FEASIBILITY STUDY ON ACOUSTIC 2D-TELEMTRY IN THE DANUBE DOWNSTREAM OF THE HYDROPOWER PLANT FREUDENAU, VIENNA

Master Thesis

by

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Abstract

Anthropogenic alterations of rivers have caused a loss of biodiversity and a decrease in fish populations, as some fish rely on open migration routes to fulfil their life cycle. Hydropower plants cause a disruption of the river continuum and block this route, as it has happened at the hydropower facility Freudenau in Vienna. To connect water bodies once again, a fish pass has been built next to the hydropower plant. The functionality of this mitigation measure needs to be monitored to guarantee the functionality of the fish pass. Passive acoustic telemetry enables the observation of fish within a study site with a high spatiotemporal quality and allows to draw conclusions on future decision making. This feasibility study investigated the possibilities of telemetry system implementation and the influence of intrinsic and environmental factors on the system's performance.

To do so, three different hydrophone assemblages were deployed in the study site. Data was created without tagging fish, but by attaching three transmitters to a floating buoy, being 1 m apart from each other in 1, 2 and 3 m depth. This buoy was allowed to float through the area to observe the traceability of the tags in different parts of the research area. The data logged by the deployed hydrophones was retrieved and spatial detection characteristics were analyzed, as well as the influence of in-situ characteristics on small scale basis.

Detection and positioning characteristics varied on the temporal and spatial scales. Detection results and positioning success were exceptionally low in front of the turbines of the power plant. Positioning within the first 280 m downstream of the power plant failed completely. Detection rates of single receivers were found to increase with increasing distance to the power plant (possibly due to air bubble intrusion), as well as with increasing deployment depth of the hydrophones and in the center of the channel. Determining for positioning success was mostly the configuration of user-defined variables (deployment depth of hydrophone, distance between hydrophones) and the discharge, influencing the positioning error. The mean positioning error of all tags was 2.8 ± 2.6 m. Highest positioning error was found in 3 m depth. Lowest positioning error was found in 2 m depth, possibly due to sound reflections of the river bottom and the water surface. Positioning was found to be possible within great extents of the study site, however, limitations of telemetry systems, as well as variations in the system's performance need to be investigated in detail to improve knowledge on applicability of telemetry systems within this study site. In general, passive acoustic telemetry implementation is possible within the study site, but with spatial limitations in front of the power plant and optimized array configuration.

Abbreviation

Term	Explanation
CPDI	‘Close Proximity Detection interference’, caused by hard reflective surfaces that can change properties of acoustic waves
FTD	Floating tag device
HPP	Hydropower plant
Listening trio	Three receivers that were able to detect a tag’s signal at the same time to locate it
Positioning error (PE)	Distance between calculated tag position and real tag position
Receiver	Receives acoustic signals of the transmitter/tag
Synchronization	A receiver detects another receiver’s beacon. These detections are needed to post-treat and produce high quality data
Tag	Transmitter, implanted into fish, sending acoustic signals received by the receivers
Triangulation	At least three receivers must detect one signal at the same time to be able to create a virtual position

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1. <u>Introduction</u>

Before anthropogenic development started, the Danube was a mainly braided river with a high biodiversity. Due to anthropogenic changes of the river morphology, its flora and fauna have changed significantly. Flood protection measures, channelization and impoundments have resulted in a loss of habitat diversity (Hein et al., 2019; Hohensinner et al., 2004). Especially for migratory fish species that rely on longitudinal connectivity of a river system to fulfil their life cycle and to reach spawning grounds for reproduction. Sturgeon species like the *Huso huso* for example used to migrate from the black sea to the middle or even upper Danube to spawn (Schmutz and Jungwirth, 1999). Nowadays, most sturgeon species as the *Huso huso, Acipenser gueldenstaedtii* and the *Acipenser stellatus* are extinct in the upper and middle Danube (Hensel & Holčík, 1997). Potamodromous fish migrate within freshwaters. This includes endangered fish species such as the Danube salmon (*Hucho hucho*), but also rheophilic cyprinids such as barbel (*Barbus barbus*) or the common nase (*Chondrostoma nasus*) (Brevé et al., 2014). Movement patterns differ among aquatic taxa and even within different stages of one species' life. Many species remain in small habitats and inhabit these for all their life, while others may migrate mid to long range distance for reproduction or in search of food (Melnychuk, 2012). Migrations for spawning purposes are called homing behaviour if returning to their own place of hatching (Winter & Fredrich, 2003). Nowadays, homing migration is inhibited by barriers. These changes lead to a loss of biodiversity (Meulenbroek et al., 2018; Sakaris, 2013). Dams and hydropower plants (hereafter HPP) used for energy production disrupt the river continuum and prevent migratory fish from passing to their spawning grounds. Furthermore, impoundments change water level dynamics and change river system ecology (Waidbacher et al., 2018). Fish migrating downstream swim through the turbines of HPP and experience a high mortality rate. Commonly used Francis, Pelton and Kaplan turbines (present in Freudenau), cause high pressure changes and have a high rotation speed, which often results in injuries and death to passing fishes (Ferguson et al., 2008; Hogan et al., 2014; Mueller et al., 2017). These aspects influence the productivity of the Danube, and the fragmentation of habitats affects fish populations in a negative way (Schmutz & Jungwirth, 1999).

To address habitat degradation and to improve quality of water bodies on a long-term basis, the European Union introduced a legislation, the "Water Framework Directive" (WFD), that obliges every member state of the European Union to achieve a good ecological status of their surface and groundwater. This legislation controls the status of water bodies based on six-year cycles, in which locally defined objectives need to be achieved. The classification is based on fish communities, different water quality aspects, as well as supported by water quantity, river morphology and connectivity aspects (Chave, 2001; Voulvoulis et al., 2017; Waringer et al., 2005). This is defined in Annex V of the Water Framework Directive, expecting for the good status a slightly differed biological community that would occur without anthropogenic alterations (Chave, 2001). Fish communities are good indicators of habitat structure as well as of the ecological integrity of river systems due to their complex habitat requirements at different stages of their life cycles (Schmutz et al. 2014; Schiemer 2000; Schmutz and Jungwirth 1999).

The hydropower plant Freudenau (HPP) in Vienna represents such an alteration. It was put into operation in 1998 and is located just downstream of Vienna. To compensate for environmental alterations caused by the HPP Freudenau and to ensure longitudinal connectivity between these two water bodies, a fish pass was built next to the HPP Freudenau, as an effort to reconnect both Danube parts (Waidbacher et al., 2018). A fish pass is a man-made structure, enabling migration for key species of that region (Silva et al., 2018). The nature-like fish pass present at HPP Freudenau has a free-flowing section of approximately 900 m. The average slope of the section is 0.7 % and the average flow velocity is around 0.6 m/s with a mean discharge of 1.6 m^3/s. The discharge of the fish pass is directly dependent on the discharge of the main channel. (Meulenbroek et al., 2018)

To act as an alternate migration possibility a fish pass needs to meet two main criteria: Firstly, it needs to be passable for fish. Consequently, the characteristics of a fish pass must be suitable for migration to all species according to Austrian guideline key species (Stefan Schmutz & Mielach, 2013). This includes minimum depth, discharge and other abiotic factors. (Pander et al., 2013) Secondly, the entrance of the fish pass needs to be discoverable and possible to pass by migrating species. No barriers can be present at the entrance and the inlet structure must be suitable for the migrating fish species. Furthermore, the fish pass should reach to the bottom of the main river channel. However, another important factor is the discharge of the attraction flow, which guides the fish to the entrance of the fish pass (Pander et al., 2013). Migratory fish species are drawn to the discharge of the attraction flow. This discharge must be sufficient enough so that the fish can find the entrance of the fish pass and navigate the obstacle successfully.

There are various theories on how fishes can fulfil their homing behaviour. (Bett & Hinch, 2016) The study from Ueda (2019) revealed that olfaction and vision play important roles in finding their way to the spawning grounds. The olfactory imprinting hypothesis claims the most important factor for navigation during homing behaviour are imprinted olfactory cues, which are a specific chemical mixture of odorants present in the water body the fish was born (the Olfactory Imprinting Hypothesis (Bandoh et al., 2011)). Another theory states that conspecific cues guide the adult fish towards the spawning grounds. This implicates the release of pheromones by the young of the year ('The Pheromone Hypothesis', Buchinger et al., 2015). Rather than being contrary, the imprinted cues could also include pheromones, so a combination of both theories is possible, too. (Keefer & Caudill, 2014)

Besides the main function as a migration facility, the Freudenau fish pass also provides spawning habitat for all guilds of Danube fish. In a previous study, 72% of potentially migrating species were able to transit this fish pass successfully (Meulenbroek, 2019). The discharge at the downstream end of the pass is less than 2% of the Danube's daily mean flow, which is below internationally recommended standards (Pichler, 2011). Simply constructing a fish pass may not be a guarantee for migration success. Many fish passes have not functioned properly in the past due to lack of attraction flow, inadequate location of entrance or hydraulic conditions (Williams et al., 2012).

While Pichler (2011) still assessed the fish pass as "good", there still are uncertainties, especially concerning the ability and quantity of fish to find the entrance structure of the fish pass. There is an urgent need for effective monitoring to improve situations at fish passes as it remains unknown, how many fish are able to find the fish pass but are not capable to do it due conditions at the entrance of the fish pass (Roscoe & Hinch, 2010). A quantitative estimation of fish within the fish pass cannot be proportionally related to a total amount of fish present in the Danube because total estimations of Danube fish populations are not known due to unprecise sampling techniques (Zalewski, 1985). Furthermore, migration activity has not been investigated enough to calculate reliable numbers of migrating fish. Consequently, more insight into the migratory behaviour itself is necessary to fill this gap of information.

To investigate migration patterns of key species at the entrance of the fish pass, high-resolution data is needed to identify or critical situations for migrating individuals. One technique to gather high resolution data is telemetry (Goulon et al., 2018). Acoustic 2D telemetry enables the observation of habitat use and migration routes of key species and reveals movement patterns of single individuals with the precision of just a few meters (Deak et al., 2014). Furthermore, an autonomous data collection system ensures continuous observation during day and night. Therefore, autonomous acoustic receivers are deployed in the investigated area and sense and store data continuously over a longer period of time. This technology is called passive acoustic telemetry and is used to study movement patterns of different aquatic species. (Titzler et al., 2010) Acoustic hydrophones (hereafter: receiver) operate independently and can be deployed for several weeks without maintenance. As a result, the movement of acoustic transmitters (hereafter: tags) can be continuously observed. It is an appropriate method for assessing information about fish behaviour with high resolution in time and space (Silva et al., 2018). Derived data from passive telemetry studies can help to understand dynamics of fish stocks and migratory behaviour, such as homing, group movement patterns, and habitat preferences (Bain, 2005; Heupel et al., 1997; Wingate & Secor, 2007). Using acoustic tags and receivers can also help identify preferred migration routes of key species as in the Freudenau case study (Kraus et al., 2018).

In general, telemetry systems are influenced by user-configuration and environmental conditions. This is why the implementation of these systems in a certain area is a complex process. To achieve satisfying results, a site-specific configuration of the telemetry system for each study site is inevitable. In river systems, abiotic conditions change frequently. Therefore, it is necessary to consider the location of the receivers and the influence of abiotic conditions such as topography, temperature, salinity, turbidity and discharge of the river as sound propagation across water can be diminished by natural (e.g., air bubbles, structure, vegetation) and man-made (e.g., boat engine, HPP) environmental characteristics. (Bergé et al., 2012; Lee et al., 2011)

The Danube's discharge regime is very dynamic and changes frequently, which can complicate the implementation of telemetry systems in the river. Floods of high magnitude occur in the Danube seasonally and may damage receivers (Bergé et al., 2012). Looking closely into in-situ applicability and functionality of the telemetry system enables a deeper understanding of how this system works in a particular environment (S. T. Kessel et al., 2014). To ensure successful autonomous data collection in future studies, this study aimed to increase knowledge of passive acoustic telemetry system's performance at this particular area by using an iterative process of optimization to find system configurations suitable for the study site.

Vision

This thesis represents a feasibility study on how to implement functioning receiver assemblages which are able monitor the research area and continuously observe the behaviour of migrating fish. To be able to provide methodological guidance, the extent of influence of user-defined and environmental characteristics needs to be identified and understood. This study will provide data to create a fundamental practical knowledge to be able to implement follow-up studies successfully with the highest data quality possible. In conclusion, this thesis will provide data to optimize the implementation of telemetry systems in the Danube and therefore enable the observation of behavioural patterns of fish at desired locations (e.g. fish pass facilities). With the retrieved results of future passive 2D telemetry studies efficiency of fish passes can be optimized.

1.2. Research Question

To specify the aim of the research the following research questions were defined:

Main research question

Is the application of passive 2D telemetry in the Danube downstream of the HPP Freudenau feasible and which user-defined and environmental conditions influence the quality of data acquisition?

1.3. Sub questions

1. Which array set-up achieves the best data quality for monitoring migratory activity of key species in the future?

2. To what degree does water depth, discharge and turbidity affect the functionality of a receiver array?

3. How precisely does a receiver array estimate the position of tags?

1.4. Hypothesis

Hypothesis 1: The detection rate depends on the array configuration (depth of- and distance between receivers).

Hypothesis 2: The operationality of the telemetry system can be influenced by small scale fluctuations of discharge conditions.

Hypothesis 3: Calculated tag positions represent true positions or have a positioning error of less than 2 m.

2. Materials and methods

2.1. Study site

The Danube catchment has a total size of 801,463 km^2. The 2,857 km long river travels through 18 countries before discharging into the Black Sea. The study area is situated close to Vienna (Austria) at the south-eastern border of the city, downstream of the HPP Freudenau (48°10’37.1” N 16°28’55.0” E) and expands around 1 km further downstream (see Fig. 2). The average discharge at this point is 1,900 m^3/s and the HQ_1 is calculated at 5,290m^3/s. Depth in this heterogenous area is mostly two to five meters, however, point depth can reach up to eight meters. The water temperature within this stretch varies between 2.4 °C and 21.9°C. The hydrological regime of the Danube River in Vienna in spring and early summer represents higher discharge levels compared to the rest of the year, due to snowmelt caused by rising temperatures. The winter period is characterized with lower discharge. (Stagl & Hattermann, 2015) (Fig. 1) The river stretch at this point is 250 to 400 meters wide.

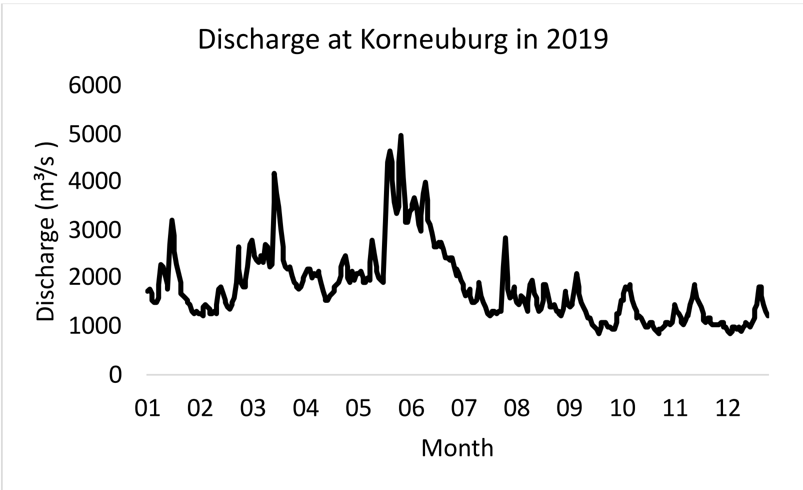

*Figure 1: Daily mean discharge at gauging station Korneuburg (ID: 207241), north of the HPP Freudenau (*Korneuburg Durchfluss 2019*, 2020)*

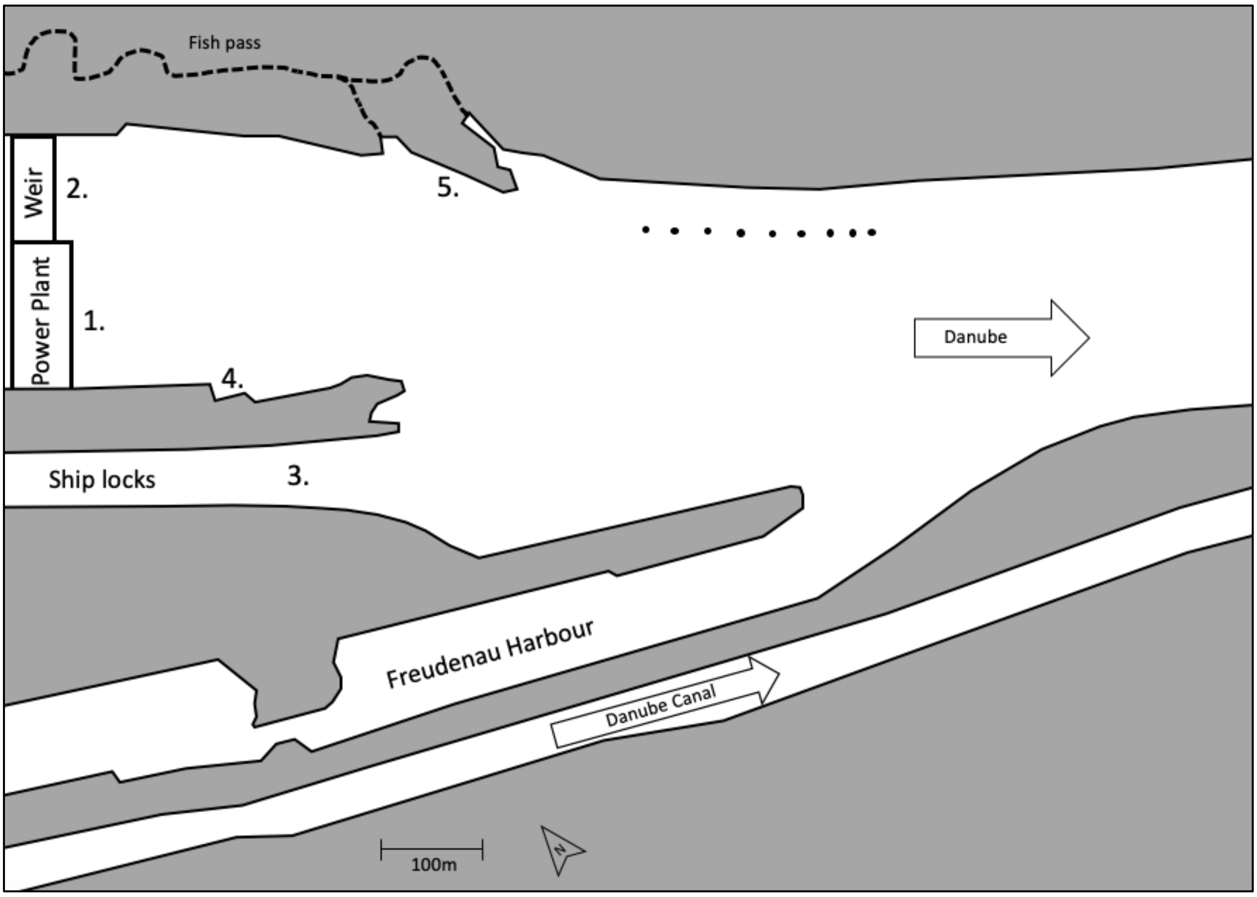

Figure 2: Study site in detail with features of interest

The HPP at the upstream end of this study site is the first obstacle after the dam of Bratislava and around 70 km of free-flowing Danube. The HPP at the upper end has six Kaplan bulb turbines (Fig 2, 1.). The number of actively working turbines is dependent on the water quantity available in the Danube. Left of the turbines, weirs were built (2.). The weirs open automatically, if the discharge of the Danube exceeds 2,800 m^3/s or in case of turbine failure. This function protects the city against unexpected flooding. On the orographically right side of the HPP, two locks (3.) carry ships up or downstream. The water outlet of the locks (4.) is located on the right side with 130 m distance to the turbines` outlet. The entrance to the harbour of Freudenau is located 750 m downstream on the right site. On the left site below the HPP, a fish pass was built on the Danube Island (5.). It has two entrances 320 m and 470 meters from the HPP. The water expelled by the turbines creates a strong current, which is directed to the side of the fish pass entrances. The substrate in this area consists mainly of large cobbles and medium to coarse gravel. In some areas the gravel may be sealed with sand (Sommerhäuser et al., 2003)

2.2. Acoustic Telemetry

In acoustic telemetry, desired information is transmitted by an acoustic signal emitted by a tag. This signal can be received while actively searching for signals, as well as by passively deployed receivers. Active tracking is executed by e.g. boat mounted receivers, actively searching and following the tagged fish. This method provides broad spatial coverage, but limited resolution on spatial and temporal scale. Passive telemetry methods increase temporal and spatial resolution but is generally limited to a smaller area. This method provides high resolution data with a precision of just a few meters and allows a consistent observation of signals. Spatial coverage is only limited to the number of receivers and temporal limitations are given by the batteries' lifespan. This way, areas can be monitored for months without interruption and the activity of tagged individuals will be exposed continuously within the investigated area. An emitted acoustic signal, which is detected by only one receiver, does not disclose the position of the tag and the direction of the acoustic signal remains unknown. However, the strength of the received signal gives an estimation about the distance to the tag. When exact positioning of the tags is desired, triangulation plays an important role. To reveal the position of a transmitter, the signals needs to be heard and identified by at least three receivers (hereafter: array) at the same time (Fig. 3) (Skerritt et al., 2015). For this process, an array of receivers must be present within a transmitter range and synchronized in UTC time.

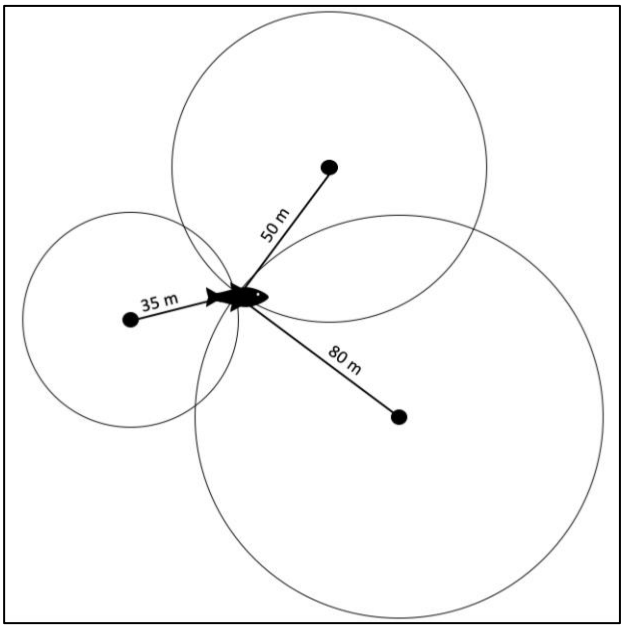

Figure 3: Visualization of positioning process (distances are mentioned for illustration)

The receivers must be placed in a steady position and need to be able to detect each other in the area being monitored. Steady positions of the receivers are fundamental, because these coordinates represent the base for further analysis and must not be changing during the entire deployment period. If an array is functioning and receivers detect each other on regular basis, tag detections and their distances to receivers can be calculated by the software 'UMap' on spatial and temporal scale in a post-treatment process to generate single positions for each transmitter at a given time. This system uses CDMA (code division multiple access) coding to enhance data quality in challenging environments with multipath echoes, high noise levels and shipping traffic and enables high sample sizes without interference between single tags. This technology gives the opportunity to monitor hundreds of animals simultaneously at a high sampling rate. (Niezgoda et al., 2002).

2.2.1. Receiver

The acoustic receivers of this study were of the type "WHS 3250" (by Lotek®). The receiver has a length of 580 mm, a diameter of 60 mm and a weight of 1,7 kg. The maximum recording time of a receiver is indicated with around 165 days, when using 4 (L) lithium primary D-cells. The receivers are designed for sub-surface deployment and supports autonomous data collection, mobile tracking, and high-resolution data results. During deployment phase, detections of acoustic signals of other receivers and tags (receiver/tag-ID, time, signal strength) are stored onto a 2 GB removable SD-card. Acoustic signals can be detected omnidirectionally on the top of the receiver (receiver "tip"). Only in front of the receiver tip, can no signals be detected, which leads to a "donut shaped" detection field. The receivers are capable of distinguishing individual transmitters, recording log long-term data and can even obtain environmental data. In order to calculate 2D positionings, the data detected by the receivers can be manipulated with the Software UMap (by *Lotek*). Additionally, these receivers are outfitted with a built-in Bluetooth device, which allows live tracking of tag and receiver signals but does not allow download of data. However, Bluetooth is not needed when it comes to deployed long-term arrays and will substantially reduce the durability of batteries.

2.2.2. Tags

The tags used in this study were of the type "MM-M-11-45" (by Lotek®). The dimensions of the tags are 12 x 75 mm and weigh 14,5g above the water. Every transmitter sends an acoustic signal with a unique identification code at a burst rate of 3 or 5 seconds (1200 or 720 per hour). These tags are designed for observations of microhabitats and migration activities, as well as specimen monitoring at hydro facilities. Furthermore, CDMA coding makes detection of hundreds of deployed tags possible, without interfering with each other (up to 80.000) (Loeffler, 2011).Tags operate on a frequency of 76 kHz as higher frequencies often result in lower detection ranges (Moore et al., 1997). Low frequency waves between 30 - 300 kHz have been found to be most suitable in complex environments as harbours and hydro-electrical stations and are more accurate in comparison with equivalent-sized radio transmitters. (Jung et al., 2015)

2.3. Study design

The HPP Freudenau represents the upper border of the study site and an obstacle for migrating fish. The objective was to implement receiver arrays with spatial coverage that allow high resolution monitoring (2D positioning) of the whole study site. Especially monitoring the key area in front of the HPP and the fish pass is essential to obtain valuable information about local movements and habitat use of occurring fish.

In the study site, heterogenous environmental conditions are present, with high flow velocity below the turbines and heterogenous river bottom throughout the whole area. Additionally, flow fluctuations change abiotic conditions on short temporal scales. Expected local and seasonal conditions need to be considered when choosing deployment constructions and locations of receivers to prevent damage and to ensure high data quality (Hobday & Pincock, Doug, 1997). Even short-term high flow events can result in receiver movement and will lower precision of calculated positionings, as the steady position of each receiver is essential for post-treatment calculations.

Locations with consistent high flow conditions are not suitable for “weighted-buoy” deployment constructions as they tend to move in strong currents by the drag of the buoy. Alternatively, receivers can be mounted on walls. Furthermore, the probability that the acoustic signal gets picked up by a receiver can be influenced by several environmental parameters, including ambient noise (e.g. high flow conditions, boat traffic, waves) and the properties of the water (temperature and turbidity) (Bain, 2005; DeCelles & Zemeckis, 2014). That is why array formations need to be created according to expected flow conditions, to optimize the system’s performance. Thus, arrays that produce satisfying data during a low discharge regime might not be effective for high discharge conditions. As a consequence, depth, discharge and turbidity need to be taken into account to implement an array successfully and to cover an area reliably.

The most effective way to identify key migration routes and habitat use in this particular area is to cover an entire area with an array, although in this case unused habitats will be monitored as well. In the future, arrays can then be adapted to concentrate on key habitats, migration routes or to avoid abiotic limitations. Grid arrays (receivers spread uniformly across the study site) are suitable for a first approach in a new area (Kraus et al., 2018). On the one hand, this simplifies the synchronization of an array because one receiver might be able to communicate with even more than two receivers. On the other hand, a grid-array helps to cover an area effectively. (Bergé et al., 2012)

Throughout the tests, we used an iterative approach, observing and evaluating the results of each test and advancing with gathered results in upcoming tests to sort out area-specific issues. Depending on the array performance in each test, we later adapted location and configuration of receivers, aiming for a complete coverage of the area in front of the HPP to the entrances of the fish pass, possibly expanding up to one kilometer downstream. As the HPP represents the upstream barrier of the study site, we implemented the first array right below this construction, working our way downstream with multiple array set-ups. In front of the HPP high fish densities can be expected, thus monitoring this area could be of high interest in future (Agostinho et al., 2008). The tests were executed in January, April and June, to examine the effect of seasonal fluctuations of discharge levels, turbidity and temperature on the performance of the telemetry system. Tests were executed with different time frames due to organizational and security reasons. In this feasibility study, no fish were tagged, and the data was created by dummy tags.

2.4. Developing an array

Planning an array requires the consideration of the number of receivers being deployed, timing and position of deployment, receiver settings, current flow and environmental characteristics. As our study site is located in close proximity to the HPP, a harbour and ship locks, several stakeholders are present in this area, which limits possibilities of receiver deployment. Special attention needs to be drawn to possible area restrictions, as well as high priority areas and how to cover them effectively.

2.4.1 Number and distance of receivers

An array that should fulfil the task of exact positioning must consist of a minimum of three synchronized receivers (DeCelles & Zemeckis, 2014). The deployment of multiple receivers creates an overlap of detection areas that can increase positioning distance of a tag to its array (Agostinho et al., 2008). When determining the number of receivers for an array, it is important to consider the size of an area and the anticipated discharge conditions. The number of receivers must be suitable for covering the desired area under expected discharge conditions. Increased discharge will result in a higher ambient noise level, which interferes with acoustic signals of the system. The probability of detection should be equal regarding the position of the tag (or the behaviour of the fish) within an array. Optimum distance between receivers can even vary under stable discharge conditions, influenced by physical characteristics of the water such as air bubble intrusion of the turbines of the HPP. Consequently, the gaps between receivers should be decreased in areas or periods with projected high noise levels. If reduced distances between receivers still result in poor data quality (decreased positioning success or detection rates), deploying additional receivers may improve array performance. According to expected discharge, distances between receivers should be adapted to ensure consistent data quality.

2.4.2. Abiotic conditions and topography

Several environmental factors have an effect on the transmittability of sound waves under water. Subsurface environments can contain high levels of ambient noise, like in this case, sound waves from boat traffic, the HPP and the ambient noise produced by the current. Noise can be caused naturally by high flow situations due to precipitation and snow melt. Therefore, natural high flow intervals in this region can almost certainly be expected between May and June, as well as short-term fluctuations in spring and autumn. Amplitudes can be extreme and high flow events can occur within hours. Furthermore, the Danube´s discharge is dynamically controlled by the HPP according to energy demand and water availability.

Another important factor in this situation is the close proximity of the HPP. Firstly, hydropower plants produce noise by water flow through turbines. Secondly, acoustic signals can be reflected by concrete walls of the HPP, causing acoustic echoes. Acoustic waves bouncing off obstacles or the water surface can also generate echoes, which are known to have influence on detection probability of acoustic signals and lower data quality. Thirdly, Kaplan turbines (present in HPP) are known to introduce air bubbles into the water column and to severely decrease acoustic signal propagation (Kessel et al. 2014), while favoring signal absorption (Gjelland & Hedger, 2013).

Hydraulic and thermal conditions can increase potential signal absorption or reflection of sound (Trevorrow, 1998; Voegeli & Pincock, 1996). Placing single receivers in deep holes or in close proximity to walls can result in a lack of signal detection, because these receivers are constructed to detect omnidirectionally. Signals from above the hydrophone cannot be obtained. In particular, receivers in the center of an array need to be able to detect omnidirectionally, as they may theoretically be part of several smaller arrays. In order to optimize these requirements, it is favorable to place all receivers in the same depth if possible and avoid deployment next to big obstacles. (Baktoft et al., 2015)

2.4.3 Configuration of the receivers

The configuration of receivers needs to be adjusted based on location, desired data quality and abiotic conditions. Most determining factor in this case is the beacon. The beacon is a signal emitted by each receiver in a regular user-defined interval, which is detected by other receivers. In high flow environments where signal propagation can be challenging, a high beacon burst rate can increase the total number of beacons to create a larger sample size and increase the chance of signal detection. Every receiver emits an individual beacon, that enables the identification of each receiver. Detection of the receiver beacon leads to synchronization between receivers and eventually of the whole array, which is essential for further processing of the data. One receiver can also be part of two arrays, although the rest of the receivers do not detect each other's beacon. Thus, if the beacon of one receiver is detected by two other receivers, an array is established, and acoustic signals of the tags can be triangulated to determine the exact positions. The Bluetooth control should be set to "always off" in each receiver participating in an array because this feature is only required for mobile tracking and will decrease battery durability.

2.4.4. Mounting of the receiver

Deployment constructions of receivers are fundamental to secure receivers and to ensure data quality of an array. The deployment construction must be suitable for the place it will be deployed, including the consideration of movement prevention. It is very important that the deployment construction does not have an impact on the operationality of the system and does not relocate itself due to strong currents or drag of the buoys.

For every single receiver, a plastic case was designed to protect the it against collisions with stones and driftwood. The receiver tip had no protection to guarantee omnidirectional listening at any time. It was fitted with two screws inside of the tube to prevent the receiver from moving. To optimize signal detection, receivers should be fixed as steady and with least movement possible as the provided software requires exact locations for the calculation of positions. During this study we used two different deployment methods (Fig. 4). The method we chose mainly depended on flow and topographic characteristics at the exact deployment location. In the main channel, we used a self-designed weight construction for receiver deployment. We filled car tires with concrete and incorporated a metal tube in the center for tire/weight. To guarantee receivers remained in place in the study area, weights of 50 kg+ were required. To be able to recover the deployment constructions and to make it visible for shipping traffic, we attached a yellow floating rope with a yellow buoy. Depending on deployment location, synthetic ropes may be confronted with severe abrasion. A metal chain on the first meters of the construction can help to avoid this problem.

Figure 4: left receiver in plastic case ready to be deployed, middle: deployed receiver mounted to a wall, right: receiver with weight and buoy ready to be deployed

High currents in front of the turbines make it impossible to deploy receivers with weights and buoys due to potential drifting and damage of the receiver construction. Therefore, we used a suspension arrangement on the walls of the HPP for receiver deployment. Once this is fixed, the receiver can be mounted within minutes. In this case, movement of the construction during deployment time is minimized.

2.5. Deployment of the receivers

The deployment was executed with a small vessel equipped with a crane. Deployment was executed with at least three crew members aboard. One steering the boat and two lifting the construction up and putting it into the water. The receivers with the deployment construction were prepared and operational before being loaded onto the vessel. Due to shipping traffic, the possibilities of deployment were limited, and receivers were exclusively deployed where no shipping traffic occurred. It was necessary to drive a few meters upstream of the desired deployment location because of the steady current present in the Danube and especially in front of the turbines. Then, the receiver and weight are lowered into the water. Drifting downstream at this point is inevitable and the weight is lowered until it hits the bottom of the river. The rope is held tight and the vessel is driven to the location where the rope exits the water vertically. Where the rope enters the water vertically, a GPS-point is taken, and the buoy is attached at the end of the rope and released into the water. The total length of the rope had at least a length of 2 times water depth at this location of the river.

2.6. Data collection

2.6.1. Bluetooth control (BTC) and detection range

In order to control a deployed array, the functionality of individual receivers can be controlled with a live tracking receiver. Therefore, one receiver (which is not part of an array) is installed in a steady position on the boat with the receiver tip submerged. This receiver is connected to a computer via Bluetooth. This way, signals that are detected by the receiver on the boat can be viewed live on the screen. The presence and absence of receiver signals can be controlled, and malfunctioning receivers can be identified by their beacon. With this knowledge, strategic or problematic receiver locations can be identified, and arrays can be optimized in order to cover the research area effectively.

The detection range is a parameter which is influenced by technical requirements of the telemetry system, environmental characteristics and anthropogenic influences present in the area. The detection range indicates the distance at which signals of a transmitter or receiver are still detected when applying live tracking via Bluetooth control (BTC). The maximum distance was estimated by measuring the distance between a receiver and the furthest location the signal could still be detected. As the upstream section of the study site is limited by the HPP, these detection ranges were estimated driving downstream of the array. Maximum distances can exceed expectations by far, however, measured distances cannot be seen as indicator for distances between receivers for triangulation. Continuous signal reception of an array may also depend on topographic features in close proximity and might be different for each receiver pair.

Estimating maximum detection distances enables the identification of problematic or strategically valuable positions. This method represents a very limited and short-time impression, as it is just possible with live-tracking on the boat. Successful 2D positioning depends on temporal long-term results, however, BTC gives a value to compare receiver locations on a first sight. Detection ranges can vary under changing abiotic conditions and therefore, need to be interpreted with caution, due to the short-term operation with the Bluetooth device.

2.6.2. Detection rate

The detection rate gives an insight on the functionality of a single receiver or an array and its performance in relation to other receivers of the array. The performance of a single receiver can be influenced even on a small scale and may be altered by high flow situations in front of the HPP or environmental features such as depth of deployment. The detection rate is the proportion between the emitted signals and the signals detected by other receivers. During this study, we standardized the detection rate to detections per ten hours to prevent short-term environmental changes from influencing the data set. The number of detections / 10h (hereafter: DR) indicates the communication between the receivers which is essential for the synchronization of an array. The DR provides valuable information about the effectiveness of signal propagation and detection within a certain discharge scenario and array. The detection rate is an important tool that helps identify key strategic positions or limitations of an array.

2.6.3. Create positioning data

As this study does not include fish being tagged, data needed to be created alternatively. Expecting a depth of 3 - 4 m on average, three tags were attached to a rope of three meters with a buoy on top and a weight at the bottom. This set-up (hereafter: FTD) guaranteed that the tags appeared in the chosen depths of 1 m, 2 m and 3 m. By deploying tags in different depths, we can obtain information about detection variations in different depths and even on suitability of this method for fish species that inhabit different types of environments or different parts of the water column. The whole construction was taken upstream by boat, close to the HPP and released between the locks water outlet and the boat ramp on the other side (Fig. 5 'FTD deployment-zone'). There, it was left floating downstream, every time with approximately the same distance to the HPP, avoiding any interference possibly created by the presence of the vessel to execute these tests. The maximum downstream drift distance was set to the distance where the last receiver could be detected via BTC. In case of shipping traffic or the appearance of groins the tags were collected to protect them from being damaged. Locations and time of the upper and lower end of the drift were recorded. Surveys on the right side were limited due to the water outlet of the locks and resulting safety issues. In July, a GPS-device was mounted directly onto the buoy to be able to identify positioning error of the array. The location data obtained by the GPS-device is assumed to be true positions. This enables a comparison between calculated data and true positions to estimate the PE. Investigating different depths of tags can obtain valuable information regarding the effectiveness of the technology for key species of upcoming projects.

2.6.4. Listening trio

In order to triangulate a position, data from at least three receivers that detected a tag at the same time is needed. By estimating the distance of the tag to each receiver, the exact position of the tag can be calculated by a software and the triangulation principle. The 'maximum distance of the listening trio' is the average value of the distances of all three receivers to the tag position.

2.6.5. Positioning success

The positioning success is the number of tag-emitted signals within the array range in relation to calculated positions in post treatment. The positioning success represents the number of tag signals that have been detected by a functioning array at the same time, divided by possible positions within a given time. Tag-emitted signals were assumed as possible positioning if just one receiver detected a signal. This number basically represents the number of signals which were used for the triangulation in a post treatment process compared to those which were not used for positioning and were heard by less than three receivers.

2.6.6. Positioning error

The positioning error (hereafter: PE) is the spatial variation between receiver obtained location data and real position data. In this study, positions obtained by a commercial GPS-device were assumed to be true positions. The GPS-device was attached to the floating buoy together with the tags. Time and place of deployment and recapture of the buoy were recorded with another GPS to be able to identify time periods for analysis and to compare GPS-device and receiver data locations. Using a geographical system, distances between real positions and receiver positions were measured by always measuring the smallest distance between the receiver position (point data) and the GPS track (line/string data). The PE is calculated for three tags attached to the FTD (1, 2 and 3 m) to compare the PE of different depths and was only calculated for July.

2.6.7. Data analysis

After receiver retrieval/recovery, data was retrieved via USB and manipulated in the Software U-Map®. This software creates two types of data sets: it summarizes detection rates for each receiver and tag, as well as produces georeferenced maps with 2D-locations of individual tags. To produce these outputs, exact locations of receivers need to be entered and tag-IDs need to be defined. Detection rates and positioning success were analyzed and related to a number of environmental and user-defined variables. During this procedure, Pearson-correlation and regression analysis were performed. The significance criterion was α = 0.05 (Lakens, 2013)

Visualization of calculated positionings within the study site maps were produced to highlight positioning success and limitations in the study site. Data sets, especially in this heterogenous environment, represent very local outcomes. That is why relations of data quality indicators and environmental characteristics need to be treated with caution. (Bergé et al., 2012) Acoustic telemetry systems may produce variable data quality due to performance fluctuations, which may provide prejudice to study findings (Binder et al., 2016). Due to echoes or calculation mistakes, some positionings can be inaccurate. These outliers appear as mirror points (synch. with only 2 receivers) or can be identified by observing the time of each positioning and the displayed locations by experienced software users. PE was estimated in July only, while DR, positioning success, distances between receivers, max. average distances of the listening trio were calculated for every test.

Table 1: User defined variables: configuration variables and physical variables and definitions of data quality indicators

Variable	Unit of measurement	Description
Configuration		
Number of receivers	Number	Number of receivers deployed and participating in an array
Distance between receivers	m	The mean distance of the two closest receivers of each receiver participating in an array
Beacon interval	Seconds (s)	The interval a receiver emits a beacon signal for synchronization with other receivers
Physical characteristics		
Water Temperature	°C	Mean water temperature measured at least two times per week during deployment period
Discharge	m^3/s	Current discharge during deployment period measured in the closest measuring facility (Korneuburg)
Turbidity	mg/L	Mean water turbidity measured of at least two times per week during deployment period
Distance to HPP	m	Distance of each receiver was measured to the center of the impoundment in a rectangular angle
Indicators of data quality		
Detection rate (DR)	$DR = \frac{Detections}{duration\ of\ test(h) * 10\ hours}$	Number of detections of a single receiver that detects beacons of other receivers standardized to 10 hours
Detection range	m	Distance between a receiver and the longest distance the beacon was still detected once
Positioning success (PS)	$PS = \frac{possible\ positions}{relised\ positionings}$	The number of possible positionings divided by the number of realized positionings
Positioning error (PE)	m	Average distance per tag between the true position (GPS obtained) and the calculated position
Max distance of listening trio	$Max.L\ istening\ trio = \frac{\text{distance per receiver to tag}}{3}$	Max. distance of positioning between the tag and listening trio

3. Results

During this study, we witnessed 4 out of 24 hydrophones failing in one of the tests, but already detected signals were taken into consideration for 2D positioning. In addition, four receivers did not engage in the positioning process in January, due to hydraulic conditions at the deployment location. Guided by the results of previous arrays, we adapted several user-defined variables after each test for optimizing the system´s performance. At the end, we recorded a total of 20,048 tag emitted signals that were picked up by at least one receiver, of which 3,393 were realized as position. With several adjustments for each test, we managed to increase the positioning success from 2.9% in the first test to 18.5% in the last test. The test period ranged greatly, between 52.5 and 405.25 hours. Furthermore, the mean distance between the receivers was changed in every testTable 22).

Table 2: Summary of user-defined array properties and array performance

	Januar	April	July
Duration of test (h)	138	52,5	405,25
Working hydrophones (deployed)	8 (8)	6 (6)	6 (10)
Pos. Success (%)	2,9	13,2	18,5
Av. Det./ 10h	216	742,5	679,6
Av. Dist.between receivers (m)	141,5	152,6	105,3
List. Trio Max. Dist. (m)	172	319	193

3.1. January

During the first test in January 2019 (138 h) an array was deployed in the most upstream section (Fig. 5) of the study area. A total of eight receivers were deployed. Due to hydraulic conditions at the deployment location three receivers were mounted directly onto the HPP, while five receivers were deployed with weights and buoys in the river channel. The receivers had been distributed uniformly over the investigated stretch (grid-approach). The mean distance between the receivers was 141 m. The mean DR of all receivers was calculated with 167 signals, 2 receivers did not exceed a DR of 27 close to the turbines (Fig. 5, ID 9 and 10). Excluding these 2 receivers, the mean DR of remaining six receivers reached 216. Receivers in front of the turbines showed exceptionally low DR, while receivers with more distance to the HPP showed intermediate DR values (Table 3, Fig. 5). The most downstream receivers located centrally in the river channel represented the highest DR. In general, increasing distance from the turbines resulted in a higher DR.

Table 3: Detection rates of single receivers in January: Columns show the active listening receivers, rows show the detected receivers, blacked out fields represent receivers detecting themselves

January	Active listening		Det./10 hours		Max beacon = 1800				
Receiver	9	7	1	10	5	3	6	2	
AMR0025 1009		13	5	11	11	11	4	2	
AMR0033 1007	12		18	18	691	56	124	17	
AMR0027 1001	11	21		18	90	899	78	113	
AMR0026 1010	11	19	17		20	36	19	58	
AMR0031 1005	11	822	95	20		298	532	70	
AMR0029 1003	10	84	930	53	174		79	1308	
AMR0032 1006	8	142	56	19	518	80		58	
AMR0028 1002	5	15	110	49	48	1291	39		Avg. All
Average detections	**10**	**160**	**176**	**27**	**222**	**382**	**125**	**232**	**167**

In January, we used two tags (ID1: 1 m; ID2: 2 m depth) to create data (Table 4: Detection rates of tags for each receiver. We found that receiver 9 and 10 did not detect the tags and did not participate in the positioning process. Every receiver detected tag ID 1 more frequently than the tag in 2 m depth. Bluetooth control surveys indicated maximum distances from 0-2 m in front of the turbines and up to 582 m in downstream direction. The maximum distance of a listening trio was 172 m on average, so positioning success significantly increased downstream of the array. Of 1,644 possible positionings, 48 were realized (2.9 %). Positionings were calculated on the left shore of the Danube and 320 m downstream of the turbines. In front of the turbines, no positioning was possible at any time. The longest continuously tracked tag was 133 m, located centrally in the river channel.

Table 4: Detection rates of tags for each receiver in January, columns represent receiver IDs, rows represent tag IDs, attached to the buoy.

Tags/receiver	9	7	1	10	5	3	6	2
1	0	434	794	1	411	469	199	255
2	0	348	622	0	345	387	144	237
mean	**0**	**391**	**708**	**1**	**378**	**428**	**172**	**246**

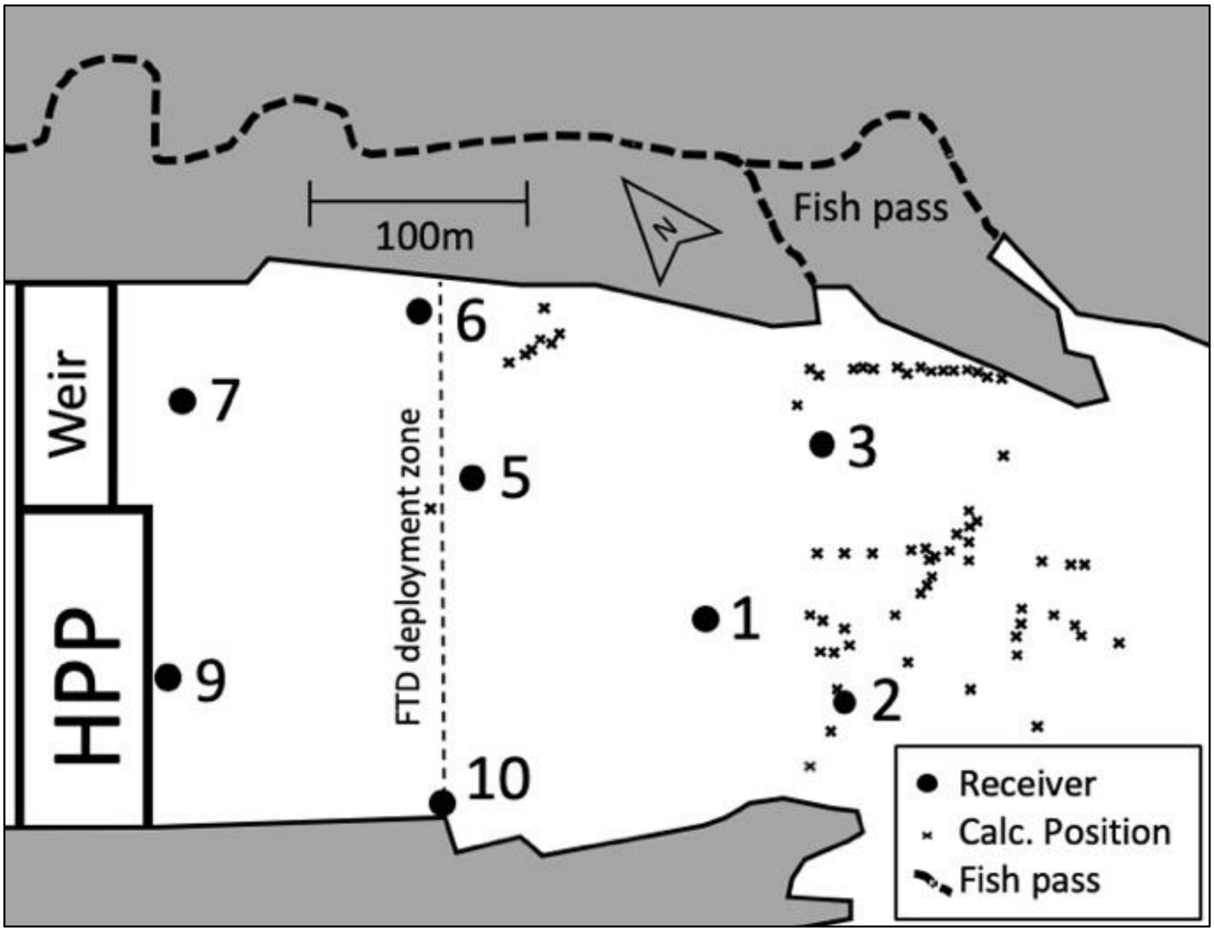

Figure 5: Visualization of positioning success in July 2020

Derived measures for improvement

Due to low detection rates and ranges in front of the turbines (ID 9, 10), inconsistent positioning in the left shore area (ID 7, 6), and limitations with the right of access, we excluded the area in front of the turbines for future arrays. For upcoming tests, we shifted arrays further downstream to examine array properties in areas with improved positioning performance. Distances between receivers and deployment construction were not evaluated as the restraining factor and we continued deployment with the same constructions in the next test.

3.2. April

According to the results from January, we excluded the uppe8st part of the area for receiver deployment in April, starting 280 m downstream of the turbines. An array was implemented (52.5 h) with a total of six receivers. The array was deployed in a potential key migration zone in front of the fish pass entrances. Receivers were deployed with weights and buoys exclusively, with a mean distance of 152.6 m between the receivers. Over the entire array, mean DR of the whole array was 742.5 signals in 10 hours (Table 5). One receiver (ID 4) had a very low DR (238.7) compared to other receivers of the same array. This receiver was situated in a shallow section with 2 m depth. Two centrally located receivers (8, 9) showed exceptionally high DR. The reason for the low DR of receiver 7 (with similar conditions) remains unknown. Positioning downstream of the array, succeeded with a max. mean distance of the listening trio of 319,3 m. Maximum distances of receivers ranged between 261 and 830 m (BTC). Of 1.153 possible positionings, 152 were realized (13,2 %). Again, tags near the left shoreline (<120 m) were detected with sporadic success, while in the center of the channel continuous positioning succeeded up to 492 m (Figure).

Table 5: Detection rates of single receivers in April: Columns show the active listening receivers, rows show the detected receivers, blacked out fields represent receivers detecting themselves

April	**Active listening**		**Det./10 hours**		**Max beacon = 2400**		
Receiver	7	3	10	8	4	9	
1007 AMR0033		343	343	310	203	426	
1003 AMR0029	349		461	1214	156	992	
1010 AMR0026	389	149		1944	149	1953	
1008 AMR0024	328	1138	1919		241	1786	
1004 AMR0030	325	179	179	349		1246	
1009 AMR0025	495	886	1455	1922	446		Avg. All
Average detections	**377**	**539**	**872**	**1148**	**239**	**1280**	**742**

DR of tags in April showed that this time all the receivers were able to detect every tag (Table 6). Interesting in this case is receiver ID 4, which has the lowest DR detection other receivers, but had intermediate DR when it came to tag detection. This receiver was located in the shallowest area.

Table 6: Detection rates of tags for each receiver in April: columns represent receiver IDs, rows represent tag IDs, attached to the buoy.

Tags/receiver	7	3	10	8	4	9
5	67	235	315	374	261	615
6	62	382	208	408	254	593
7	51	346	245	436	298	637
mean	**60**	**321**	**256**	**406**	**271**	**615**

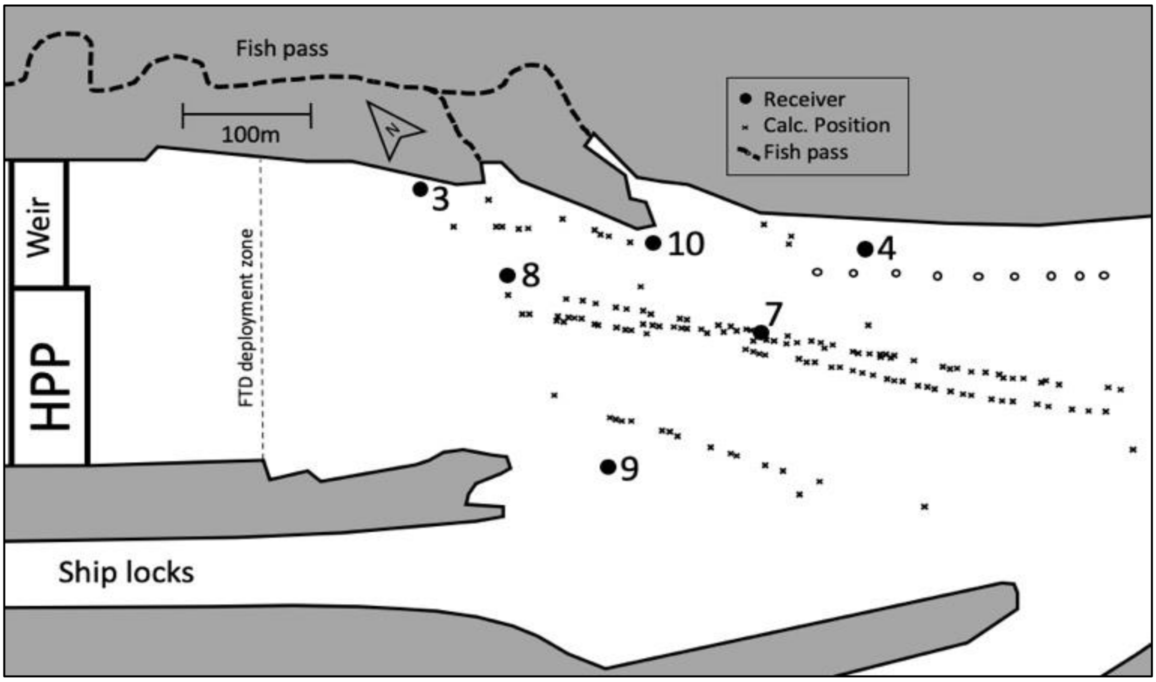

Figure 6: Visualization of positioning success in April 2019

Derived measures for improvement

Due to low positioning success of 13,2 % and a fragmented spatial coverage for high resolution positioning data it was agreed to move receivers closer to each other, to increase the detection probability and effectively cover the area. To monitor the key zone of the area, additional receivers were deployed in the next test. Having the lowest detection results in the shallow area, depths have been taken into account in further tests.

3.3. July

In July, we implemented an array in the same area as in April. We increased the number of receivers to ten and the overall deployment period of the array to 405.25 hours. All receivers were deployed with weights and buoys. Four receivers (ID 1, 3, 5, 9) failed during the test and just obtained detections for a shorter period of time. Already obtained data was still used for position calculation. The receivers were spread uniformly over the investigated stretch with an average distance between the receivers of 105.3 m (grid-approach). Of 17,251 possible positionings, 3193 were realized (18.5 %) (Figure 7). The mean DR of the whole array was 679.6 signals. BTC revealed maximum detection distances between 511 and 711 m. Greatest average distance of the listening trio was 193.3 m, where positioning downstream of the array still succeeded. The longest continuous registered path was 443 m. In Fig. 7 positioning probability per area of all tags is displayed in July. Therefore, we differentiated between areas with no positioning success, areas with sporadic and areas with extensive positioning (in a line transect) depending on positioning success. On the left side of the Danube, positioning succeeded sporadically for the first 110 m after FTD release, the main channel and the right side still reflected no positioning success (0 %). Sporadic or patchy positioning could be found 250 to 300 m downstream of the HPP (3.6 %). Continuous and extensive positioning occurred from 300 m to 540 m (33 %) downstream of the HPP, with the positioning in the main channel exceeding up to 720 m downstream.

Table 7: Detection rates of single receivers in July: Columns show the active listening receivers, rows show the detected receivers, blacked out fields represent receivers detecting themselves

July	Active listening		Det./10 hours		Max beacon = 2400		
Receiver	8	2	10	7	6	4	
1009 AMR0025	62	22	7	6	0	1	
1003 AMR0029	0	101	95	110	104	106	
1008 AMR0024		1632	1854	783	481	1678	
1002 AMR0028	1656		1613	1221	507	594	
1010 AMR0026	1807	892		1189	217	855	
1007 AMR0033	610	1031	1176		1131	1034	
1005 AMR0031	412	528	394	422	376	351	
1001 AMR0027	506	538	468	210	5	449	
1006 AMR0032	183	499	281	1248		249	
1004 AMR0030	1980	809	1099	1392	235		
Average detections	**802**	**672**	**776**	**731**	**340**	**591**	652

In July three different tags were used. Again, the tag at 1 m depth was detected most frequently, and the tag in 3 m depth the least frequently, sometimes even completely absent when looking at detections of single receivers (Table 8).

Table 8: Detection rates of tags for each receiver in July: columns represent receiver IDs, rows represent tag IDs, attached to the buoy.

Tags/receiver	8	2	10	7	6	4
5	1959	3514	3768	0	2785	3084
6	1711	3274	2952	0	2249	2429
7	0	0	2722	0	2128	2265
mean	1223	2263	3147	0	2387	2593

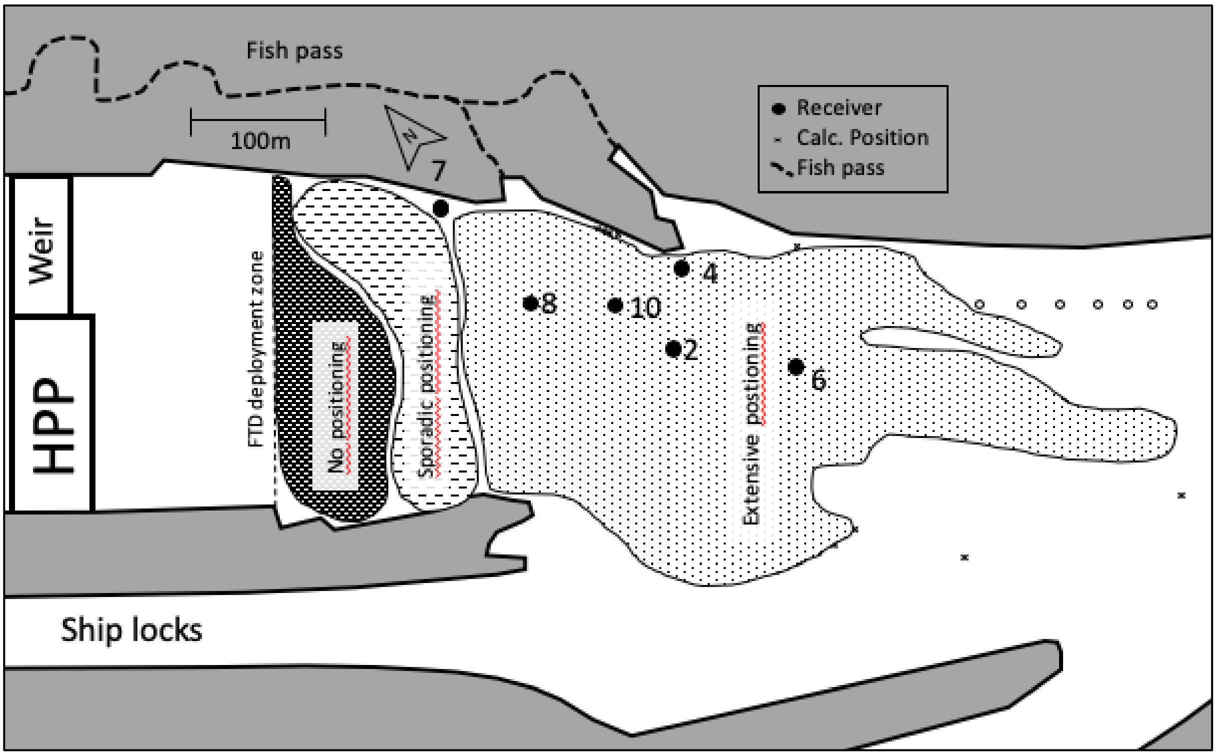

Figure 7: Visualization of positioning success in July 2019, divided into zones without any positioning, sporadic positioning with fragmented single positionings and areas with extensive and continuous positioning

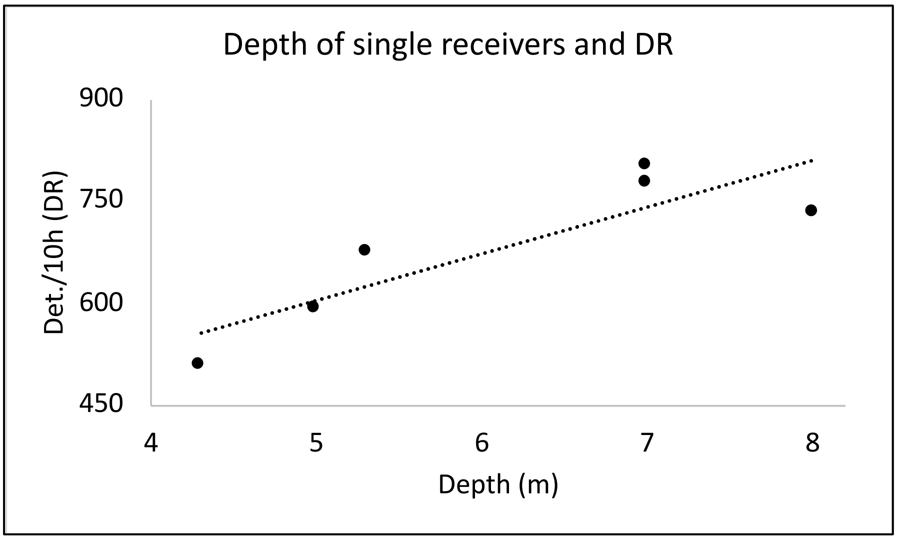

Figure 8: DR of single receivers in different depths in July

In July, there was a positive trend of single receivers' detections placed in deeper sections (Fig. 8). Receivers in areas with a depth of less than 5 m were found to have a max. DR under 600, while receivers in deeper sections exceeded this value by far. A linear regression analysis was performed to test this relation statistically. The deployment depths of receivers were detected to be a significant predictor for DR and had a significant strong effect on how many detections can be detected by single receivers, $R^2 = .751$; $\beta = .867$; $t\ (5) = 3.48$; $p < .05$. As shown in Figure 8 the it was confirmed that higher depth of the receiver results in higher detection rates.

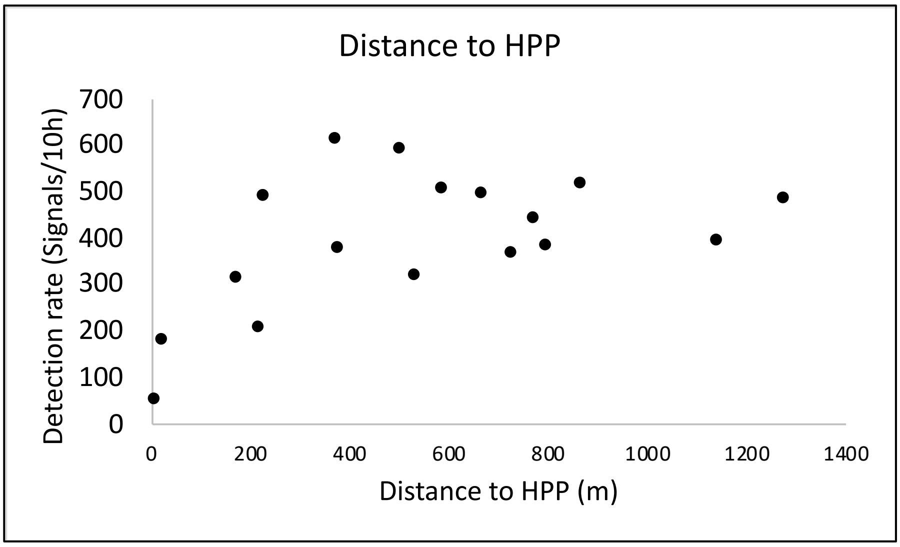

Figure 9: DR rates of single receivers with increasing distance to the HPP

Comparing the DR of all functioning single receivers of all three tests (N=17) with distance to the HPP, DR generally increased with increasing distance from the HPP (Fig. 9). In distances within 200 m, detections were low and did not enable any positioning in the area. Minimum values of DR steadily increased with distance, while max. values were inconsistent, with highest values around 400 m away from the HPP. DR correlated positively with the distance to the HPP, r (17) = .506, p = .019.

Positioning error

During this test a GPS-device was attached to the FTD to be able to link calculated positions with real positions. PE varied greatly on spatial scale between 0 and 21 m. It was compared to turbidity and discharge, as well as depths of single tags. The mean PE of tags of all depths was 2.8 ± 2.6 m, with a max. of 21.2 m. Considering the three tags on the FTD, lowest average PE was found at 2 m (2.6 ± 2.3 m) depth, followed by positionings in 1 m depth (2.8 ± 2.5 m). The tag in 3 m depth expressed the highest PE (3.0 ± 2.9 m). Of 782 calculated positionings 38 (4.9 %) reflected true positions, 195 positions under 1 m (24.9 %) and 388 positions under 2 m (49.7 %). 393 positions (50.3 %) were above PE 2 m. The total range of all PE decreased with increasing depth of the tag, except for one outlier of tag 3.

Pearson correlations between the PE, the tag depth and the discharge in the Danube river were calculated (N = 9). As expected, PE correlated significantly positive with the discharge, r (9) = .660, p = .026, whereas PE did not significantly correlate with the tag depth, r (9) = .063, p = .436.

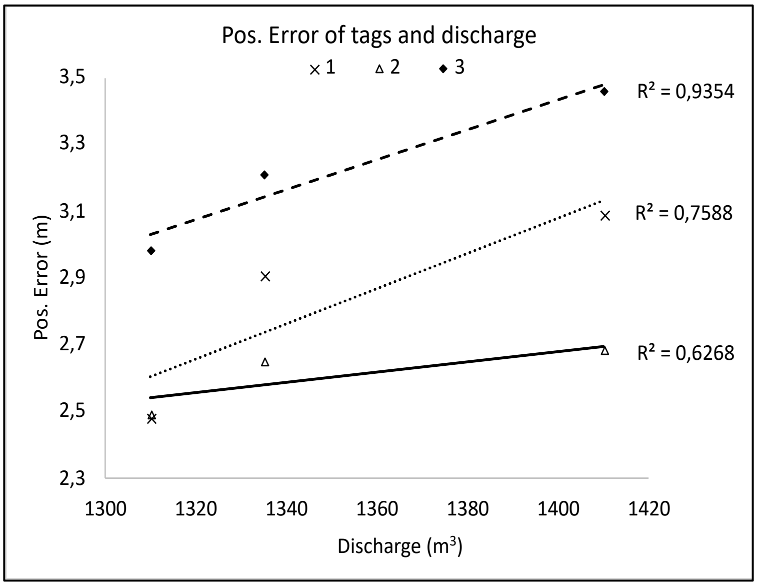

Figure 10: Positioning error compared to discharge and depth of tag (1 m, 2 m, 3 m)

With increased discharge all three tags showed a higher PE (Fig. 10). The greatest difference was observed in 3 m depth, which had the greatest PE at any time of the study, while the tag in 2 m depth showed lowest PE and variability with changing discharge. The tag in 2 m depth was most resilient against discharge influences (2.6 ± 0.1 m). Looking at the average PE of all tags under different turbidity levels of the same (measuring days as ‘discharge’), a positive trend was found (Figure 11) (r (9) = .765, p < .05).

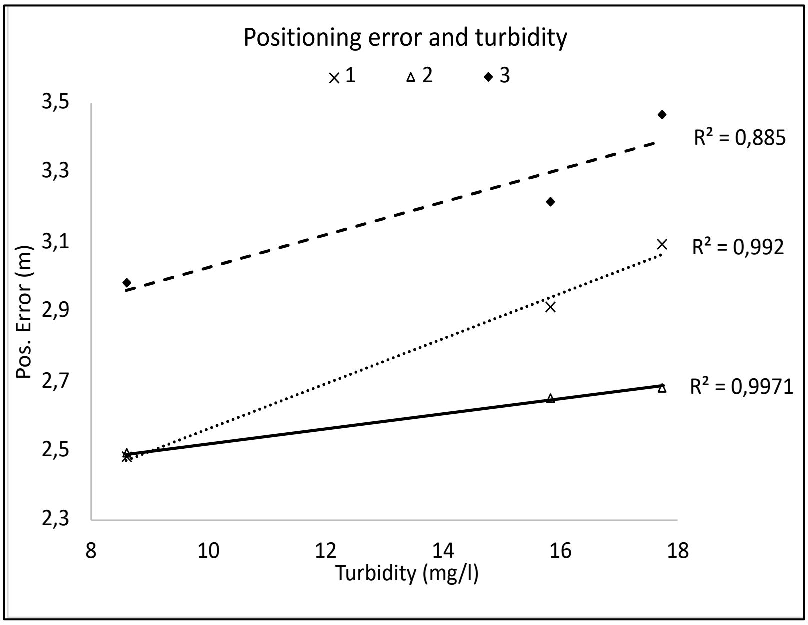

Figure 11: Positioning error compared to turbidity and depth of tag (1 m, 2 m, 3 m)

All tests revealed spatial limitations of positioning in front of the turbines. Positioning was found to be feasible 280 meters downstream of the turbines, while on the left side of the Danube sporadic positioning was still feasible 200 meters downstream of the weirs. One single positioning was calculated within the area in front of the turbines. Maximum listening distances of receivers in front of the turbines did not exceed 2 m (BTC). One receiver 130 m downstream of the HPP did not exceed 205 m, while detection range of receivers outside of this area ranged between 435 and 558 m. Sporadic positioning on the left shore was possible from 150 m to 250 m downstream of the weir, where continuous positioning with high resolution coverage began. This area with potential high-resolution data expanded 550 m downstream of the turbines. A positive exponential correlation (R^2=0.9909) was observed between the number of functioning receivers and the successful positioning per month. For this analysis we excluded failed receivers and receivers that did not function due to hydraulic conditions, however, receivers that obtained valuable data before failing were included in the positioning process. We found data quality (especially positioning success) improving with increasing number of receivers.

4. Discussion

During this research we investigated the applicability of three different hydrophone assemblages with acoustic telemetry receivers and the influence of intrinsic and environmental parameters on data outputs. As the area downstream of Freudenau has not been monitored before, we incorporated a passive telemetry system to deepen our understanding about the applicability of this technology in the Danube, a fast flowing and challenging river. Every new array resulted from findings and limitations of the previous array(s) and user-defined parameters have been modified in order to optimize the system's performance in this particular area. Decisions taken during the iterative process were based on current test results and safety limitations, similar to Clements et al. (2005) who optimized their telemetry system in order to minimize gear and data loss.

In general, detection ranges, positioning success and detection probability of all arrays were location-specific and demonstrated similar spatial limitations. Every test revealed a lack of positionings in front of the HPP. In fact, this study found that DR of single receivers increased with increasing distance to the HPP. With distances greater than 280 m from the HPP, extensive positioning was possible, showing that even minor spatial variations can change physical parameters and have significant influence on array performance. Babin et al., (2019) also reported that closeness to power plants can reduce signal detection by up to 95%. Detection probability may decrease with increasing surrounding noise, as more acoustic waves will interfere with signals of the system (Reubens et al., 2019). Water columns close to the HPP can be altered by intensified air bubble intrusion and vibrations introduced by the Kaplan turbines of the HPP Freudenau (Rivetti et al. 2014). These turbines are known to generate cavitation, a pressure difference that occurs inside the Kaplan turbine and produces air bubbles (Escaler et al., 2006). Air bubbles within the water column can cause sound dispersion (Lee et al., 2011) and multipath reflections (Dol et al., 2013). Especially, environments with air entrapments can increase sound absorption and scattering. (Gjelland & Hedger, 2013; S. T. Kessel et al., 2014) Also visual observations revealed high water turbulences and presence of air bubbles in this area.

Detection probability and range can be influenced by environmental variables, such as sediment type, topography, mounting design, the transmission characteristics of the tags and the configuration of the receivers (Clements et al., 2005; Heupel et al., 1997; Hobday & Pincock, Doug, 1997). Detection ranges via BTC were found between 0 and 830 m, with maximum distances of 2 m in front of the HPP. Similar results have been found in another study, which found maximum detection ranges between 840 and 846 m (Scherrer et al., 2018).

This data (BTC) was found to be inconsistent and highly reliant on receiver and boat location, finding even single detections far from the array, although no detections were present within the array itself. Calculating the detection range can be temporally variable and dependent on refraction of acoustic signals and spreading losses with increasing distance (Huveneers et al., 2016; Steven Thomas Kessel et al., 2015; Lee et al., 2011; Mathies et al., 2014). BTC serves the purpose to estimate receiver ranges, however, range estimations were more complex than expected and may differ due to biotic and abiotic noise (Hobday & Pincock, Doug, 1997). High flow conditions can cause flow noise by movement of the receiver (Reubens et al., 2019). Further, depth, tag battery power, water temperature, salinity and turbulence can have a major impact on reliable detection and can impede transmission of signals (Babin et al., 2019; Gjelland & Hedger, 2013; How & de Lestang, 2012; Huveneers et al., 2016; Mathies et al., 2014; Stocks et al., 2014).

Results of another study, found significant lower detection ranges in close proximity of a HPP and drastic detection reduction in combination with concrete structures (Babin et al., 2019). However, spillways were not active during the experiment, and the reduction in detection probability could be caused by reflective surfaces rather than by increased ambient noise. (Babin et al., 2019) Similar results have been found in other studies, being caused by 'Close Proximity Detection Interference' (CPDI), which could be caused by heterogenous structures and hard substrate in the area of receiver deployment (S. T. Kessel et al., 2014). In close proximity of the HPP large concrete walls and gravel may reflect acoustic echoes that prevent accurate decoding and logging of data (Steven Thomas Kessel et al., 2015; Payne et al., 2010). Binder et al., (2016) related changes in data output mainly to variation of deployment depth of receivers and CPDI in relation with wave action, which was not measured in this research. Furthermore, detection rates of single receivers increased with increasing deployment depths, meaning that receivers in deeper areas had a higher DR compared to receivers in shallow areas on average. Hayden et al., (2016) experienced similar results in a long-term test in a lake and Hobday (1997) found out that receivers in shallow water have a reduced chances of signal detection. Irregularities in detection results may also be connected to topographic and physical characteristics of the river stretch. The substrate at this point of the Danube is very heterogenous (rock, gravel, sand, concrete), which makes detection of signals more complicated due to echoes and distraction of acoustic waves (Bergé et al., 2012).

Acoustic signals of this telemetry system can be sensed over several hundred meters, however, our detection probability and positioning success increased with decreasing distance between receivers. The decrease of distance between receivers in July (April: 153 m, July:

105 m) resulted in an increase of positioning success from 13,2% (April) to 18,5% (July). A comparable study observed that an increase of distance between receivers can lead to a decrease of probability of detection (Hayden et al., 2016). It remains unclear why DR in April and July are relatively similar, but positioning success increased.

While receivers seemed to be working normally, observing the DR of receivers with each other, one receiver (Fig. 7, ID 7) did not detect any tag in July, but has picked up several receiver beacons. It is possible that topographical features or macrophytes were in line of sight between receiver an tag location, as these features can block acoustic signals and prevent signal propagation (Baktoft et al., 2015; Cagua et al., 2013; S. T. Kessel et al., 2014; Selby et al., 2016; Welsh et al., 2012). The same observation can possibly be made with the deepest tag (7) in July, which has not been detected by 3 out of 6 receivers.

Positioning error

In July, findings in this study represented that almost 50 % of all positions had a PE under 2 m, 25 % under 1 m and 5 % of the calculated positionings were true positions (mean 2,79 ± 2,55 m). Comparing these numbers with other studies, a variety of less precise (Espinoza et al., 2011; Scheel & Bisson, 2012), similar (Roy et al., 2014) or more precise (Andrews et al., 2011) PE values was found among other studies. However, results of Roy et al., (2014) were obtained in a reservoir. Andrews et al., (2011) experienced PE below 2 m, but executed the experiment in a marine area with a depth of 8-19 m and homogenous substrate (sand). Both experiments investigated abiotic conditions, which are assumed to be more favorable than to the area downstream of a HPP with challenging discharge dynamics. No statistical correlation was found for environmental parameters such as temperature, turbidity and salinity.

There was a significant correlation of turbidity and discharge influencing PE, but turbidity and discharge measurements were recorded on the same days and might be directly related. In this case, it remains unclear if turbidity or if another environmental parameter may be the reason for the change in PE, due to the low sample size. Richards and Leighton (2000) found that sound propagation is influenced by suspended solids and that these can attenuate sound propagation.

In this study, increasing discharge increased the PE of transmitters in all depths. Steel et al. (2014) stated that discharge fluctuations change several physical parameters within a riverine system, and inter-correlated influences might cause changes in PE. Additionally, they also found a negative correlation between turbidity and position efficiency in riverine systems. Turbidity is directly linked to increased discharge and might be related for this reason for PE variability (Steel et al., 2014). Because ambient noise levels rise with increasing discharge, acoustic positioning may also encounter increased PE occurring with greater current (Mathies et al., 2014; Reubens et al., 2019). The highest PE was found in 3 m depth at any time during the study. Bergé et al., (2012) found similar results, and PE increasing significantly with increasing water depth of a tag.

Positioning in the center of the channel was found to be more successful than at the shorelines, similar to the findings of Bergé et al., (2012). Increased near-shore multipath signals can reduce probability of detection and cause receivers to detect less signals (Rennie & Rainville, 2006). In our study, positioning in depths of less than 2 m was rarely possible. This might also be attributed by the viewing angle of deeper deployed receivers which are unable to communicate with receivers in shallow water (Cimino et al., 2018). Positioning error is strongly influenced by intrinsic and environmental factors. Therefore, it was very difficult to identify the influence of each vector due to inter-correlation of the parameters. (Bergé et al., 2012)

Overall, user-defined parameters appear to be the primary influence on data quality (Bergé et al., 2012). That is also why we managed to increase positioning success by adapting distance between receivers. This process makes data sets difficult to compare, as environmental characteristics were time and location specific and vary with every array. Additionally, the designated key area (the entrance area of the fish pass) was prioritized in opposite to the abandoned area in front of the turbines. Still, covering the whole area for a greater spatial understanding was the purpose of this study and would provide a broader insight in the dynamics of fish migration, but harsh hydraulic conditions at this point require an exaggerative effort to generate satisfying results. Number and location of receivers at any study site needs to focus on a cost-effectiveness-ratio (Babin et al., 2019). To save resources and act responsibly, the area in front of the turbines was excluded for future array implementation.

The deployment construction used in this experiment was reliable and did not suffer major problems. One of the main problems was the abrasion of the rope close to the weight itself, as it kept rubbing on the stainless-steel cylinder or on rocks nearby caused by the moving buoy in strong current. Destruction of the rope means that the deployment construction (with receiver) cannot be found and retrieved, therefore this should be prevented by using a metal chain for the first few meters to protect the line from abrasion.

Results of this study may not represent a definite evaluation, but an impression of detection and positioning probability of different arrays under specific abiotic conditions. Temporal and spatial limitations, interconnectivity of influencing factors, prevalence of user-defined variable on changes in data quality, as well as limitations of resources did not allow for a complete understanding but gave an insight into the performance and applicability of the system within this stretch of the Danube.

The implementation of a telemetry system in a dynamic environment can be challenging. Site-specific tests can expose details about effective array creation for high quality data output. Once site-specific design changes are implemented, fish migratory patterns can be successfully identified (Hayden et al., 2014; Swadling et al., 2020). This study underlines the importance of becoming familiar with a research area and understanding environmental characteristics and their influence on the performance of the system. Understanding site-specific characteristics and the circumstances is essential to identify limitations and challenges for an array. It is crucial to fully understand factors that change detection probability of acoustic signals and interconnectivity between them, as every water body and their physical parameters can have unique characteristics. Even areas that look alike at first sight, can have a large variability considering present conditions and therefore also detection characteristics. (Gjelland & Hedger, 2013)

If areas with limitations can be identified, heterogenous spacing between receivers in one array might help to overcome difficult conditions in known areas (Binder et al., 2016). Increasing the receiver density in difficult areas might help to cover a greater extent of the study site accurately. But as already mentioned above, effectiveness of an array and costs need to be in a healthy relation (Babin et al., 2019). Another method to increase probability of detection and positioning success is the overlap of single arrays to increase probability of positioning (Brownscombe et al., 2020). Results of acoustic telemetry studies need to be treated with caution as telemetry systems may produce variable data quality due to performance fluctuations, which may introduce prejudice to study findings (Binder et al., 2016). It is advisable to test performance of a telemetry system in the study site to get an insight into operational effectiveness in certain areas (S. T. Kessel et al., 2014). Long term studies will be needed to fully understand how this technology functions under variable environmental conditions. Thus, it is fundamental to carefully plan arrays, deployment constructions, and receiver configuration according to expected long-term weather and discharge forecasts. Other studies also reported a significant influence of wind speed and wave action on detection probability (Babin et al., 2019; Reubens et al., 2019). Therefore, these factors should be taken into account in follow-up studies.

In conclusion, grid arrays with distances between receivers below 140 m were found to be suitable for the Danube downstream the HPP Freudenau, but larger distances between receivers further downstream have been able to produce data as well. Deployment depth, tag depth and discharge were found to have an influence on DR and PE. Positioning error was found to be relatively precise compared to other studies, especially under consideration of the challenging environment present in the study site.

Although characteristics of acoustic telemetry systems in certain environments are known, it is important to investigate functional limitations of the system in a certain study site, because in-situ characteristics can be challenging to a system's capabilities. First sight impressions may lead to misjudgment of present conditions and consequently to failing of studies' objectives. Still, telemetry studies contribute to conservation as an important monitoring tool, producing spatiotemporal data and enabling uninterrupted observation of aquatic taxa, leading to an in-depth understanding of species' behaviour. This potential information helps to optimize conservation measurements that aim for ecosystem complexity and biodiversity, as well as strengthening of the endemic biocoenosis.

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