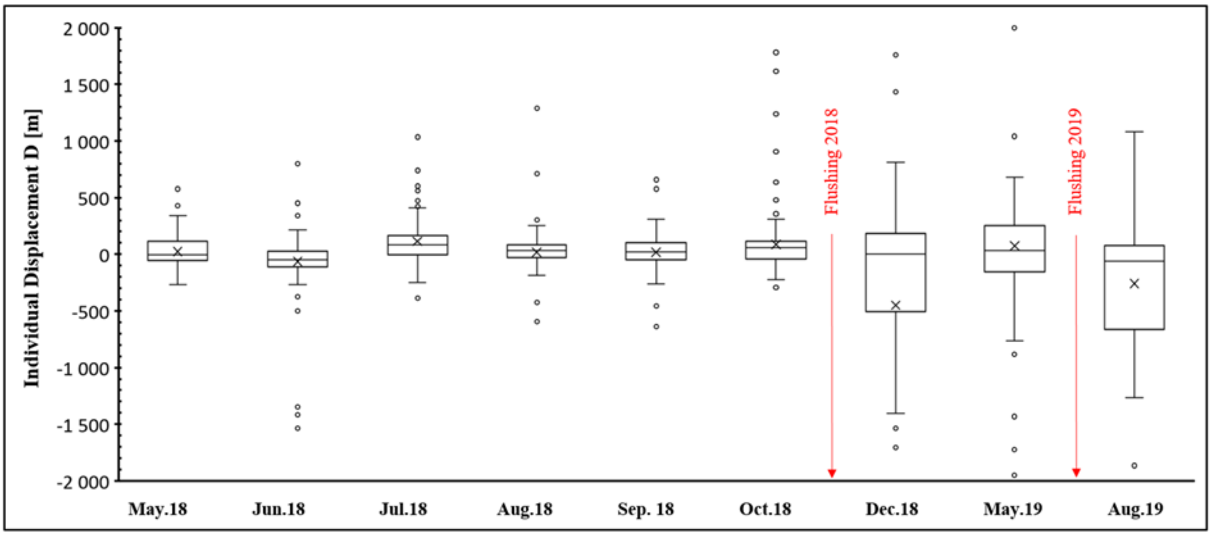


Figure 37: Individual displacement of rainbow trout in the residual flow section from May 2018 until August 2019. n_{may18} =138; n_{june18} =107; n_{july18} =93; $n_{august18}$ =128; $n_{september18}$ =87; $n_{october18}$ =127; $n_{december18}$ =59; n_{may19} =63; $n_{august19}$ =23.

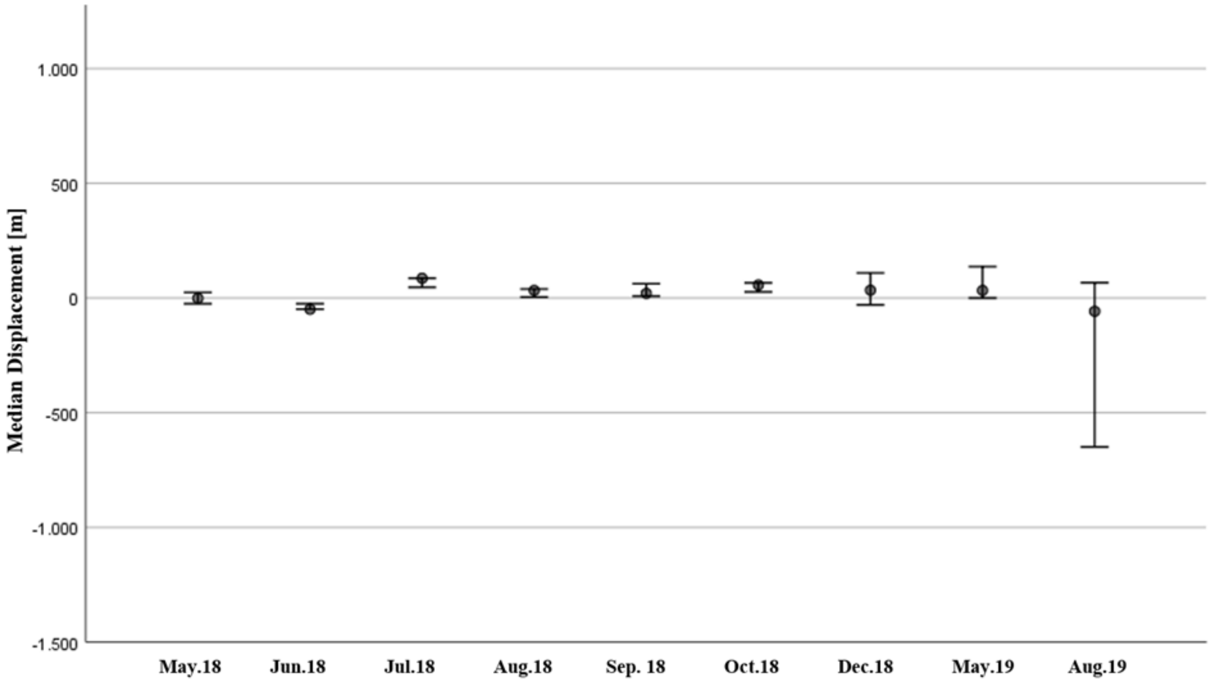


Figure 38: Median displacement and confidence intervals of movement of rainbow trout in the residual flow section from May 2018 until August 2019. n_{may18} =138; n_{june18} =107; n_{july18} =93; $n_{august18}$ =128; $n_{september18}$ =87; $n_{october18}$ =127; $n_{december18}$ =59; n_{may19} =63; $n_{august19}$ =23.

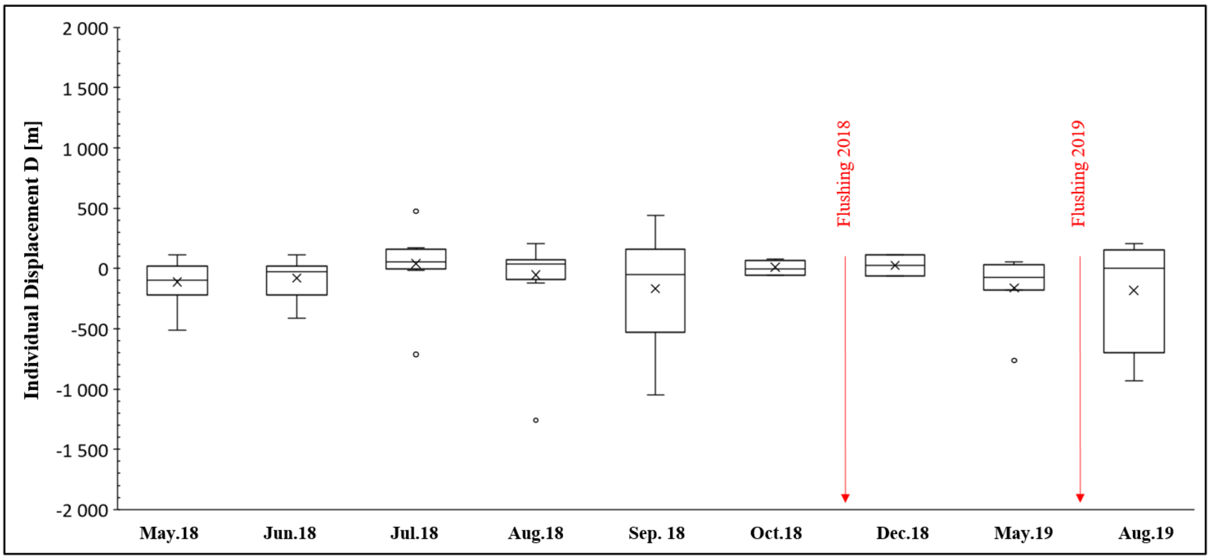


Figure 39: Individual displacement of grayling in the residual flow section from May 2018 until August 2019. n_{may18} *=15;* n_{june18} *=7;* n_{july18} *=12;* $n_{august18}$ *=16;* $n_{september18}$ *=6;* $n_{october18}$ *=10;* $n_{december18}$ *=3;* n_{may19} *=7;* $n_{august19}$ *=4.*

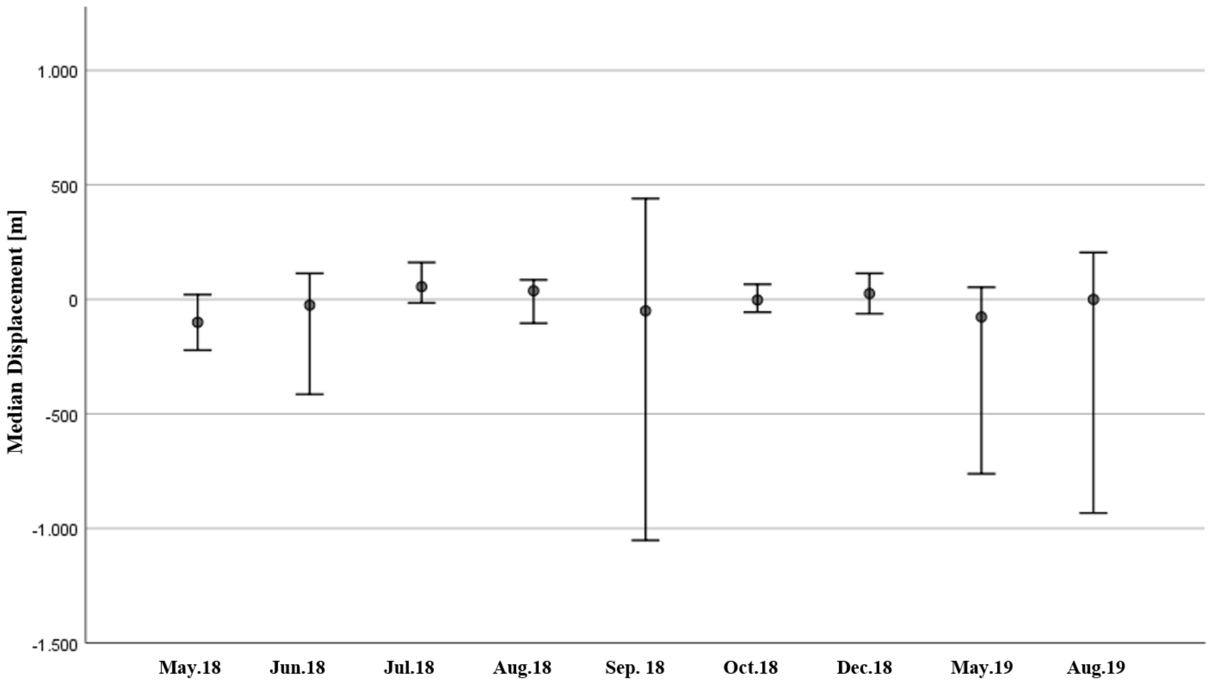


Figure 40: Median displacement and confidence intervals of movement of grayling in the residual flow section from May 2018 until August 2019. n_{may18} *=15;* n_{june18} *=7;* n_{july18} *=12;* $n_{august18}$ *=16;* $n_{september18}$ *=6;* $n_{october18}$ *=10;* $n_{december18}$ *=3;* n_{may19} *=7;* $n_{august19}$ *=4.*

5.3.2 Control Section

In the CS, individual movement behavior data of 1 321 recaptured salmonids was collected until August 2019. D was restricted for all three study species before the flood in the end of October 2018. Median displacement (significance check) as well as mean displacement (see “x” in boxplots) stayed close to 0 with exception of some statistical outliers.

Comparable to the results of P (proportion of sedentary individuals), the flood led to displacement within the fish assemblage. While covered distances stayed small, statistical outliers occurred comparatively more often in contrast to the samplings before the flood event (see Figure 41, Figure 43 and Figure 45). Still, in December 2018, about 17 % of recaptured individuals (93 of 555) were found more than 500 m from the point of first capture. This development did not lead to significant changes of D, since median displacement of December 2018 remained close to 0 and the corresponding whiskers overlapped with the previous and the following samples (see Figure 42, Figure 44 and Figure 46).

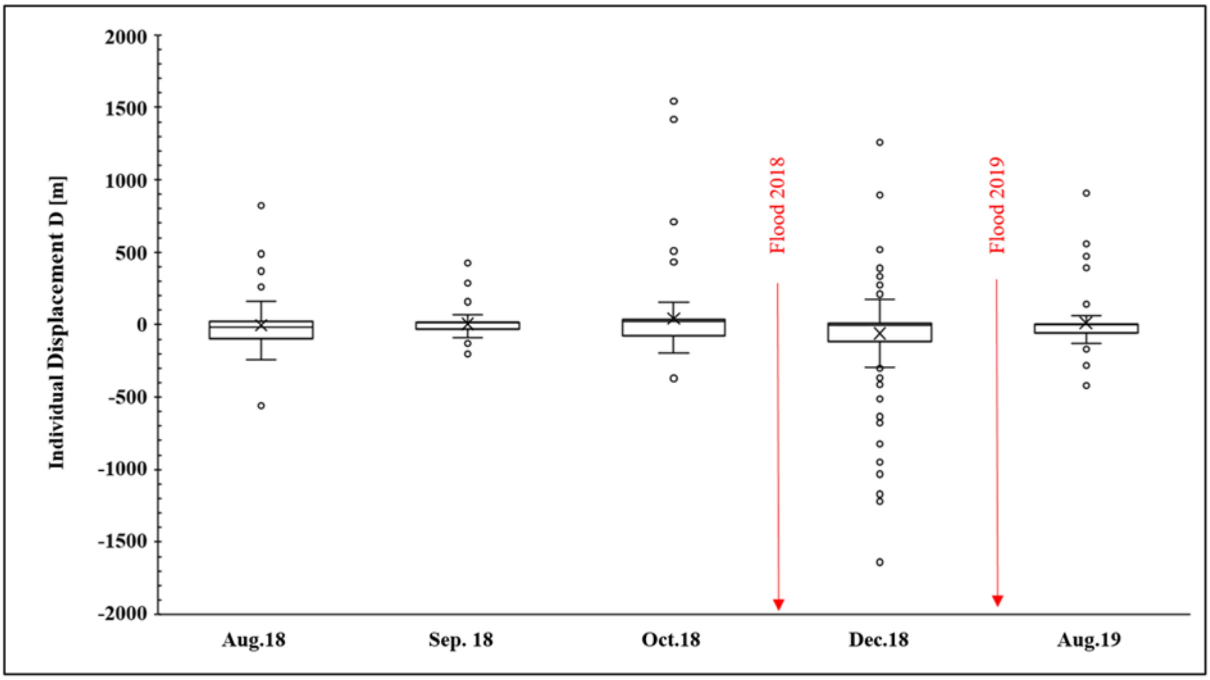


Figure 41: Individual displacement of brown trout in the control section from August 2018 until August 2019. $n_{august18}$ *=108;* $n_{september18}$ *=102;* $n_{october18}$ *=131;* $n_{december18}$ *=234;* $n_{august19}$ *=53.*

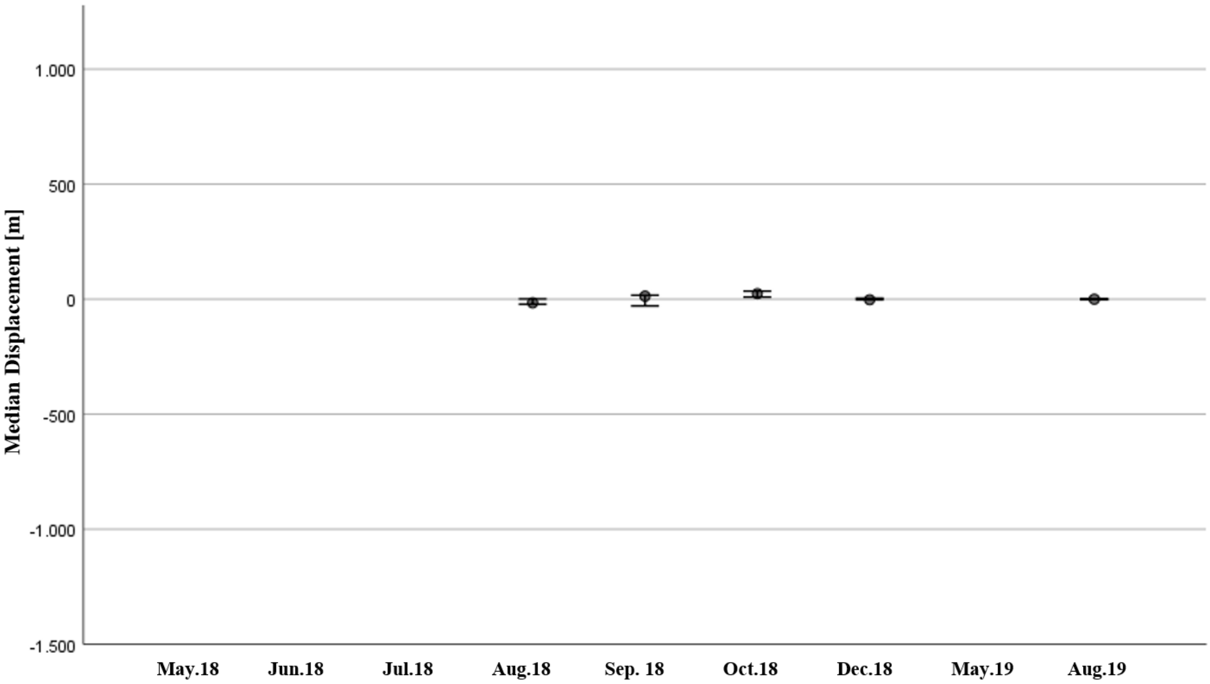


Figure 42: Median displacement and confidence intervals of movement of brown trout in the control section from August 2018 until August 2019. $n_{august18}$ *=108;* $n_{september18}$ *=102;* $n_{october18}$ *=131;* $n_{december18}$ *=234;* $n_{august19}$ *=53.*

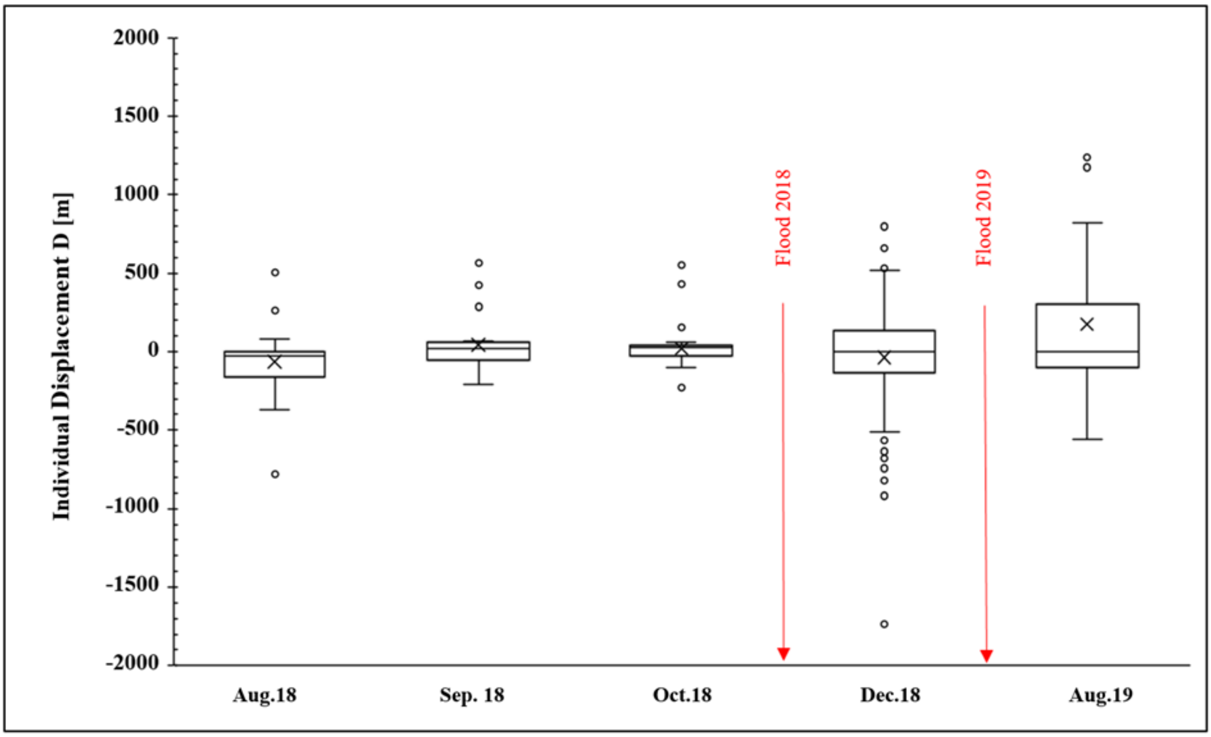


Figure 43: Individual displacement of rainbow trout in the control section from August 2018 until August 2019. $n_{august18}$ =72; $n_{september18}$ =20; $n_{october18}$ =96; $n_{december18}$ =200; $n_{august19}$ =35.

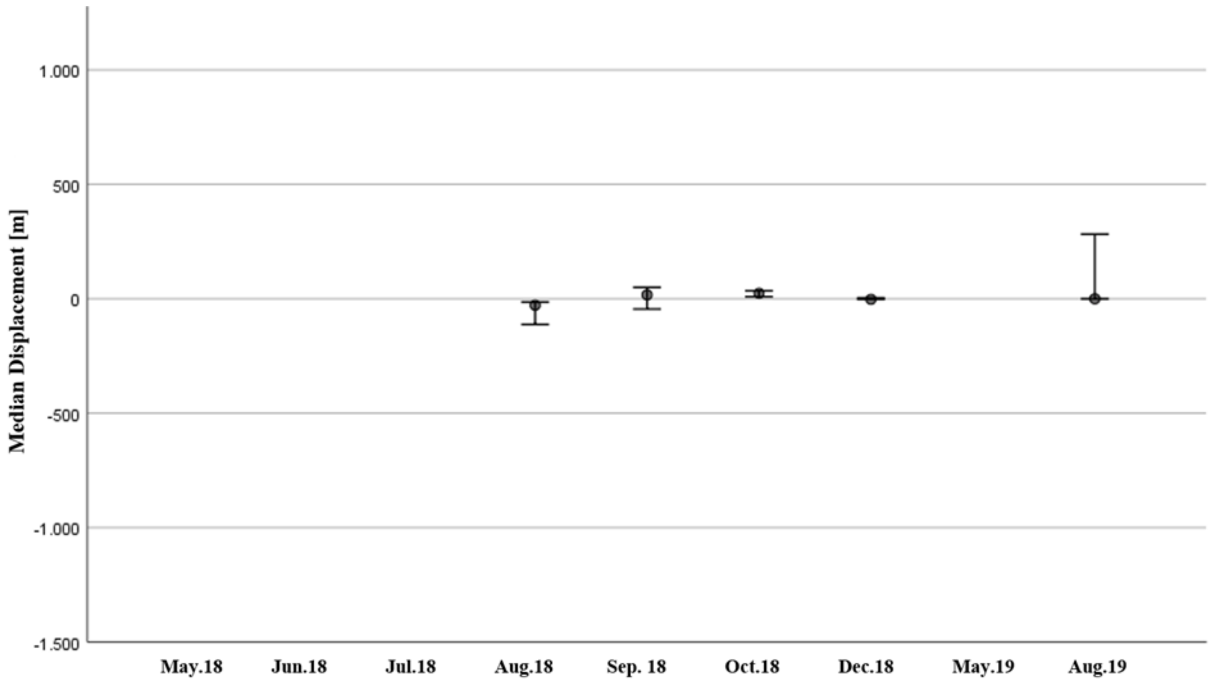


Figure 44: Median displacement and confidence intervals of movement of rainbow trout in the control section from August 2018 until August 2019. $n_{august18}$ =72; $n_{september18}$ =20; $n_{october18}$ =96; $n_{december18}$ =200; $n_{august19}$ =35.

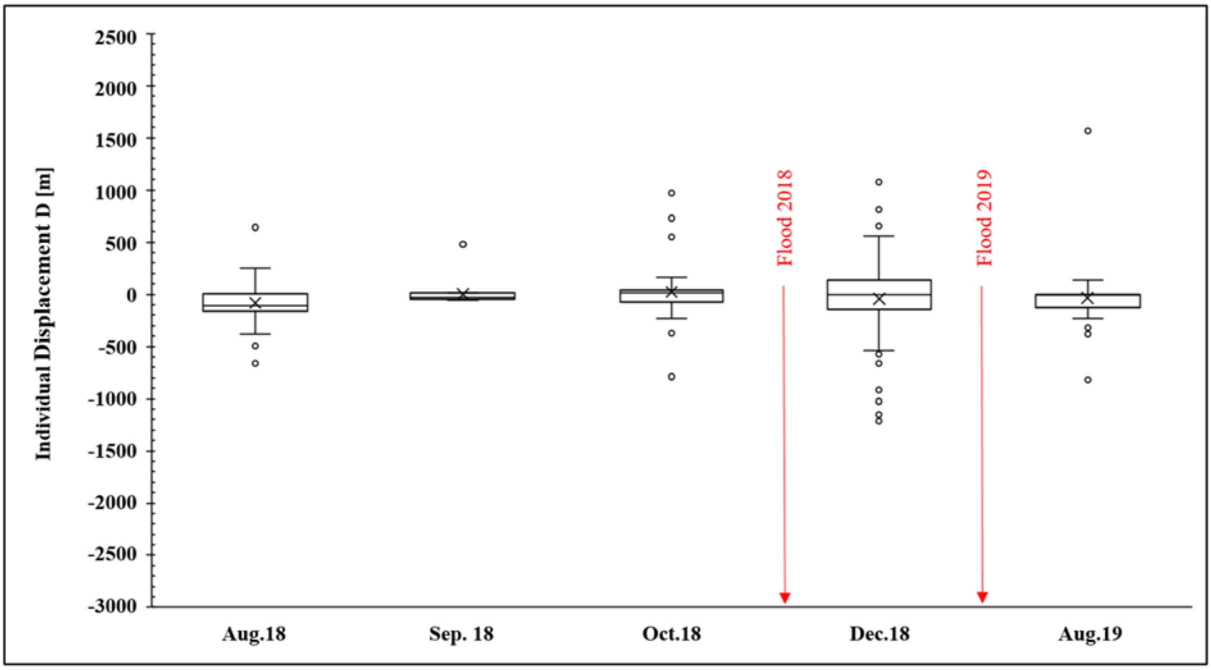


Figure 45: Individual displacement of grayling in the control section from August 2018 until August 2019. $n_{august18}$ =74; $n_{september18}$ =20; $n_{october18}$ =38; $n_{december18}$ =120; $n_{august19}$ =40.

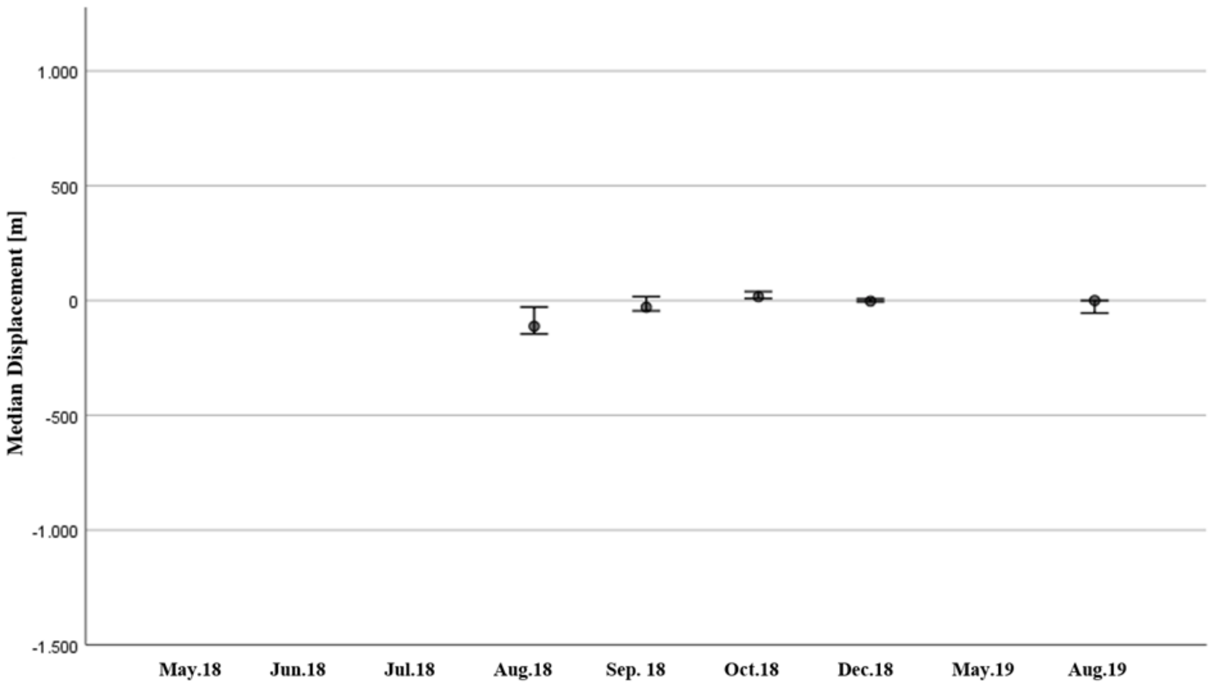


Figure 46: Median displacement and confidence intervals of movement of grayling in the control section from August 2018 until August 2019. $n_{august18}$ =74; $n_{september18}$ =20; $n_{october18}$ =38; $n_{december18}$ =120; $n_{august19}$ =40.

5.3.3 Comparison of mean movement between August 2018 and August 2019

In addition to the boxplots, mean movement of the mobile and the sedentary fraction is compared in Table 11 and Table 12. In difference to D (individual displacement) fish samplings by boat beyond the core study sites in August 2018 and December 2018 are included in the dataset. The comparison between the samplings from August 2018 and December 2018 are particularly meaningful (before and after the flood/flushing event), since the samples were taken methodologically comparable (spot checks within the investigation section including electrofishing by boat in downstream areas of the respective section).

Due to the methodological design (see classification design of P in 4.5.1), the arithmetic mean of the sedentary proportion did not change greatly over time. From August 2018 until August 2019, mean movement of the sedentary fraction is about 59 m and ranges from 0 m to 97 m.

On the contrary, mean movement of the mobile fraction developed differently in the two study sections:

In August 2018 mobile salmonids moved on average 517 m in the RFS and 326 m in the CS. Also, in the time period between August 2018 and October 2018 mobile individuals in the residual flow section occupied larger areas than in the control section (RFS: 560 m, CS: 394 m). Among 232 individuals in the relevant length category only one tagged rainbow trout was caught during the boat sampling downstream of the section in August 2018. This individual was initially marked in stretch ID 2 (close to the weir) and moved ~3 km in downstream direction. Movement in upstream direction was restricted as well. From May 2018 until 28. October 2018 (start of the drawdown flushing) 30 tagged individuals were counted by the remote detection antenna in the vertical slot fish pass close to the weir.

After the drawdown flushing, mean movement of mobile salmonids increased to 1351 m in the residual flow section, while mobile fish moved only 600 m on average after the HQ20-flood in the control section. The additional fish sampling effort by boat downstream of the corresponding section delivered information, whether individuals were displaced beyond the investigation area by the flood/drawdown flushing or not. In the RFS 177 salmonids were caught between stretch ID 23 (bottom end of the section) and the river mouth of River Möll and River Drava, one grayling and nine rainbow trout were tagged. The only recaptured mobile grayling was recaptured close to the river mouth and moved more than 4600 m from the point of first capture in downstream direction. During the complementary samplings in both directions (upstream and downstream) in December 2018 in the control section, 535 salmonids were caught beyond the study section, 22 of them carried a PIT-tag (4 %).

Table 11: Mean movement of salmonids in the RFS divided in sedentary fraction and mobile fraction.

Month	Species	n	Mean Movement Sedentary Fraction [m]	Mean Movement Mobile Fraction [m]	n Mobile
August 2018	**Salmonids**	195	62	**517**	26
	RBT (>200)	63	48	385	6
	RBT (<201)	79	71	558	13
	RBT	142	60	504	19
	BT	37	69	729	3
	G	16	62	425	4
August until October 2018	**Salmonids**	455	63	**560**	57
	RBT (>200)	233	59	476	20
	RBT (<201)	123	78	556	24
	RBT	356	65	520	44
	BT	67	57	918	6
	G	32	54	507	7
	→	Flood including a drawdown flushing			
December 2018	**Salmonids**	76	61	**1351**	40
	RBT (>200)	46	68	1279	27
	RBT (<201)	13	66	1459	7
	RBT	59	67	1316	34
	BT	14	36	932	5
	G	3	88	4637	1
May 2019	**Salmonids**	86	68	**673**	41
	RBT (>200)	59	82	726	35
	RBT (<201)	4	48	251	1
	RBT	63	79	712	36
	BT	16	43	331	3
	G	7	73	470	2
	→	Flood including a drawdown flushing			
August 2019	**Salmonids**	34	24	**753**	17
	RBT	23	46	761	14
	BT	7	0	1013	1
	G	4	0	569	2

Mean movement of the mobile fraction reduced to 673 m in May 2019 in the RFS (qualitative and quantitative samplings within the section).

During the last sampling days in August 2019 no individual smaller than 201 mm was recaptured in the RFS, average movement of mobile individuals resulted in 753 m. After the second flood in the control section, the 30 mobile salmonids were recaptured on average 528 m from their home stretch.

Table 12: Mean movement of salmonids in the CS divided in sedentary fraction and mobile fraction.

Month	Species	n	Mean Movement Sedentary Fraction [m]	Mean Movement Mobile Fraction [m]	n Mobile
August 2018	**Salmonids**	254	71	**323**	43
	RBT (>200)	20	79	399	6
	RBT (<201)	52	63	221	7
	RBT	72	67	303	13
	BT	108	57	347	16
	G	74	94	317	14
	BT (>200)	30	58	400	5
	BT (<201)	78	56	324	11
	G (>200)	46	97	348	10
	G (<201)	28	86	237	4
August until October 2018	**Salmonids**	661	47	**394**	79
	RBT (>200)	84	37	386	11
	RBT (<201)	104	53	279	12
	RBT	188	46	330	23
	BT	341	42	431	34
	G	132	65	405	22
	BT (>200)	118	40	351	9
	BT (<201)	223	43	459	25
	G (>200)	92	59	436	14
	G (<201)	40	80	352	8
	→	Flood - HQ20			
December 2018	**Salmonids**	554	58	**600**	188
	RBT (>200)	131	66	502	43
	RBT (<201)	69	69	501	26
	RBT	200	67	502	69
	BT	234	46	645	66
	G	120	68	673	53
	BT (>200)	96	42	603	27
	BT (<201)	138	49	675	39
	G (>200)	113	69	670	49
	G (<201)	7	58	711	4
	→	Flood - HQ1			
August 2018	**Salmonids**	128	37	**528**	30
	RBT (>200)	32	58	577	12
	RBT (<201)	3	0	628	3
	RBT	35	58	587	15
	BT	53	25	413	8
	G	40	42	534	7
	BT (>200)	35	30	546	3
	BT (<201)	18	15	333	5

On species level, mobile rainbow trout tended to stay closer to the point of first capture than mobile brown trout in both sites, at least until the flood/flushing event in the end of October

2018. The low number of recaptured mobile brown trout in the RFS has to be taken into account in this context.

With exception of May 2019, mobile rainbow trout smaller than 201 mm covered greater distances than larger rainbow trout in the RFS. In December 2018 the 7 mobile individuals behaved in a similar manner than the 27 individuals larger than 200 mm.

In the CS the pooled period from August until October 2018 und the sampling from December 2018 include more than 20 mobile individuals of each species. Mean movement of mobile rainbow trout was lower than mean movement of mobile brown trout and mobile grayling. In terms of the two size classes no major differences were found.

<u>Activity at the remote detection antenna in the vertical slot:</u>

From the first day of the study in May 2018 until to the beginning of the drawdown flushing, in total 30 tagged individuals were recorded in the vertical slot. During the flood events in October 2018 enhanced activity was observed in the fish pass, although the dotation was limited (Figure 47).

Figure 47: Water was pumped into the fish pass (vertical slot), while the low-level outlets of the weir had been opened during the drawdown flushing in October 2018

The remote detection antenna registered two brown trout and nine rainbow trout from 28.10.2018 18:55 until 02.11.2018 14:30. All individuals had been tagged in May 2018, only one rainbow trout was larger than 160 mm at that time. This individual (code

982126053367705; 290 mm) was first caught and tagged in stretch ID 1 close to the weir. One month later it was recaptured in stretch ID 4 (downstream movement of 266 m). After the registration during the drawdown flushing, the same rainbow trout was caught again in May 2019 in stretch ID 18, about 1950 m downstream from its point of first capture at a size of 325 mm.

Another rainbow trout (tagged in May 2018, home stretch ID 6, 135 mm) was registered in the fish pass on 28.10.2018 at 22:22, one month later in December 2018 it was recaptured during the spot checks in stretch ID 1 with a size of 246 mm.

The rainbow trout with the alpha-numeric code 982126053361245 was marked in stretch ID 5 with a size of 100 mm. It was registered for the first time in the vertical slot on 25.08.2018. After numerous registrations in the following months it seems that the fish had lived in the fish ladder. The last time the individual swam through the antenna was during the drawdown flushing on 30.10.2018.

5.4 Turnover Rate (T)

The spot checks directly following the quantitative sampling and tagging in May and August 2018 resulted in a tag-rate of 0.71 in the RFS and 0.63 in the CS. This means that 71 % or 63 % of fish in the relevant size class were tagged during the quantitative samplings. Converted to turnover rate, the starting value of T was 0.29 in the residual flow section (see Table 13). Turnover rate increased to 0.50 in June 2018, afterwards the development was more constant. A moderate increase over time resulted in T = 0.59 in October 2018 - underlining the sedentary behavior of the fish assemblage.

Table 13: Data basis for turnover rate in the RFS. Quantitative sampling events are labelled with "(quant.)".

Month	Code	n Recpatures	Tage-rate	Turnover Rate T
May 2018	05	223	0.71	0.29
June 2018	06	227	0.50	0.50
July 2018	07	250	0.46	0.54
August 2018	08	300	0.46	0.54
September 2018	09	188	0.47	0.53
October 2018	10	269	0.41	0.59
December 2018	12	115	0.21	0.79
December 2018 (quant.)	12	90	0.20	0.80
May 2019 (quant.)	17	260	0.23	0.77
August 2019	20	114	0.11	0.89

The abrupt change from October to December 2018 (T = 0.79 or 0.80) shows the effect of the drawdown flushing (see Figure 48). Several untagged individuals may had been flushed out of the reservoir into the residual flow section, other marked fish may had left the investigation area. The increased number of caught individuals as well as a slight decrease of T in May 2019 suggests recolonization movements of displaced individuals. The second drawdown flushing in June 2019 resulted in T = 0.89 (August 2019). Thus, only 11 % of recaptured individuals in the relevant size class were marked with a PIT-tag on the last day of the investigation period.

In the CS, during nonmigratory period in summer, T developed slightly increasing over time (Figure 48) – starting at 0.37 in August 2018 (see Table 14). The HQ20-flood led to a noticeable rise from 0.42 to 0.54 or 0.55. In difference to the residual flow section T decreases clearly until August 2019 and resulted in T = 0.45. This turnover rate is close to the recorded values before the flood events.

Table 14: Data basis for turnover rate in the CS. Quantitative sampling events are labelled with "(quant.)".

Month	Code	n Recpatures	Tage-rate	Turnover Rate T
August 2018	08	338	0.63	0.37
September 2018	09	194	0.56	0.44
October 2018	10	382	0.58	0.42
December 2018	12	232	0.46	0.54
December 2018 (quant.)	12	682	0.45	0.55
August 2019	20	159	0.55	0.45

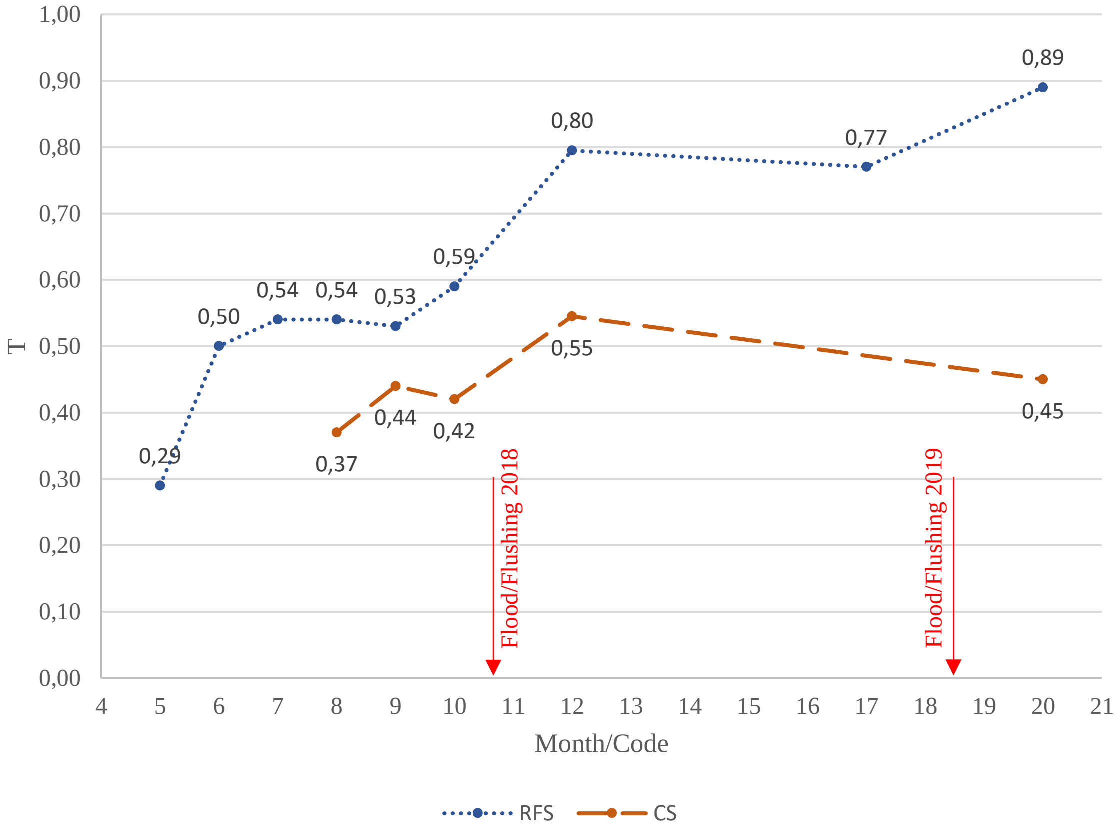


Figure 48: Comparison of T between the study sections.

5.4.1 Check for significance

BOKU University carried out statistical analysis regarding the tag-rate of the fish samplings and its development throughout the study period (Pinter et al., 2021). The tag-rate describes how many individuals of a sample carried a PIT-tag, T equals 1 minus the tag-rate. Figure 49 (RFS) and Figure 50 (CS) display the results of the regression model, the expected tag-rates (black dots) are compared with the observed tag-rates (red dots), the dotted lines picture the confidence intervals:

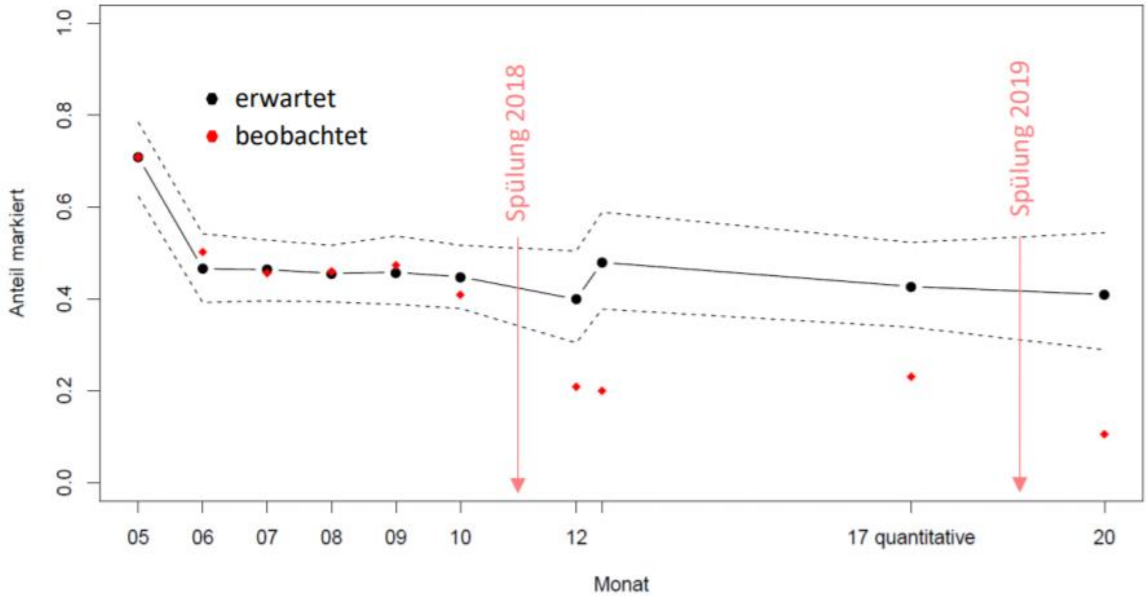


Figure 49: Regression model – comparison between expected and observed tag-rate (tag-rate = 1-T) in the RFS (Pinter et al., 2021).

The results of the regression model show comparable tag-rate developments in both sections: Until the first flood event in October 2018, the observed tag-rate is almost conforming with the expected tag-rate. The observed tag-rates (red dots, quantitative sampling and qualitative sampling separated) from December 2018 are outside the confidence intervals (dotted line). This means a significant change of the tag-rate (and T) in both study sites, possibly due to enhanced discharges. Immigration of untagged fish from the surrounding river region into the sections as well as emigration of marked individuals took place. While the predicted tag-rate corresponds exactly with the observed tag-rate in the control section in August 2019 (month code 20, Figure 50), the observations in the residual flow section was far below the prediction (significant deviation; Figure 49).

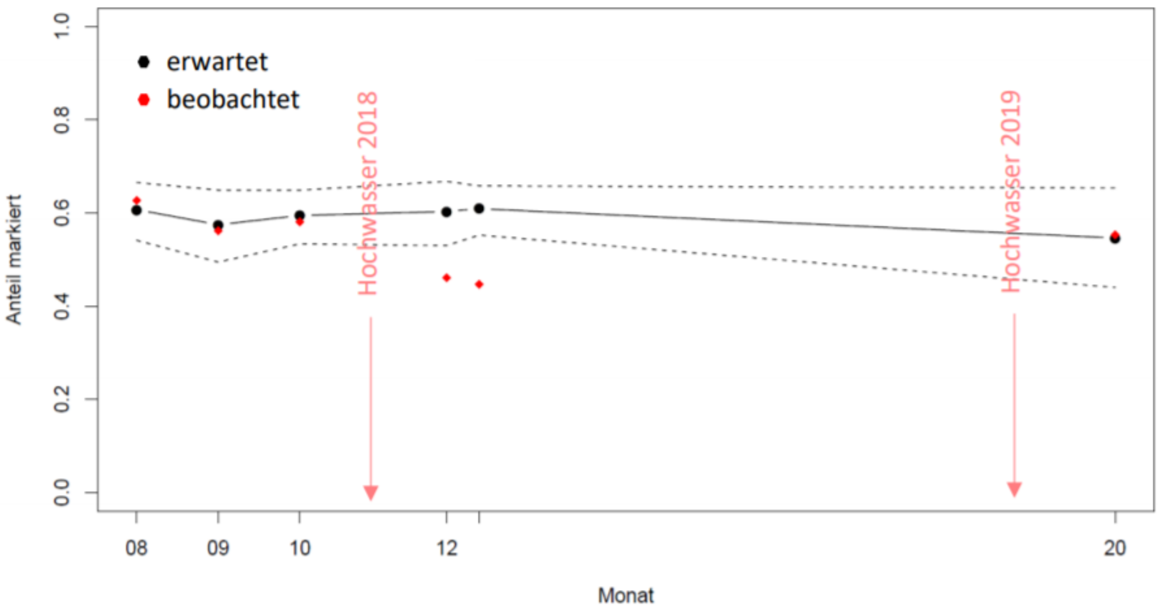


Figure 50: Regression model – comparison between expected and observed tag-rate (tag-rate = 1-T) in the CS (Pinter et al., 2021).

6 DISCUSSION

This master thesis examined the movement behavior of salmonids at the River Möll in Carinthia. The study is designed like a BACI-study, where a certain impact is investigated before and after occurrence in two environments – the affected living space and the reference site. The present mark-recapture study tested, if the adverse impact of drawdown flushing on a fish population is identifiable with fish movement data.

Salmonid movement was investigated over a period of 16 months (May 2018 until August 2019), partially with qualitative samplings but also quantitative fish stock assessment took place throughout the study period. All together 6 978 salmonids were PIT-tagged and monitored in two river sections at the River Möll.

While the hydrological regime was nearly undisturbed in the control section (CS), altered flow and sediment conditions prevailed the residual flow section (RFS) below the hydropower-reservoir Rottau. The reflux of the residual flow turbine nearby the weir leads to constant (unnatural) discharge-conditions throughout the year. During the flood event at River Möll in October 2018 the low-level outlets of reservoir Rottau were opened, and deposited sediments were released into the residual flow section. The fish stock assessment after the flood including the drawdown flushing resulted in decreased fish densities and biomass in the RFS, while the fish assemblage in the control section was almost unaffected by the flood event itself.

The application of the three study variables turnover-rate (T), individual displacement (D) and the proportion of sedentary individuals (P) give different views on fish movement: T serves as an indicator to determine a certain change in the river section. This parameter can be used for overview statistics. Generally, it considers the development of the fish assemblage as a whole. But it does not provide information about individual movement like covered distances or the direction of movements.

Therefore, the proportion of sedentary individuals (P) was assessed. This parameter enables the detection of small-scale movements within the study sections. Additionally, it might allow assumptions concerning the condition of the available habitat. Studies which treat the proportion of sedentary individuals supposed that P can be related to habitat complexity and availability of needed structures in close proximity (Radinger and Wolter, 2014; see also Solomon and Templeton, 1976; Schrank and Rahel, 2004). Thus, P will be low, if exploratory behavior increases due to insufficient morphological structure (high degree of mobile component) (Radinger and Wolter, 2014).

The parameter individual displacement (D) uses a comparable determination design to P: the stretch of recapture is related to the stretch of first capture. By calculating the distance between the midpoints of the relevant stretches, individual movement receives absolute numerical values. Due to methodological issues, D has limited accuracy, because all caught fish of a stretch (on average 118 m length) were assigned with the same mid-point. In fact, this issue occurred twice, as only recaptured individuals were analyzable with D. It is important to bear this in mind during data evaluation and interpretation. Nevertheless, although the numerical values are a little imprecise, they show differences between small- and large-scale movements.

The evaluation of parameter P and D is dependent on recaptures of marked individuals. Even the alpha-numeric code of each PIT-tag has to be detected and documented precisely for every single fish to enable statistical analysis. On the other hand, it is unnecessary for the evaluation of T to identify an individual, it is only important to check whether it carries a PIT-tag or not.

Species-specific and life-history dependent salmonid movement was investigated during summer (nonmigratory period from May 2018 until October 2018) and in the course of a flood including a drawdown flushing. It was hypothesized that

- there were no differences in summer movement patterns between the two sections (H1)
- downstream displacement of fish in December 2018 was higher in the residual flow section (flood including a drawdown flushing) than in the control section (flood only) (H2)
- movement patterns differ between species (H3)
- juvenile fish are more affected by the drawdown flushing than adult fish (H4)

and expected that the chosen parameters (T, D, and P) will deliver consistent results regarding the treated subjects, but in some cases the evaluation showed discrepancies. It was therefore even more important to take a close look at all three parameters – especially separately from each other – to be able to make coherent assumptions about salmonid movement in the River Möll.

Several movement studies describe a restricted movement paradigm (RMP) (sensu Gowan et al., 1994) during nonbreeding, summer feeding periods. Critics of the RMP claim that most fish movement study designs are biased against the detection of movement because conclusions and findings are based on recaptures within the study area. Therefore, moving fish may had been underestimated in the results as they were never recaptured. Radinger and Wolter (2014) reviewed 160 empirical data sets and analyzed freshwater fish movement. They distinguished between fish families as well as between stationary and mobile component of fish assemblages and describe characteristic mean movements (Radinger and Wolter, 2014) (see Figure 51).

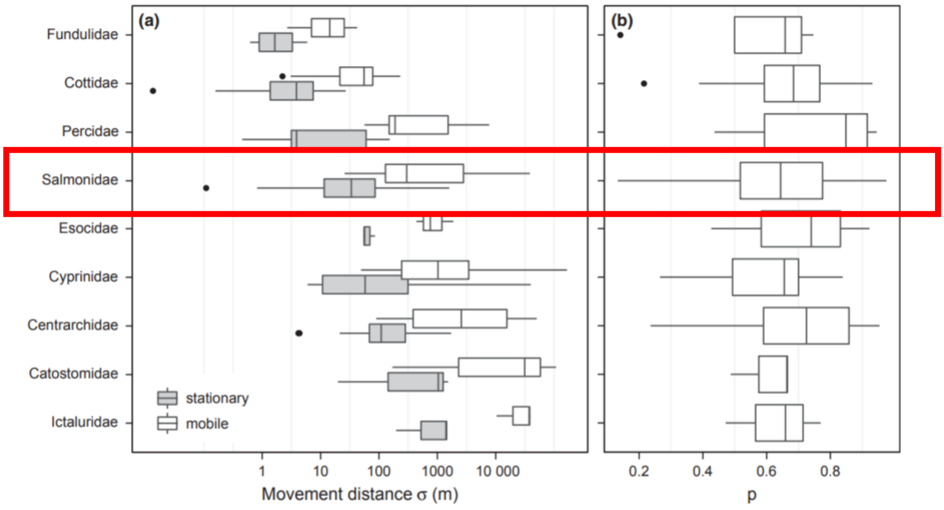


Figure 51: Characteristics of movement parameters across families: (a) movement distances of the stationary (grey boxes) and mobile (white boxes) component. (b) Share of the stationary component (P). (Radinger and Wolter, 2014)

Figure 51 shows that the sedentary component of salmonids mainly exhibits movements smaller than 100 m while mobile individuals cover distances up to a few kilometers. The study sections at River Möll had a length of more than 2 kilometers (RFS 2 670 m, CS 2 040 m), upstream escapes from the residual flow section were recorded by the remote detection antenna in the vertical slot. In addition, T was calculated. This parameter helps to know, whether marked fish stayed within the sections or if unmarked fish had immigrated. It shows, how the ratio between tagged and untagged individuals developed at any given time of the investigation period. As long as T stays constant or rather develops slightly increasing, it is possible to describe movement of the whole fish assemblage sufficiently, partly also for the mobile fraction. Therefore, it is suggested, that the methodological bias described in literature (criticism of the RMP) could be kept to a minimum in the present study – at least during summer.

Within a river system several factors may influence the movement behavior of freshwater organisms. For example, food availability, predation pressure or habitat complexity are mentioned frequently in literature in respect of fish movement. According to Figure 48 (Comparison of T between the study sections), fish at River Möll mainly stayed within the study sections during summer 2018 (May until October), as T developed smoothly increasing. The additional electrofishing effort in the RFS by boat in August 2018 as well as the evaluation of the remote-detection antenna in the vertical slot support this presumption. It is assumed, that the restricted movement paradigm (RMP) is valid during summer 2018 for both investigated sections of the River Möll. The evaluation of P and D shows as well that salmonid movement was restricted: Until the flood event occurred, the pooled evaluation of P during summer resulted in 0.85 (RFS) and 0.88 (CS), which was comparatively high in regard to the findings of Radinger and Wolter (2014) in Figure 51 (b). In view of the studies of Gresswell and Hendricks (2007) and Aparicio et al. (2018), where 80 % of recaptured trout stayed within 100 m from the point of first capture in summer, $P_{RFS\_Summer} = 0.85$ and $P_{CS\_Summer} = 0.88$ is also rather high. Further, with exception of the samplings of June 2018 where the confidence intervals of rainbow trout did not overlap with the confidence intervals of the following months, individual displacement (D) indicated high site fidelity during summer as well.

Table 15: Comparison of T (Turnover Rate) between residual flow section (RFS) and control section (CS).

Month	Code	T RFS	T CS
May 2018	05	0,29	
June 2018	06	0,50	
July 2018	07	0,54	
August 2018	08	0,54	0,37
September 2018	09	0,53	0,44
October 2018	10	0,59	0,42
→	Flood including a drawdown flushing		
December 2018	12	0,79	0,54
December 2018 (quant.)	12	0,80	0,55
May 2019 (quant.)	17	0,77	
→	Flood including a drawdown flushing		
August 2019	20	0,89	0,45

Due to the fact, that T was more or less constant throughout summer 2018 (see Table 15), P has even more explanatory power. The high share of sedentary individuals implies good habitat conditions in both sections. Although the runoff- and sediment-regime of the section below the weir is anthropogenically heavily impacted, the remaining water body offers a diverse range of habitats. In order to compensate the sediment deficit below the weir, tons of gravel are poured into the RFS every year (according to statements from the owner of fishing rights). Furthermore, numerous morphological structures such as groynes were built. As a result of these measures, the fish stock assessment resulted in high abundance and biomass, the length frequency diagrams in 5.1.1 indicate habitats for all size classes. Several studies describe the importance of habitat complexity and its consequences for fish movement behavior. Poor morphological heterogeneity leads to higher movement distances or – in other words - if all necessary habitats to fulfill an individual's life-cycle occur in close proximity, movement distances remain short (Solomon and Templeton, 1976; Schlosser, 1995; Schrank and Rahel, 2004; Palm et al., 2009). It seems, that both sections at the River Möll provide sufficient morphological structures for all age classes. Most of the fish did not have to leave their home stretches.

In the light of all points mentioned above it is suggested that movement was restricted during summer 2018 in both river sections and therefore, hypothesis 1 can be confirmed.

The mobile-sedentary split is hard to assess (Young, 2011), mainly due to methodological issues (see Rodríguez, 2002) or often because of limited investigation periods (< 1 year). Especially the methodological approach differs between movement studies, and this can lead to varying views on the mobile-sedentary split. Because of the investigation design of the present study, the movement range for the sedentary fraction is set wide. The home stretch ± 1 stretch results in a corridor of about 300 m. This may lead to an underestimation of the mobile share of the population. Compared to other studies, an individual is only assessed as sedentary, if it is recaptured within 50 m from the point of first capture (Aparicio et al., 2018; Rodríguez, 2002). The mean movement distances of both sedentary and mobile fraction (evaluation of D) are displayed in Table 16. In consideration of the methodological inaccuracies, covered distances of the sedentary fraction stayed below 100 m. Interestingly, mean movement of the mobile share of the population enhanced over time. So called 'strays' (independent of size class or species) were obviously seeking for new habitats. Competition with dominant fish, predation risk or the search for larger food supply (Railsback et al., 1999) are possible reasons for this development. In comparison with Figure 51 (a), the observed covered distances of the mobile as well as the sedentary fraction match with the findings of Radinger and Wolter (2014).

Table 16: Comparison of P and mean movement distances of all salmonids throughout the study period.

Section	Month	n	P	Mean Movement Sedentary Fraction [m]	Mean Movement Mobile Fraction [m]	Factor mob./sed.
Residual Flow Section	May 2018	166	0.89	71	285	4.0
	June 2018	126	0.83	77	462	6.0
	July 2018	121	0.76	70	475	6.7
	August 2018	195	0.87	62	517	8.3
	September 2018	109	0.91	64	568	8.9
	October 2018	151	0.86	64	609	9.5
	→	Flood including a drawdown flushing				
	December 2018	76	0.47	61	1351	**22.3**
	May 2019	86	0.52	68	673	9.9
	→	Flood including a drawdown flushing				
	August 2019	34	0.50	24	753	**30.8**
Control Section						
	August 2018	254	0.83	70	323	4.6
	September 2018	142	0.92	36	325	9.1
	October 2018	265	0.91	34	555	16.4
	→	Flood				
	December 2018	554	0.66	58	600	10.4
	→	Flood				
	August 2019	128	0.77	37	528	14.1

Literature describes the factor between mean movement of the mobile fraction and mean movement of the sedentary fraction. It was determined that mobile salmonids move 18 times farther than sedentary individuals (Rodríguez, 2002). In comparison Radinger and Wolter (2014) observed 14 times longer movement distances; in the study of Aparicio et al. (2018) mobile individuals undertake ~ 12 times longer movements than stationary individuals. In the residual flow section the factor "mob./sed." gradually approaches the values given in literature, with exception of the fish samplings following the drawdown flushing events. In December 2018 and August 2019, the factor increased, indicating that the drawdown flushing caused enhanced movement in the RFS. In the control section the factor remained between 4 and 17 throughout the investigation period, even the flood events did not lead to major changes.

As already mentioned in 4.2, the assessment focuses mainly on the impact of the drawdown flushing event in October 2018. The second event in June 2019 is treated only for reasons of completeness. The evaluation of the three study parameters provides more detailed information on what happened after the drawdown flushing 2018:

The initially marked fish population in the residual flow section was reduced by almost 90 % (Pinter et al., 2021). No individual of the age group 'young of the year' was found after the drawdown flushing, although numerous small individuals were caught during the samplings before the event (see length-frequency diagrams in 5.1.1). The negative impact on the fish stock is obvious. In the control section a reduction of fish abundance was documented as well, but the initially tagged fish stock was only decimated by ~10 %. The question arises if the drawdown flushing had lethal consequences for the fish assemblage? Or did fish just drift off into other river sections due to high flow velocities and enhanced suspended solid concentrations and never came back?

According to the literature "downstream displacement" of fish is documented frequently because of high discharges (floods), especially if the morphological complexity of a river section is low and therefore suitable habitats as refuges are missing (Heggenes, 1988b; Pearsons et al., 1992; Ward et al., 2003). The investigated residual flow section provides a heterogeneous and quite well structured riverbed, but it does not have any off channel habitats, like tributaries or sidearms (with exception of the vertical slot close to the weir), which would be urgently needed, especially for juvenile fish with low swimming abilities (Bell et al., 2001). Particularly during high flows, flow-calmed areas are rare due to the trapezium-shaped cross section of the river channel. Whereas it is more probable, that areas with low flow velocities occur in the floodplains of the control section. It was expected that the fish population in the residual flow section will be struggling with enhanced suspended solids and the flood wave and leave the study section in downstream direction. In comparable studies, enhanced, unnatural movements were observed as well below reservoirs after a drawdown flushing in Switzerland (Grimardias et al., 2017) and after a sluicing operation in Wyoming, USA (Bergstedt and Bergersen, 1997).

For the post event evaluation of the three study parameters, it is important to note, that due to the strong increase of T (absence of marked individuals) in the residual flow section, it can no longer be assumed that the entire population is adequately represented by recaptured individuals in December 2018 (see "criticism of the restricted movement paradigm (RMP)").

After a moderate increase of T during summer, the drawdown flushing event in October 2018 leads to a rapid and significant change of T from T_{RFS_Oct18} = 0.59 to T_{RFS_Dec18} = 0.79/0.80 in the residual flow section (see Table 15). Also, P_{RFS} drops within the section from 0.87 between August and October 2018 to 0.47 in December (Q = 0.30; significant change), this means that more than 50 % of all recaptures (n=76) were caught beyond their home range.

But, in consideration of the large home range corridor of ~ 300 m (overestimation of the sedentary share of the fish population), also the flood event itself led to a dislocation of fish within the control section, when P_{CS} reduced from 0.88 between August and October 2018 to P_{CS_Dec18} = 0.66 (Q = 0.14; no significant change). Furthermore, T_{CS} recorded enhanced turnover in the control section after the flood event as $T_{CS\_Oct18} = 0.42$ increased to $T_{CS\_Dec18} = 0.54/0.55$ (significant change). On the other hand, in the complementary samplings beyond the control section (both upstream and downstream) in December 2018 only 22 of 535 caught individuals were tagged. The fact, that only four percent of caught individuals were marked in immediate environment of the investigation section shows that the fish assemblage stayed close to formerly occupied habitats and were mostly unaffected by the enhanced discharge situation during the flood. This was also confirmed by the mean movement of the mobile fraction in the control section (see Table 16), which remained more or less unchanged between October 2018 and August 2019.

Individual displacement (D) resulted in higher mean movements of the mobile fraction in the residual flow section. As e.g. Figure 37 shows, some individuals were recaptured quite far (downstream) from their home stretch in December 2018, since the shape of boxplots is altered in comparison to the samplings before the drawdown flushing. Regarding median movement the parameter does not show any significant changes between the samplings before the flood/flushing event and the samplings in December 2018 in both sections, since confidence intervals overlap for all study species.

Consequently, the evaluation of the study parameters shows, that the high flows in the end of October 2018 led to enhanced salmonid movement in the River Möll. It is obvious, that displacement was stronger in the impacted residual flow section, but "downstream movement" in particular could not be proven statistically. Therefore, it is not permissible to confirm hypothesis 2: downstream displacement in December 2018 was higher in the residual flow section than in the control section.

Though, a closer look on the mobile fraction (parameter P – proportion of sedentary individuals) generates interesting opportunities for interpretation, at least for a small part of the "lost" individuals in the RFS. There is no doubt, displacement took place due to the drawdown flushing. Fish left the impacted section, but the question arises in which direction? In literature displacement is discussed almost without exception in downstream direction. In fact, it is difficult to imagine, that fish chose the way upstream towards the weir to escape from the sudden changes in their environment. But the evaluation of P showed indications of upstream movement:

In Figure 33 in 5.2.5 the behavior of the mobile fraction is displayed in the control section. It is evident, that mobile individuals leave their point of first capture in upstream direction in almost

50 % of the cases. Even the samplings after the flood event show that more than 40 % of 188 mobile individuals were recaptured upstream of their home stretch. This implies that upstream movement is not unlikely during/after high flows at River Möll.

In the residual flow section upstream movements were documented as well. In Table 17 all individuals of the mobile fraction in the RFS are listed including their escape direction from their home stretch. All 15 upstream escaping individuals in December 2018 can be assigned to the rainbow trout.

Table 17: Escape direction of the mobile fraction within the residual flow section.

Month	n	Upstream	Downstream	% Upstream
May 2018	19	9	10	**47**
June 2018	22	8	14	**36**
July 2018	29	25	4	**86**
August 2018	26	19	7	**73**
September 2018	10	5	5	**50**
October 2018	21	18	3	**86**
→	Flood including a drawdown flushing			
December 2018	40	15	25	**38**
May 2019	41	23	18	**56**
→	Flood including a drawdown flushing			
August 2019	17	6	11	**35**

Further, all together 72 assignable individuals (~ 2 % of all tagged individuals in the RFS) were detected by the remote detection antenna in the vertical slot throughout the study period, 59 rainbow trout and 13 brown trout. These registrations were not considered in Table 17 but can clearly be assigned to the upstream moving fraction. During the drawdown flushing event in October 2018, 9 rainbow trout and 2 brown trout entered the vertical slot, probably in attempt to seek shelter as the fish pass is the only available refuge (tributary) in the residual flow section.

After a reservoir flushing in Salzburg (KW Urstein), 2 of 6 recaptured fish (out of ~5 000 tagged and stocked fish) were recaptured upstream the point of first capture (Petz-Glechner et al., 2005). One rainbow trout was even able to pass a barrier (Sohlschwelle Lehen), which was not passable for fish during normal discharge conditions. Thus, the upstream movement of this individual must have taken place during the operation of the drawdown flushing (at high water level).

Of course, considering the force and impact of such an operation close to the weir, it is unlikely that individuals left the residual flow section in upstream direction during the drawdown flushing. In this study the river section upstream the reservoir Rottau was not checked for tagged individuals after the flushing event, but this is recommended for future investigations. At least qualitative samplings could have provided a lot of information. As long as the low-level outlets had been opened, the flow continuum was theoretically restored. If “upstream displacement” actually took place, salmonids would only have been exposed to a “normal flood with natural suspended solids concentrations” as soon as they had passed the reservoir. And as the control section showed, the flood itself was not particularly harming for the fish population (Pinter et al., 2021). Therefore, the decisive duration of exposure to enhanced suspended solids concentrations (Newcombe and Macdonald, 1991) could have been quite low. This also applies to fish that quickly found their way to the River Drava (downstream direction). After several recaptures of tagged individuals near the Möll estuary during the qualitative spot checks in the River Drava in December 2018 (see Figure 52), it is at least certain that fish had undertaken long movements (several kilometers) to escape from the extreme situation during the drawdown flushing.

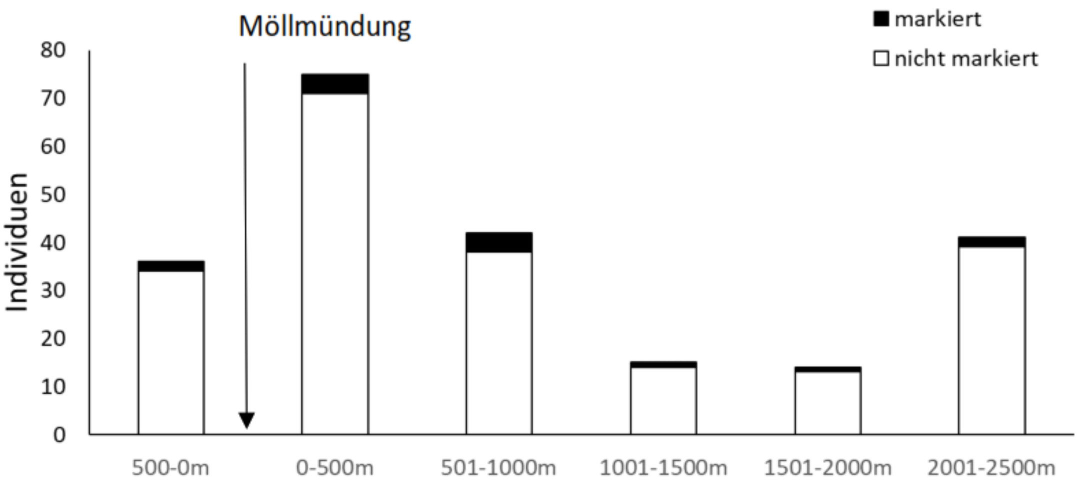


Figure 52: Of 223 captures during qualitative spot checks in the River Drava around the Möll estuary (black arrow) in December 2018, 11 individuals carried a PIT-tag. The share of tagged individuals is displayed in black, unmarked fish in white (Pinter et al., 2021).

Since it is clear, that tagged individuals had left their home ranges due to the high discharges in the end of October 2018, the question arises, whether displaced fish undertook recolonization movements or not?

As Figure 29 shows, recolonization movements show species-specific differences in the River Möll, for rainbow trout recolonization was obviously restricted. Once fish were displaced, more than 80 % of recaptured graylings and brown trout returned to their home range. On the contrary P of rainbow trout remained unchanged or even decreased until the end of the investigation period in both sections (in August 2019 $P_{CS\_RBT\_Aug19}$ was below 0.60, in the RFS less than 40 % of recaptured rainbow trout occupied former home ranges ($P_{RFS\_RBT\_Aug19}$ = 0.39)). It can therefore be assumed that a “home range shift” (sensu Crook, 2004) has occurred. Stream-dwelling rainbow trout perhaps found new suitable habitats, irrelevant in upstream or downstream direction. Further, homing might be limited if the distance of displacement was too big (Lucas and Baras, 2001). According to Figure 52 marked individuals were found ~2,5 km downstream the Möll estuary, this amounts in a total displacement of at least 5 km.

Furthermore, if morphological structure is changed substantially, former habitats will not be occupied again (McEwan and Joy, 2013). The morphological alterations because of the flood including a drawdown flushing 2018 were not assessed (yet), but this could be another reason, why rainbow trout did not return to formerly occupied river stretches (home range shift). On the other hand, in the CS recolonization of rainbow trout was restricted as well. This in turn suggests that rainbow trout are simply less attached to familiar habitats than the other study species. Heggenes et al. (2007) describe that individual as well as intra-specific variations in movement behavior due to local adaptions is the rule for trout (Heggenes et al., 2007). This may perhaps be an explanation for the accumulation of fish in the stilling basin of the weir Rottau in Winter 2019. Many fish were observed close to the weir in February and March 2019 (Pinter et al., 2021), but very few of 219 caught salmonids carried a PIT-tag (5 %). It is assumed, that captured rainbow trout (caught by rod) originally came from the reservoir – recognizable due to their phenotypic appearance – and could not pass the weir during recolonization movements. In terms of recolonization movements in the River Möll it is feasible, that intra-specific differences between stream-dwelling and lake-dwelling rainbow trout occurred. While some individuals found new habitats in other river sections, others consciously seek for their familiar, environment in the reservoir, with low flow velocities. It also proves that at least some rainbow trout that had been washed out of the reservoir in downstream direction survived the drawdown flushing.

Maybe the fish stock assessment could have overestimated the lethal consequences of the drawdown flushing for the fish population below the reservoir, at least for adult individuals. In the course of the study it remained unclear, where the majority of marked salmonids stayed after the drawdown flushing. Further investigations regarding the hydraulic situation or other abiotic factors like suspended sediment concentration or oxygen deficit during the drawdown flushing can possibly provide clearer answers for the loss of tagged salmonids.

Fact is, that displacement in the control section was lower than in the residual flow section. After displacement due to the drawdown flushing, lake-dwelling rainbow trout, brown trout and grayling returned verifiable to their formerly occupied territories, while stream dwelling rainbow trout apparently experienced a home range shift. The high share of brown trout and grayling in the fish population in the control section, might be one of the reasons, why turnover rate (see Table 15, Figure 50) as well as the proportion of sedentary individuals (P) recovers over time (see Table 16, Table 18). Another (related) feasible reason is the enhanced appearance of unmarked fish in the sampling of December 2018, which were displaced from the surrounding river sections, and left the control section to return to their former habitats.

In Table 18 all recaptured fish from August 2019 in the CS are displayed. The column "SoR minus HS" equals the "Stretch of Recapture" minus the "Home Stretch" (see 4.5.1) and shows the species-specific differences in recolonization movements. If "SoR minus HS" resulted in 0 or ± 1, the individual was assigned to the sedentary fraction, otherwise to the mobile share of the population. After two flood events 85 % of all recaptured brown trout returned to their formerly occupied stretches (actually P was 0.91 for brown trout > 200 mm), also 83 % of recaptured graylings were found within their home ranges (recolonization movement of grayling was nearly significant, Q = - 0,19).

For stream-dwelling rainbow trout P resulted in 0.57 in August 2019, recaptures in the stretch of first capture (SoR-HS = "0") occurred by far less frequently than for the other study species. The willingness to return was obviously limited, probably because rainbow trout simple adapted better to new, comparable surroundings. It seems that differential movement behavior within the population occurred at River Möll.

As we become more able to track individual animals as they migrate across space and time, it seems clear that differential migration is the rule rather than the exception and that significant variation exists in migratory behavior within populations (Brönmark et al., 2013).

Table 18: Comparison of recaptures in the CS from August 2019. (BT = brown trout, RBT = rainbow trout, G = grayling)

	Species	Length	SoR minus HS	Species	Length	SoR minus HS	Species	Length	SoR minus HS
August 2019	BT	287	**0**	RBT	333	**0**	G	280	**0**
	BT	226	**0**	RBT	196	**-2**	G	281	**0**
	BT	259	**0**	RBT	319	**-1**	G	268	**-3**
	BT	249	**0**	RBT	215	**0**	G	275	**-1**
	BT	294	**0**	RBT	301	**-1**	G	361	**-2**
	BT	265	**0**	RBT	195	**2**	G	257	**0**
	BT	261	**0**	RBT	265	**-1**	G	345	**1**
	BT	215	**0**	RBT	246	**-1**	G	366	**-1**
	BT	174	**0**	RBT	335	**-1**	G	337	**-7**
	BT	180	**0**	RBT	311	**8**	G	427	**-1**
	BT	243	**0**	RBT	246	**3**	G	346	**0**
	BT	214	**0**	RBT	265	**1**	G	290	**0**
	BT	290	**0**	RBT	305	**-2**	G	251	**0**
	BT	333	**1**	RBT	282	**-1**	G	287	**1**
	BT	197	**0**	RBT	235	**-2**	G	390	**-2**
	BT	196	**0**	RBT	286	**-1**	G	415	**-2**
	BT	236	**0**	RBT	254	**0**	G	379	**-1**
	BT	268	**-1**	RBT	315	**-1**	G	395	**-1**
	BT	217	**4**	RBT	282	**0**	G	266	**-1**
	BT	322	**6**	RBT	230	**-1**	G	275	**-1**
	BT	282	**-1**	RBT	253	**2**	G	273	**-1**
	BT	185	**-1**	RBT	226	**2**	G	352	**0**
	BT	195	**-3**	RBT	270	**0**	G	376	**0**
	BT	240	**-1**	RBT	217	**6**	G	282	**-1**
	BT	276	**-1**	RBT	245	**2**	G	386	**0**
	BT	195	**-2**	RBT	195	**9**	G	245	**0**
	BT	186	**-1**	RBT	215	**6**	G	260	**0**
	BT	295	**0**	RBT	220	**0**	G	380	**0**
	BT	271	**0**	RBT	265	**-1**	G	296	**0**
	BT	195	**0**	RBT	229	**0**	G	321	**0**
	BT	189	**0**	RBT	218	**7**	G	255	**0**
	BT	272	**0**	RBT	209	**10**	G	269	**0**
	BT	227	**0**	RBT	208	**-1**	G	330	**0**
	BT	170	**0**	RBT	214	**-4**	G	342	**0**
	BT	247	**0**	RBT	292	**-1**	G	281	**0**
	BT	210	**0**				G	285	**-2**
	BT	167	**0**				G	243	**12**
	BT	227	**-1**				G	261	**0**
	BT	225	**-1**				G	402	**0**
	BT	233	**-2**				G	281	**1**
	BT	265	**0**						
	BT	254	**0**						
	BT	210	**0**						
	BT	185	**3**						
	BT	247	**0**						
	BT	215	**-1**						
	BT	226	**0**						
	BT	264	**0**						
	BT	174	**4**						
	BT	185	**-1**						
	BT	175	**-1**						
	BT	199	**-3**						
	BT	187	**0**						

Since the residual flow section was dominated by rainbow trout (~ 75 % of the fish population) it is possible, that the majority of the population may not even have attempted to return into the residual flow section (no recovery of tag-rate, see Figure 49). Those individuals (rainbow trout), who were able to remain anywhere within the study section, probably stayed in the new/altered environment. Others, who were displaced in areas beyond the investigation are, perhaps adapted and remained there.

To confirm the results regarding the recolonization behavior, it would be interesting to take a sample of the three study species in the control section, mark and then displace them experimentally. Höjesjö et al. (2015) carried out a similar study with juvenile brown trout in Sweden and observed increased activity post displacement, but no clear signs of homing (Höjesjö et al., 2015). According to the present findings at River Möll, naturally displaced salmonids, in exception of stream-dwelling rainbow trout, are probably more successful in finding former occupied river stretches than experimentally displaced salmonids.

The assumption, that recolonization movement was generally restricted in the residual flow section due to substantial morphological alterations (see McEwan and Joy, 2013), is considered unlikely, as 83 % of recaptured brown trout (n = 23) in 2019 returned to the territory of first capture (see Table 20). On the contrary, only 42 % of all recaptured rainbow trout (n = 86) were caught in their home range in 2019.

Table 19: Count of recaptures before and after the drawdown flushing events in the residual flow section.

Residual Flow Section	**Count of Recaptures (n)**				
	Rainbow Trout	**Brown Trout**	**Grayling**	**Total**	**Sampling design**
October_2018	127	14	10	151	qualitative spot check
Share [%]	**84**	9	7		
December_2018	59	14	3	76	quantitative sampling
Share [%]	**78**	18	4		
May_2019	63	16	7	86	quantitative sampling
Share [%]	**73**	19	8		
August_2019	23	7	4	34	qualitative spot check
Share [%]	**68**	21	12		
Total	**272**	**51**	**24**	**347**	

Although quantitative samplings were carried out in December 2018 and May 2019, the count of recaptures decreased clearly in comparison to the qualitative spot checks before the drawdown flushing (see Table 19). This is an indication that there were fewer fish in the section left. The share of rainbow trout of each sample also decreased over time, from 84 % in October 2018 to 68 % in August 2019. Probably not because further rainbow trout left the study section, but because relatively more brown trout and graylings returned.

Table 20: Recolonization movement was rather the rule than the exception for recaptured brown trout in 2019 in the residual flow section.

	Species	Length	Home Stretch	Stretch of Recapture	HS minus SoR	Share
May 2019	Brown Trout	410	22	22	**0**	**sedentary**
	Brown Trout	136	22	22	**0**	**sedentary**
	Brown Trout	205	22	22	**0**	**sedentary**
	Brown Trout	220	22	22	**0**	**sedentary**
	Brown Trout	155	10	11	**1**	**sedentary**
	Brown Trout	185	11	11	**0**	**sedentary**
	Brown Trout	170	10	11	**1**	**sedentary**
	Brown Trout	260	10	9	**-1**	**sedentary**
	Brown Trout	190	18	14	**-4**	**mobile**
	Brown Trout	205	12	12	**0**	**sedentary**
	Brown Trout	185	18	18	**0**	**sedentary**
	Brown Trout	189	21	18	**-3**	**mobile**
	Brown Trout	236	18	18	**0**	**sedentary**
	Brown Trout	169	18	18	**0**	**sedentary**
	Brown Trout	213	18	18	**0**	**sedentary**
	Brown Trout	210	19	21	**2**	**mobile**
August 2019	Brown Trout	215	21	21	**0**	**sedentary**
	Brown Trout	216	21	21	**0**	**sedentary**
	Brown Trout	176	18	10	**-8**	**mobile**
	Brown Trout	310	7	7	**0**	**sedentary**
	Brown Trout	235	7	7	**0**	**sedentary**
	Brown Trout	240	7	7	**0**	**sedentary**
	Brown Trout	234	7	7	**0**	**sedentary**

Summarizing, restricted movement was recorded during summer as well as displacement of salmonids because of enhanced discharges – this is valid for all three study species. Rainbow trout and grayling even left its home range significantly after the drawdown flushing in the residual flow section. In terms of recolonization movements, the behavior of grayling (almost significant) and brown trout was fundamentally different from recolonization behavior of stream-dwelling rainbow trout. Therefore, H3 – movement patterns differ between species – can be confirmed.

Hypothesis 4 – juvenile fish are more affected by the drawdown flushing than adult fish – could not be answered with sufficient accuracy, since the number of recaptures after the flushing event was too low for reliable findings in this regard. Throughout the study period, not even one grayling < 201 mm was recaptured in the residual flow section. In December 2018, at least 10 out of 14 recaptured brown trout were smaller than 201 mm and 13 out of 59 rainbow trout were assigned to the size class < 201 mm.

Generally, the examined parameter P (see Table 5, significance check in Figure 31) and D (see Table 11) do not show any significant differences in movement behavior in December 2018 between the two size classes < 201 mm and > 200 mm. In the CS, mean movement distances were also comparable between the two size classes after the flood (see Table 12).

According to the quantitative samplings of December 2018, the abundance of tagged juvenile rainbow trout was massively reduced from 608 ind./ha before the drawdown flushing to 22 ind./ha after the event (Pinter et al., 2021). It was not possible to display this decline for juvenile individuals in the RFS with fish movement data, mainly due to low recaptures (both size classes) of brown trout and grayling after the drawdown flushing. Further, because of the rapid growth of rainbow trout before the reservoir was flushed, most tagged fish were larger than 200 mm at the sampling days in December 2018.

A look at the column "SoR minus HS" in Table 21 and Table 22 (all recaptures < 201 mm from December 2018) shows, that the high site fidelity of salmonids was disrupted by the high discharge in the end of October 2018.

Table 21: Recaptured brown trout < 201 mm from December 2018 in the residual flow section.

	Species	Length	Home Stretch	Stretch of Recapture	SoR minus HS	Share
December 2018	Brown Trout	170	19	19	**0**	**sedentary**
	Brown Trout	140	5	19	**14**	**mobile**
	Brown Trout	150	17	18	**1**	**sedentary**
	Brown Trout	149	18	18	**0**	**sedentary**
	Brown Trout	150	16	22	**6**	**mobile**
	Brown Trout	145	14	22	**8**	**mobile**
	Brown Trout	181	22	22	**0**	**sedentary**
	Brown Trout	116	22	22	**0**	**sedentary**
	Brown Trout	185	16	16	**0**	**sedentary**
	Brown Trout	184	16	16	**0**	**sedentary**

For brown trout < 201 mm 3 out of 10 recaptures can be assigned to the mobile proportion. Interestingly, only one recaptured individual was tagged near the weir (~400 m – 500 m; home stretch: ID 5), its stretch of recapture was about 1.700 m downstream (stretch ID 19). However, individuals initially tagged further downstream tended to remain close to their home stretch or the adjacent one (e.g., stretch ID 22 is located ~ 2.400 m - 2.500 m downstream the reservoir). Of those 13 rainbow trout < 201 mm caught in December 2018, 6 stayed sedentary, 3 moved upstream and 4 left their home range in downstream direction (see Table 22), therefore more than 50 % of recaptured juvenile individuals were assigned as mobile. A few juvenile individuals of rainbow trout stayed in their familiar surroundings, even in stretches closer the weir.

Table 22: Recaptured rainbow trout > 201 mm from December 2018 in the residual flow section.

	Species	Length	Home Stretch	Stretch of Recapture	SoR minus HS	Share
December 2018	Rainbow Trout	190	6	6	**0**	**sedentary**
	Rainbow Trout	191	17	beyond 24	**beyond (+)**	**mobile**
	Rainbow Trout	193	21	19	**-2**	**mobile**
	Rainbow Trout	185	14	18	**4**	**mobile**
	Rainbow Trout	163	18	18	**0**	**sedentary**
	Rainbow Trout	190	17	18	**1**	**sedentary**
	Rainbow Trout	180	5	18	**13**	**mobile**
	Rainbow Trout	195	12	11	**-1**	**sedentary**
	Rainbow Trout	191	11	11	**0**	**sedentary**
	Rainbow Trout	170	10	4	**-6**	**mobile**
	Rainbow Trout	175	4	4	**0**	**sedentary**
	Rainbow Trout	191	9	24	**15**	**mobile**
	Rainbow Trout	185	20	16	**-4**	**mobile**

But, also due to low recaptures of individuals larger than 200 mm, it was not identifiable with the available salmonid movement data, if the adverse impact of the drawdown flushing was greater for juvenile or for adult fish.

The detection of spawning migration was not the goal of this study, but because of the study design it could generally have been recognized. In the control section under more or less natural hydrological conditions spawning migration was expectable. The most suitable parameter for the detection is the turnover rate (T), as the absence of tagged individuals is detectable. Until October 2018 T remained constant in the CS (before the start of the spawning season for brown trout). The quantitative check in December 2018 recorded a slight increase of T, however, this was attributed to the longitudinal displacement rather than to spawning migration. The next sampling occurred in August 2019, when the spawning season of all study species was over, and T had already recovered. Nevertheless, it is assumed, that spawning migration was restricted, because the complex morphological conditions (visual evaluation) within the river section deliver suitable habitats to fulfill a salmonid's lifecycle (see Solomon and Templeton, 1976; Schrank and Rahel, 2004; Palm et al., 2009).

Estimations of home range sizes may be dependent on the methodological approach of different studies (duration, the way how fish were tagged, frequency of recapture-attempts, stream size) and home ranges can be smaller during nonmigratory periods (Lucas and Baras, 2001). Radio-tagged fish data provides fine resolution of movements in terms of timing and distance, while mark-recapture (MR) studies deliver information at larger temporal and spatial scales (Gresswell and Hendricks, 2007). Since the methodological design of the present investigation differs from usual movement studies, it was hard to make explicit statements about the home range size of fish at River Möll, nevertheless it was possible to describe individual displacement of recaptured fish from the point of first capture. Thus, a "documented home range" is described at least in high numbers compared to other movement studies, where the "n" of observed individuals was mostly quite low, for example: n = 20 (Heggenes et al., 2007), n = 6 (Thompson et al., 2011), n = 220 (Höjesjö et al., 2015), n = 49 (Grimardias et al., 2017), n = 50 (Rocaspana et al., 2019). During this mark recapture (MR) study at River Möll 6 978 individuals were observed and 2 407 fish were recaptured (~35 %).

The right choice of the marking method is substantial (Lucas and Baras, 2001): Depending on the study objective, one should be clear about the advantages and disadvantages of the available techniques. For example, mark recapture or catch per unit effort techniques are very cost-efficient and necessitate little technical requirements. They are useful if the temporal and spatial resolution does not have to be too high. At the same time, it is possible, that movements are noticeably underestimated because the findings are based on recaptures only. Telemetry techniques deliver a lot of information on individual level, but telemetry is very cost-intensive and only slightly applicable for juvenile fish. In large river systems, hydroacoustic techniques may be most adequate, especially if information on population level is of interest. In respect of the high number of salmonids that had been marked, the use of PIT-tags was the right choice for this study. The count of recaptures was high enough in each sampling to make statements about the fish population, at least for fish larger than 200 mm. For future investigations it would be useful to adapt the study design especially in order to find the lost fish after the drawdown flushing. The additional application of telemetry transmitters is advised as well as the expansion of the spot checks after the flushing of reservoir Rottau. It is of key importance to find as many tagged individuals as possible to gain a thorough understanding of the impact of the drawdown flushing on the fish population. Where are the missing fish? Furthermore, it would be useful to continue tagging measures throughout the study period. In this way, it would probably be easier to make sufficient recaptures even after the flushing event, particularly in regard of fish smaller than 201 mm. But, additional marking measures would have influenced the calculation and evaluation of the turnover rate. Moreover, permanent marking procedures would have been very time consuming and costly. It probably would have exceeded the financial scope of the study. Anyway, with costs totaling more than 100 000 € (excluding costs for approval procedures, data analysis and reporting), the study was already an expensive affair.

Perhaps, an earlier occurrence of a flood (including a drawdown flushing) would have been more appropriate for the selected marking design. Statements regarding the displacement of juvenile individuals could have been made more precisely in the residual flow section. Then again, the restricted movement paradigm during nonmigratory period might not have been determined so well.

7 CONCLUSION

Once the strong environmental effect of the drawdown flushing from October 2018 was certain, the question arose, if it is possible to exemplify the adverse impact additionally with the available fish movement data. As the movement patterns of stream fish is examined in several research studies for both migratory and nonmigratory behavior, there is poor information about the impact of a drawdown flushing event on the movement behavior of salmonids.

Restricted movement was predominant in both investigated river sections before the flood event. In advance of the study, it was expected that the fish abundance in the residual flow section will be struggling with enhanced suspended solids concentration in the flood wave of the drawdown flushing and leave the study section in downstream direction. This is exactly what happened, although the escape direction could not be fully clarified yet. Displacement did not take place in the same extend than in the RFS, but salmonids in the control section were displaced significantly (turnover rate) by the flood as well.

The high site fidelity of fish during summer suggests sufficiently complex morphology in both sections. However, since the loss of individuals after the drawdown flushing event was huge, it seems clear, that there were not enough refugial habitats available during this extreme discharge situation in the residual flow section.

According to the fish stock assessment (Pinter et al., 2021), juvenile rainbow trout were significantly stronger affected by the drawdown flushing event than adult individuals. Due to insufficient recaptures of juvenile and adult individuals after the drawdown flushing, it was not possible to describe this development with movement data. The lack of recaptures is also the reason why no further size classes than < 201 mm and > 200 mm were defined and evaluated. However, the use of formerly occupied stretches (parameter P) changed significantly for rainbow trout for both size classes in the residual flow section. The flood event itself in the control section led to significant changes of P only for grayling, but also rainbow trout showed a clear trend to leave its home range. For brown trout no statistically significant changes of P due to high flows were observed.

Interestingly, species-specific as well as the intra-specific differences in movement behavior were observed after the flood event. Without this detailed knowledge of differential recolonization behavior, it would be reasonable to assume, that the drawdown flushing had highly lethal consequences for the fish population. It is not intended to say, that the drawdown flushing was not harmful for the fish assemblage. Quite the contrary, the fish stock assessment in December 2018 resulted in severe decreases of biomass and abundance, especially juvenile individuals were missing almost completely (significant loss of juvenile rainbow trout) (Pinter et al., 2021). But it is feasible, mainly due to the species composition in the residual flow section (high share of rainbow trout, 75 %), that the fish stock assessment as well as the parameter T (turnover rate) overestimates the lethality of the drawdown flushing. Because of the observed capability of stream-dwelling rainbow trout to adapt to new structures, turnover rate stayed high after the flushing, what suggests high lethality. But, since the monitored recolonization movements have been that similar in both sections it is carefully assumed, that this particular drawdown flushing event (duration, dilution of suspended solids, etc.) of reservoir Rottau in October 2018, was probably less devastating for salmonids than the fish stock assessment supposed, at least for adult individuals.

The mobile component of each population is hypothesized as being responsible for individuals exchange between populations and thus decisive for dispersal, colonization and recolonization. Accordingly, the number of mobile individuals determines the successful spread into new habitat. (Radinger and Wolter, 2014).

It is guessed that the mobile share of the fish assemblage in the residual flow section stays small even after the flood including a drawdown flushing. Therefore, it may take longer until strays of unaffected river sections find their way into the impacted stretches with decreased fish densities.

Recovery of a fish population from a sediment pressure depends on the magnitude and period of the perturbation, and composition of the sediment deposited. Fish populations are, however, capable of recovering from even the most devastating of catastrophic sediment input events (Kemp et al., 2011).

The evaluation of the suspended solid concentration (SSC) would have exceeded the extent of this master thesis. But it would be interesting to merge the turbidity data with the fish stock assessment as well as the salmonid movement data. In particular, there is need to consider the temporal resolution, as the SSC in combination with the duration of such an operation is decisive, how strong the adverse impact on the aquatic biota is (Newcombe and Macdonald, 1991). Consequently, answers for the massive loss of juvenile fish might be found, as the negative effects of fine sediments on fish are life-history dependent (Kemp et al., 2011).

In addition to the PIT-tag study, a hydro-morphological assessment would be of interest for future movement investigations. As mentioned frequently in literature, the morphological complexity of a river section is attributed a major factor regarding the movement behavior. The combination with macrozoobenthic investigations would be interesting as well, since according to literature food availability also plays an important role in the movement behavior of fish. Salmonid movement increases when growth opportunities are low (e.g. Olsson et al., 2006). During the qualitative spot checks in summer, massive presence of macrozoobenthos was noticed, especially in the residual flow section. The caught fish at that time seemed to be in good health and condition. The evaluation of the growth rate resulted in enormous increase in length during summer 2018 for rainbow trout (up to18 mm/month) (Pinter et al., 2021).

The study outcome is limited by low recaptures after the catastrophic flushing of reservoir Rottau in October 2018. For future investigations, the electrofishing effort has to be maximized in the residual flow section immediately after the impact, all available resources must be used to find as many tagged individuals as possible. Beside the PIT-tag study, additional application of telemetry techniques could help to track the missing fish and lead to a better understanding of individual movement during or after a drawdown flushing event, also in terms of species-specific recolonization movements.

Due to the high organizational effort, it was unfortunately not possible to exhibit fish samplings directly after the drawdown flushing in the beginning of November. For one thing, to collect quantitative fish data in the River Möll, at least 15 people were necessary for several days. Furthermore, short-term availability of human resources, accommodation, cars, fishing equipment, etc. was limited, also because the predictability of a drawdown flushing event is dependent of several factors. Despite that, gathering of fish movement data immediately after the flood would have been of big interest, in particular also in the control section. Perhaps, displacement due to a flood event itself was more severe than determined one month later.

Nevertheless, the chosen study design worked great for the detection of salmonid movement, even though there is still room for methodological improvement. With exception of the life-history dependent statements, answers were found for all research questions. The evaluation of fish movement data enables the detection and the display of a drawdown flushing event. Moreover, due to the species-specific analysis of salmonid movement behavior, the interpretation of the fish stock assessment has been put into a new light – at least partly.

A thorough understanding of movement in a stream network is crucial for the management of salmonids and the watersheds in which they exist (Gresswell and Hendricks, 2007).

Literature:

Altman, D.G., Chatfield, C., Zidek, J., Lindsey, J., 1991. Practical Statistics for Medical Research. Taylor & Francis Ltd, Boca Raton, Fla.

Aparicio, E., Rocaspana, R., de Sostoa, A., Palau-Ibars, A., Alcaraz, C., 2018. Movements and dispersal of brown trout (Salmo trutta Linnaeus, 1758) in Mediterranean streams: influence of habitat and biotic factors. PeerJ 6, e5730–e5730. https://doi.org/10.7717/peerj.5730

Armstrong, J., Herbert, N., 2005. Homing movements of displaced stream-dwelling brown trout. Journal of Fish Biology 50, 445–449. https://doi.org/10.1111/j.1095-8649.1997.tb01372.x

Baoligao, B., Xu, F., Chen, X., Wang, X., Chen, W., 2016. Acute impacts of reservoir sediment flushing on fishes in the Yellow River. Journal of Hydro-environment Research 13, 26–35. https://doi.org/10.1016/j.jher.2015.11.003

Bell, E., Duffy, W., Roelofs, T., 2001. Fidelity and Survival of Juvenile Coho Salmon in Response to a Flood. Transactions of The American Fisheries Society - TRANS AMER FISH SOC 130, 450–458. https://doi.org/10.1577/1548-8659(2001)130<0450:FASOJC>2.0.CO;2

Benejam, L., Saura-Mas, S., Bardina, M., Solà, C., Munné, A., García-Berthou, E., 2016. Ecological impacts of small hydropower plants on headwater stream fish: from individual to community effects. Ecology of Freshwater Fish 25, 295–306. https://doi.org/10.1111/eff.12210

Bergstedt, L.C., Bergersen, E.P., 1997. Health and movements of fish in response to sediment sluicing in the Wind River, Wyoming. Can. J. Fish. Aquat. Sci. 54, 312–319. https://doi.org/10.1139/f96-269

Bilotta, G.S., Brazier, R.E., 2008. Understanding the influence of suspended solids on water quality and aquatic biota. Water Research 42, 2849–2861. https://doi.org/10.1016/j.watres.2008.03.018

Boavida, I., Harby, A., Clarke, K., Heggenes, J., 2016. Move or stay: habitat use and movements by Atlantic salmon parr (Salmo salar) during induced rapid flow variations. Hydrobiologia 785, 1–15. https://doi.org/10.1007/s10750-016-2931-3

Booth, M.T., Hairston, N.G., Flecker, A.S., 2013. How mobile are fish populations? Diel movement, population turnover, and site fidelity in suckers. Can. J. Fish. Aquat. Sci. 70, 666–677. https://doi.org/10.1139/cjfas-2012-0334

Brönmark, C., Hulthén, K., Nilsson, P.A., Skov, C., Hansson, L.-A., Brodersen, J., Chapman, B.B., 2013. There and back again: migration in freshwater fishes. Can. J. Zool. 92, 467–479. https://doi.org/10.1139/cjz-2012-0277

Brunnbauer, A., 1995. Die Möll, Gestern-Heute-Morgen – Anforderungen an einen Fluss und sein Tal. Diplomarbeit an der Universität für Bodenkultur. Wien

Castro-Santos, T., Haro, A., Walk, S., 1996. A passive integrated transponder (PIT) tag system for monitoring fishways. Fisheries Research 28, 253–261. https://doi.org/10.1016/0165-7836(96)00514-0

Chun, S., Cocherell, S., Cocherell, D., Miranda, J., Jones, G., Graham, J., Klimley, A., Thompson, L., Cech, J., 2011. Displacement, velocity preference, and substrate use of three native California stream fishes in simulated pulsed flows. Environmental Biology of Fishes 90, 43–52. https://doi.org/10.1007/s10641-010-9716-8

Crook, D.A., 2004. Is the home range concept compatible with the movements of two species of lowland river fish? Journal of Animal Ecology 73, 353–366. https://doi.org/10.1111/j.0021-8790.2004.00802.x

Crosa, G., Castelli, E., Gentili, G., Espa, P., 2009. Effects of suspended sediments from reservoir flushing on fish and macroinvertebrates in an alpine stream. Aquatic Sciences 72, 85. https://doi.org/10.1007/s00027-009-0117-z

Egger, G., Muhar, S., Schmutz, S., Petutschnig, J., Angermann, K., Trimml, S., Preis, S., Ömer, B., Strigl, A., 2003. Leitbilder und Massnahmen für Flusslandschaften : entwickelt am Beispiel der Möll. Österr. Wasser Abfallwirtsch 55, 133–140.

Espa, P., Castelli, E., Crosa, G., Gentili, G., 2013. Environmental Effects of Storage Preservation Practices: Controlled Flushing of Fine Sediment from a Small Hydropower Reservoir. Environmental Management 52, 261–276. https://doi.org/10.1007/s00267-013-0090-0

Everest, F.H., Beschta, R.L., Scrivener, J.C., Koski, K.V., Sedell, J.R., Cederholm, C.J., 1987. Fine sediment and salmonid production: a paradox. College of Forest Resources. Univ. of Washington (USA).

Gerking, S.D., 1959. THE RESTRICTED MOVEMENT OF FISH POPULATIONS. Biological Reviews 34, 221–242. https://doi.org/10.1111/j.1469-185X.1959.tb01289.x

Gowan, C., Fausch, K.D., 2002. Why do Foraging Stream Salmonids Move During Summer? Environmental Biology of Fishes 64, 139–153. https://doi.org/10.1023/A:1016010723609

Gowan, C., Young, M.K., Fausch, K.D., Riley, S.C., 1994. Restricted Movement in Resident Stream Salmonids: A Paradigm Lost? Can. J. Fish. Aquat. Sci. 51, 2626–2637. https://doi.org/10.1139/f94-262

Gresswell, R.E., Hendricks, S.R., 2007. Population-Scale Movement of Coastal Cutthroat Trout in a Naturally Isolated Stream Network. Transactions of the American Fisheries Society 136, 238–253. https://doi.org/10.1577/T05-196.1

Grimardias, D., Guillard, J., Cattanéo, F., 2017. Drawdown flushing of a hydroelectric reservoir on the Rhône River: Impacts on the fish community and implications for the sediment management. Journal of Environmental Management 197, 239–249. https://doi.org/10.1016/j.jenvman.2017.03.096

Halvorsen, M., Stabell, O.B., 1990. Homing behaviour of displaced stream-dwelling brown trout. Animal Behaviour 39, 1089–1097. https://doi.org/10.1016/S0003-3472(05)80781-X

Harcup, M.F., Williams, R., Ellis, D.M., 1984. Movements of brown trout, Salmo trutta L., in the River Gwyddon, South Wales. Journal of Fish Biology 24, 415–426. https://doi.org/10.1111/j.1095-8649.1984.tb04812.x

Haunschmid, R., Schotzko, N., Petz-Glechner, R., Honsig-Erlenburg, W., Schmutz, S., Unfer, G., Wolfram, G., Spindler, T., Bammer, V., Hundritsch, L., Prinz, H., Sasano, B. 2016. Leitfaden zur Erhebung der biologischen Qualitätselemente, Teil A1 – Fische, BMLFUW ISBN: 978-3-85174-059-2

Heggenes, J., 1988a. Effect of Experimentally Increased Intraspecific Competition on Sedentary Adult Brown Trout (Salmo trutta) Movement and Stream Habitat Choice. Can. J. Fish. Aquat. Sci. 45, 1163–1172. https://doi.org/10.1139/f88-139

Heggenes, J., 1988b. Effects of Short-Term Flow Fluctuations on Displacement of, and Habitat Use by, Brown Trout in a Small Stream. Transactions of the American Fisheries Society 117, 336–344. https://doi.org/10.1577/1548-8659(1988)117<0336:EOSFFO>2.3.CO;2

Heggenes, J., Northcote, T.G., Peter, A., 1991. Spatial Stability of Cutthroat Trout (Oncorhynchus clarki) in a Small, Coastal Stream. Can. J. Fish. Aquat. Sci. 48, 757–762. https://doi.org/10.1139/f91-090

Heggenes, J., Omholt, P.K., Kristiansen, J.R., Sageie, J., Økland, F., Dokk, J.G., Beere, M.C., 2007. Movements by wild brown trout in a boreal river: response to habitat and flow contrasts. Fisheries Management and Ecology 14, 333–342. https://doi.org/10.1111/j.1365-2400.2007.00559.x

Honsig-Erlenburg, W., Lorenz, E., 2006. Untersuchung der Möll im Bereich Pußtratten. Auftraggeber: Amt der Kärntner Landesregierung, Abt. 15 – Umwelt, Unterabteilung Ökologie und Umweltdaten Flatschacher Straße 70, 9020 Klagenfurt

Höjesjö, J., Johnsson, J.I., Bohlin, T., 2015. Behavior and growth of juvenile brown trout (Salmo trutta) following upstream and downstream displacement. Journal of Freshwater Ecology 30, 455–461. https://doi.org/10.1080/02705060.2014.971448

Kemp, P., Sear, D., Collins, A., Naden, P., Jones, I., 2011. The impacts of fine sediment on riverine fish. Hydrological Processes 25, 1800–1821. https://doi.org/10.1002/hyp.7940

Kondolf, G.M., 1995. Managing bedload sediment in regulated rivers: Examples from California, U.S.A. Washington DC American Geophysical Union Geophysical Monograph Series 89, 165–176. https://doi.org/10.1029/GM089p0165

Kondolf, G.M., Gao, Y., Annandale, G.W., Morris, G.L., Jiang, E., Zhang, J., Cao, Y., Carling, P., Fu, K., Guo, Q., Hotchkiss, R., Peteuil, C., Sumi, T., Wang, H.-W., Wang, Z., Wei, Z., Wu, B., Wu, C., Yang, C.T., 2014. Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. Earth’s Future 2, 256–280. https://doi.org/10.1002/2013EF000184

Lucas, M.C., Baras, E., 2001. Migration Freshwater Fishes. John Wiley & Sons, Oxford ; Malden, MA.

McEwan, A., Joy, M., 2013. Responses of three PIT-tagged native fish species to floods in a small, upland stream in New Zealand. New Zealand Journal of Marine and Freshwater Research 47, 225–234. https://doi.org/10.1080/00288330.2013.773918

MedCalc Software Ltd. Odds ratio calculator. https://www.medcalc.org/calc/odds_ratio.php (Version 20.027; accessed March 21, 2022)

Nathan, R., Getz, W.M., Revilla, E., Holyoak, M., Kadmon, R., Saltz, D., Smouse, P.E., 2008. A movement ecology paradigm for unifying organismal movement research. Proc Natl Acad Sci USA 105, 19052. https://doi.org/10.1073/pnas.0800375105

Newcombe, C.P., Macdonald, D.D., 1991. Effects of Suspended Sediments on Aquatic Ecosystems. North American Journal of Fisheries Management 11, 72–82. https://doi.org/10.1577/1548-8675(1991)011<0072:EOSSOA>2.3.CO;2

Northcote, T.G. 1978. Migratory strategies and production in freshwater fishes. In Ecology of freshwater fish production. Edited by S.D. Gerking. Blackwell, Oxford. pp. 326–359

Olsson, I.C., Greenberg, L.A., Bergman, E., Wysujack, K., 2006. Environmentally induced migration: the importance of food. Ecology Letters 9, 645–651. https://doi.org/10.1111/j.1461-0248.2006.00909.x

Palm, D., Brännäs, E., Nilsson, K., 2009. Predicting site-specific overwintering of juvenile brown trout (Salmo trutta) using a habitat suitability index. Can. J. Fish. Aquat. Sci. 66, 540–546. https://doi.org/10.1139/F09-016

Pearsons, T., Li, H., Lamberti, G., 1992. Influence of Habitat Complexity on Resistance to Flooding and Resilience of Stream Fish Assemblages. Transactions of The American Fisheries Society - TRANS AMER FISH SOC 121, 427–436. https://doi.org/10.1577/1548-8659(1992)121<0427:IOHCOR>2.3.CO;2

Peter, A., Erb, M., 1996. Leitfaden für fischbiologische Erhebungen in Fliessgewässern unter Einsatz der Elektrofischerei 19.

Peters, R.H., 1983. The Ecological Implications of Body Size, Cambridge Studies in Ecology. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511608551

Petutschnig, J., Schulz, R., Kucher, T., 1998. Gewässerbetreuungskonzept Möll, Arbeitspaket 2: Geschiebehaushalt. Interner Projektbericht, Institut für Ökologie und Umweltplanung. Klagenfurt

Petz-Glechner, R., Petz, W., Kainz, E., Lapuch, O., 2005. Die Auswirkung von Stauraumspülungen auf Fische – Natur in Tirol - Naturkundliche Beiträge der Abteilung Umweltschutz – 12: 74 - 93.

Pinter, K., Grohmann, M., Unfer, G., 2021. Fischökologische Studie Rottau 2018/19. Vienna.

Prentice, E. F., Flagg, T. A. & McCutcheon, C. S. (1990a) Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium, 7, 317–322.

Radinger, J., Wolter, C., 2014. Patterns and predictors of fish dispersal in rivers. Fish and Fisheries 15, 456–473. https://doi.org/10.1111/faf.12028

Railsback, S.F., Lamberson, R.H., Harvey, B.C., Duffy, W.E., 1999. Movement rules for individual-based models of stream fish. Ecological Modelling 123, 73–89. https://doi.org/10.1016/S0304-3800(99)00124-6

Rasmussen, J.E., Belk, M.C., 2017. Individual Movement of Stream Fishes: Linking Ecological Drivers with Evolutionary Processes. Reviews in Fisheries Science & Aquaculture 25, 70–83. https://doi.org/10.1080/23308249.2016.1232697

Ribi, J.-M., Boillat, J.-L., Peter, A., Schleiss, A.J., 2014. Attractiveness of a lateral shelter in a channel as a refuge for juvenile brown trout during hydropeaking. Aquatic Sciences 76, 527–541. https://doi.org/10.1007/s00027-014-0351-x

Rocaspana, R., Aparicio, E., Palau-Ibars, A., Guillem, R., Alcaraz, C., 2019. Hydropeaking effects on movement patterns of brown trout (Salmo trutta L.). River Research and Applications 35, 646–655. https://doi.org/10.1002/rra.3432

Rodríguez, M.A., 2010. A Modeling Framework for Assessing Long-Distance Dispersal and Loss of Connectivity in Stream Fish 19.

Rodríguez, M.A., 2002. RESTRICTED MOVEMENT IN STREAM FISH: THE PARADIGM IS INCOMPLETE, NOT LOST. Ecology 83, 1–13. https://doi.org/10.1890/0012-9658(2002)083[0001:RMISFT]2.0.CO;2

Sachs, L. (1992). Angewandte Statistik: Anwendung statistischer Methoden (pp. 311–319). Berlin: Springer-Verlag

Schlosser, I., 1995. Spatial variation in demographic processes of lotic fishes : conceptual models, empirical evidence, and implications for conservation. Am Fish Soc Symp 17, 392–401.

Schmutz, S., 2003. Einfluss erhöhter Schwebstoffkonzentration und Trübe auf Fische – Literaturstudie. Auftraggeber: Niederösterreichischer Landesfischereiverband.

Schrank, A.J., Rahel, F.J., 2006. Factors influencing summer movement patterns of Bonneville cutthroat trout (Oncorhynchus clarkii utah). Can. J. Fish. Aquat. Sci. 63, 660–669. https://doi.org/10.1139/f05-250

Schrank, A.J., Rahel, F.J., 2004. Movement patterns in inland cutthroat trout (Oncorhynchus clarki utah): management and conservation implications. Can. J. Fish. Aquat. Sci. 61, 1528–1537. https://doi.org/10.1139/f04-097

Sheskin, D.J., 2004. Handbook of Parametric and Nonparametric Statistical Procedures, Fifth Edition, 5th edition. ed. Chapman and Hall/CRC, Boca Raton.

Solomon, D.J., Templeton, R.G., 1976. Movements of brown trout Salmo trutta L. in a chalk stream. Journal of Fish Biology 9, 411–423. https://doi.org/10.1111/j.1095-8649.1976.tb04690.x

Stott, B., 1967. The Movements and Population Densities of Roach (Rutilus rutilus (L.)) and Gudgeon (Gobio gobio (L.)) in the River Mole. Journal of Animal Ecology 36, 407–423. https://doi.org/10.2307/2922

Thompson, L.C., Cocherell, S.A., Chun, S.N., Cech, J.J., Klimley, A.P., 2011. Longitudinal movement of fish in response to a single-day flow pulse. Environmental Biology of Fishes 90, 253–261. https://doi.org/10.1007/s10641-010-9738-2

Underwood, A.J., 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. Journal of Experimental Marine Biology and Ecology 161, 145–178. https://doi.org/10.1016/0022-0981(92)90094-Q

Ward, D., Schultz, A., Matson, P., 2003. Differences in Swimming Ability and Behavior in Response to High Water Velocities among Native and Nonnative Fishes. Environmental Biology of Fishes 68, 87–92. https://doi.org/10.1023/A:1026031128486

Wimmer, R., Moog, O., 1994. Flussordnungszahlen österreichischer Fliessgewässer. Umweltbundesamt.

Young, M.K., 2011. Generation-scale movement patterns of cutthroat trout (Oncorhynchus clarkii pleuriticus) in a stream network. Can. J. Fish. Aquat. Sci. 68, 941–951. https://doi.org/10.1139/f2011-023

Young, M.K., 1994. Mobility of brown trout in south-central Wyoming streams. Can. J. Zool. 72, 2078–2083. https://doi.org/10.1139/z94-278

Young, P.S., Cech, J.J., Thompson, L.C., 2011. Hydropower-related pulsed-flow impacts on stream fishes: a brief review, conceptual model, knowledge gaps, and research needs. Reviews in Fish Biology and Fisheries 21, 713–731. https://doi.org/10.1007/s11160-011-9211-0

Zydlewski, G., Haro, A., Whalen, K.G., McCormick, S.D., 2001. Performance of stationary and portable passive transponder detection systems for monitoring of fish movements. Journal of Fish Biology 58, 1471–1475. https://doi.org/10.1111/j.1095-8649.2001.tb02302.x

Zydlewski, G.B., Horton, G.E., Dubreuil, T.L., Letcher, B.H., Casey, S., Zydlewski, J.D., 2006. Remote monitoring of fish in small streams: A unified approach using PIT tags. https://doi.org/10.1577/1548-8446(2006)31[492:RMOFIS]2.0.CO;2

List of figures:

List of tables: