USING HALF DUPLEX TECHNOLOGY TO ASSESS FISH MIGRATION AT THE GEESTHACHT WEIR ON THE RIVER ELBE

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On the German side of the Elbe River exists only one weir, close to the town of Geesthacht (Germany), 35 km upstream of the city of Hamburg. Since 1998 fish passage is provided with a natural-like bypass channel, located at the left bank of the obstacle. Since 1st August 2010 Europe`s biggest fish pass, constructed as a double vertical slot pass, has gone into operation at the right bank. At both sites a comprehensive long-term fish ecological monitoring is carried out. Using HDX-transponder technology (= Half duplex) within the context of the monitoring, short and long scaled fish migration is assessed. According this objective, each year up to 10,000 specimen of anadromous and potamodromous species, e.g. salmon (*Salmo salar*), river lamprey (*Lampetra fluviatilis*), burbot (*Lota lota*) and ide (*Leuciscus idus*) are individually tagged with PIT-tags (= Passive Integrated Transponder) and released on both river banks in the tailwater of the weir. Re-detection of upstream migrating marked individuals is realized with 6 stationary installed frame antennas in the old fish pass. The migration corridor in the new fish pass is controlled by 18 antennas with a maximum height of 5 m and a width of 1.4 m. Assessing fish migration behaviour outdoors, up to now in Germany the HDX-technology has been used only to a limited extent. Due to the complex setup at the monitoring site and an over-average amount of marked fish it is possible to get new and unique results according fish migration. In detail, individual and species-specific results concerning migration behaviour and routes in the tailrace as well as the time span needed to trace the entrance of one of the both fish passes will be presented.

1 INTRODUCTION

Traceability and passability are the key factors for an unrestricted function of a fish pass and its overall efficiency enhancing upstream fish migration along a barrier [1]. Large-scale migration behaviour in the tailwater of a fish pass, guidance to the fishway entrance, actual entry into the fishway and its passage need to be evaluated as different components of fish pass efficiency [2]. Worldwide, the use of passive integrated transponder technology (PIT) has shown to be proved extremely valuable in fish behaviour studies, including those concerned with quantifying numerous aspects of traceability and passability of fish pass facilities in detail. Consequently, the use of transponder technology has been repeatedly recommended to actively quantifying migration of fish in the field, respectively for evaluation of fishways [3]. In spite of its exceptional importance and the fact of results of conventional trapping methods only counting upstream migrating fish at the exit of a fishway are of limited validity, particularly with respect of a very limited detection range and an unreliable evaluation of traceability, up to now, in Germany PIT-telemetry has been used rarely in the field [4]. HDX-technology together with installing multiple high-performance antennas along fish migration routes increases detection range still with relatively small PIT-tags. Thus, this technology is applicable for large-scale field assessment nowadays.

Since its commissioning in the year 1960, the Geesthacht weir is the only traverse migration barrier on the 728 km long German course of the River Elbe. Beyond a doubt, its unrestricted passability for the aquatic fauna is of particular importance for the whole Elbe catchment area [5; 6]. To facilitate upstream passage, since 1998 a natural-like bypass channel, which already is the third facility at this location, was build on the left bank of the dam. For large rivers, the DWA guideline [1] recommends fish pass facilities on both river banks. Among others, as a result of several fish migration studies on the bypass channel, this necessity was stressed already in the recent past [5; 7]. As part of mitigation measures for the cooling water outtake for the coal-fired power plant Moorburg, Vattenfall Europe Generation AG was obliged to undertake measures to protect potentially affected fish species, which have been assigned a high conservation status [8]. One of these measures has been to build a second fish pass at the Geesthacht weir. Within this context, to evaluate the effectiveness of this mitigation measure, a long-term (> 5 a), daily fishecological monitoring is prescribed by administrative regulations encompassing the use of telemetry to assess upstream fish migration via both fish passes at the Geesthacht weir.

In the recent past, just one study has been published within the context of migration behaviour of radio-tagged burbot (*Lota lota*) in the local tailrace of the Geesthacht weir [9]. Altogether, only very imprecise notions exist with respect of spatial and temporal upstream fish migration behaviour at this site. For example, due to high flow velocities and turbulences in the tailwater, Gaumert et al. [5] assume pronounced bank fidelity for migratory fish on their way upstream. This bank fidelity would lead to a 50% division of the "migratory population" without considerable cross-over migration between the banks.

On 1th August 2010 the second fish pass, constructed as a double vertical slot pass [10], was set into operation on the right river bank of the Geesthacht weir. Since that date, the parallel HDX-monitoring of the "old" and "new" fish pass offers the unique opportunity to assess overall fish migration behaviour in particular beneath the Geesthacht weir and to directly compare two completely different constructed fishways at the same migration barrier in terms of traceability and passability. The objective of this contribution to the entire proceedings is to present the first results in terms of answering the following basic questions:

1. To which extent do upstream migrating fish express bank fidelity?
2. Are there species-specifically preferred migration corridors?
3. How long does it take for individuals of each species to trace one of the both fishways?
4. How many fish enter one of the two fishways without passing them successful?

Furthermore, because of several catch reports of marked individuals within the whole Elbe catchment area, partly surprising insights concerning migration distances of selected species will be presented.

2 METHODS

2.1 Study site

The Geesthacht weir is located 35 km upstream of the city of Hamburg, respectively 140 km far away from the Elbe estuary/North Sea (Figure 1).

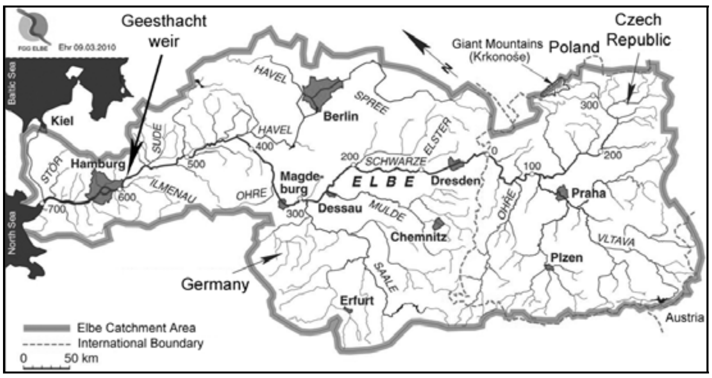

Figure 1. Elbe catchment area with location of the Geesthacht weir near river-kilometer 586 (source: Flussgebietsgemeinschaft Elbe).

Downstream the weir, water level depends on tide change, resulting in a maximum drop between headwater and tailwater during low tide of 4.5 m. Due to high flow velocities and turbulences in the tailwater, the obstacle is impassible for upstream migrators. On the left river bank (cut bank) a natural-like bypass channel facilitates upstream fish migration. On the opposite site of the River Elbe (point bank), this is provided via the new double vertical slot pass (Figure 2 & 3).

The weir comprises a 200 m wide structure divided into a series of four submersible gates (4 x 50 m) with its main function to maintain a stable water level upstream for navigation and water intake purposes. Following these submersible gates, on the right-hand side two fixed segments serve as spillways. Five irrigation gutters were sliced into the left fixed spillway-segment (Figure 2) to generate a perceptible attraction flow leading upstream migrants to the entrance of the new double slot pass, located in the outer fixed spillway-segment. Further details of the two fishways and the hydrology at the site are provided by Hufgard and Schwevers [11], respectively Schwevers et al. [10].

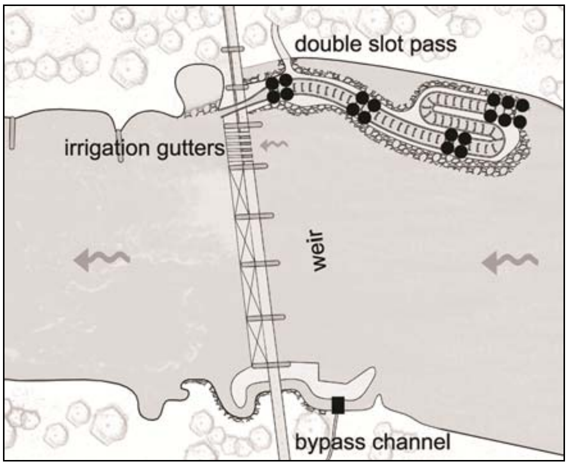

Figure 2. HDX-antenna position; ■ bypass channel (6 in parallel), ● double slot pass (18, slot-wise).

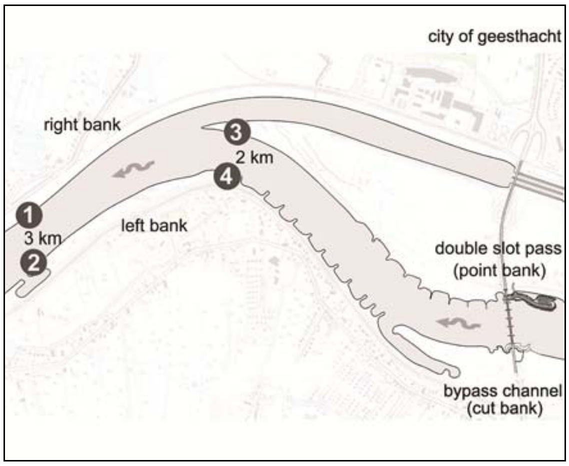

Figure 3. Release points in the tailwater of the weir and position of fishways (point bank, cut bank).

2.2 Experimental design

HDX-technology was chosen for the entire monitoring, since this system offers a number of advantages over conventional tagging technologies to monitor long-term fish movement under field conditions, including low cost thus facilitating increased sample sizes as well as the unlimited durability of PIT-tags [21].

After successful passage of one of the both fishways, individuals for tagging were sourced within the conventional monitoring [11] from a trap (bypass channel), respectively a trap box (double slot pass). Total length (nearest 0.5 cm below) and weight (± 1 g) of each individual were measured. In part, additional biometric data, e.g. maximum height and width, were recorded to the nearest mm. Following a small incision (< 5 mm), a uniquely coded tag (TI-RFID, Texas Instruments, Dallas, TX, USA) was implanted into the peritoneal cavity without using sutures afterwards. Depending on species and size of individuals transponder size was adjusted (23 x 3.85 mm or 32 x 3.85 mm). Except for river lamprey (*Lampetra fluviatilis*) of which specimens sizing ≥ 38 cm were tagged, minimum total length of individuals of further four anadromous species [Atlantic salmon (*Salmo salar*), houting (*Coregonus oxyrinchus*), sea lamprey (*Petromyzon marinus*), seatrout (*Salmo trutta f. trutta*)] as well as six potamodromous species [asp (*Aspius aspius*), barbel (*Barbus barbus*), burbot (*Lota lota*), chub (*Squalius cephalus*), ide (*Leuciscus idus*), pikeperch (*Sander lucioperca*)] was ≥ 30 cm. In the context of the marking study at the Geesthacht weir, tagging up to 10,000 fish per calendar year with HDX-transponders is carried out by specially trained personnel in compliance with Germany`s animal protection laws. In advance, the way of entire proceeding has been approved by the responsible veterinary agency.

Subsequent to tagging, individuals were immediately transferred to an aerated flow-through tank and allowed at minimum 2 h to recover from handling prior to release. After recovery, tagged individuals were released back into the Elbe, species-specific to equal parts at four distinct near-shore points in the tailwater of the weir (Figure 3). Release point 1 and 3 were located 3 km, respectively 2 km downstream the weir on the right river bank. Corresponding distances were applied for point 2 and 4 on the left river bank.

An array, consisting of 6 complete pass-through HDX-antennas (1 m x 1 m) placed in parallel, was installed in the 216 m long natural-like bypass channel under a small bridge, approximately 70 m downstream the exit of the fish pass (Figure 2). Each antenna was connected to a remote tuner box, each of which is connected via twin-axial cable to a multiplexer unit (Oregon RFID, Portland, OR, USA). Multiplexer was programmed to scan at high speed sequentially through all antennas and upon positive detection stored the unique, nine-place tag identification number, antenna number and provided date and time stamps that were downloaded to a personal computer continuously. At the double slot pass, automatic re-detection will be realized with 18 antennas (maximum height 5 m, width 1.4 m), distributed along the entire length of the facility (550 m). Except the two antennas at the direct exit of the fish pass, the remaining 16 antennas were herded of 4 along two consecutive slots (Figure 2). In contrast to the bypass channel this positioning enables detailed evaluation of swimming direction and passage duration of individual fish within the facility. Until the commissioning of this antenna array mid of 2012, manual re-detection is done by scanning trapped specimens by means of the controlling station [10; 11] at the exit of the double slot pass. Similarly to the manual scanning procedure at the new fish pass, all specimens successful passed the bypass channel and caught with a trap upstream the water intake were checked with a handheld reader. Since only a few individuals were caught in the trap without registration by means of the 6 antennas, reliability of detection of the antenna array amounted to approximately 95%. After re-capture and manual scanning, individuals were immediately released in the headwater to continue upstream migration.

With the aim to assess species-specific migration behaviour and distances beyond the direct monitoring site at the Geesthacht weir with its two fishways, the transponder study was made public with the help of the internet, several fishing periodicals as well as professional journals. Sending back HDX-transponders to the Institute of Applied Ecology and at least stating species, total length, catch date and location of the marked individual, angler and fishermen received 20 Euro per tag. Furthermore, two scientific institutes which were involved in reintroduction projects of Atlantic salmon and seatrout were equipped with handheld scanners to detect marked specimens caught at their spawning grounds in Brandenburg and Saxony, 150 km, respectively 600 km upstream from Geesthacht.

Although the long-term fishecological study already started in April 2009 at the bypass channel, for the entire publication only data gathered during the first sixteen months of parallel monitoring of the two fish pass facilities (1^{th} August 2010 – 30^{th} November 2011) were analysed.

3 RESULTS

5 anadromous and 6 potamodromous species comprising 11,137 individuals were PIT-tagged and released in the tailwater of the Geesthacht weir. In total, 37% of the marked individuals were re-detected (n = 4,166; Table 1). For the 11 species, on average, rate of re-detection was 30% (SD = 18%). Potamodromous ide and asp presented the highest proportion of re-detections (64%, resp. 53%). With 10% to 13%, rate of re-detection was lowest for anadromous houting and sea lamprey as well as for potamodromous pikeperch and barbel. The remaining 5 species exhibited intermediate rates of re-detection between 22% and 43%.

Table 1. Total number of fish species PIT-tagged and released in the tailwater of the Geesthacht weir as well as the number and rate of re-detections (%) of each species (1^{th} August 2010 – 30^{th} November 2011).

species / type of migration			**number tagged**	**number re-detected**	**re-detection (%)**
river lamprey	(*Lampetra fluviatilis*)	anadromous	7,736	3,345	43
pikeperch	(*Sander lucioperca*)	potamodromous	1,547	190	12
ide	(*Leuciscus idus*)	potamodromous	432	278	64
barbel	(*Barbus barbus*)	potamodromous	349	47	13
burbot	(*Lota lota*)	potamodromous	270	60	22
seatrout	(*Salmo trutta f. trutta*)	anadromous	240	57	24
Atlantic salmon	(*Salmo salar*)	anadromous	201	86	43
sea lamprey	(*Petromyzon marinus*)	anadromous	170	20	12
asp	(*Aspius aspius*)	potamodromous	137	72	53
houting	(*Coregonus oxyrinchus*)	anadromous	30	3	10
chub	(*Squalius cephalus*)	potamodromous	25	8	32
total			**11,137**	**4,166**	**37**

In total of all re-detections (n = 4,166), 61% of the individuals migrated upstream through the double slot pass, whereas 39% used the natural-like bypass channel. This ratio was equal, regardless of the river bank of release (Figure 4a). However, also irrespective of the river bank of release, the preferred migration corridor differed between species. This record is shown by example of the three most tagged species in Figures 4b to 4d. Above 70% of river lamprey released on the same site the double slot pass is located overcame the obstacle via this facility (4b). The same proportion of the left bank release crossed the main current of the River Elbe and moved upstream using the new fishway. Less than 30% of total marked river lamprey used the bypass channel located on the cut bank of the weir to reach their spawning grounds, also this was regardless of the point of the releasing site. Even though the ratio of cross-over migrating pikeperch and individuals which expressed bank fidelity was not as equal in comparison with river lamprey (60% right bank release, 74% left bank release), most of re-detections of this species occurred at the bypass channel. For ide released on the right bank, 98% changed the side of the Elbe during upstream migration and entered the bypass channel together with all individuals of this species released on the left bank.

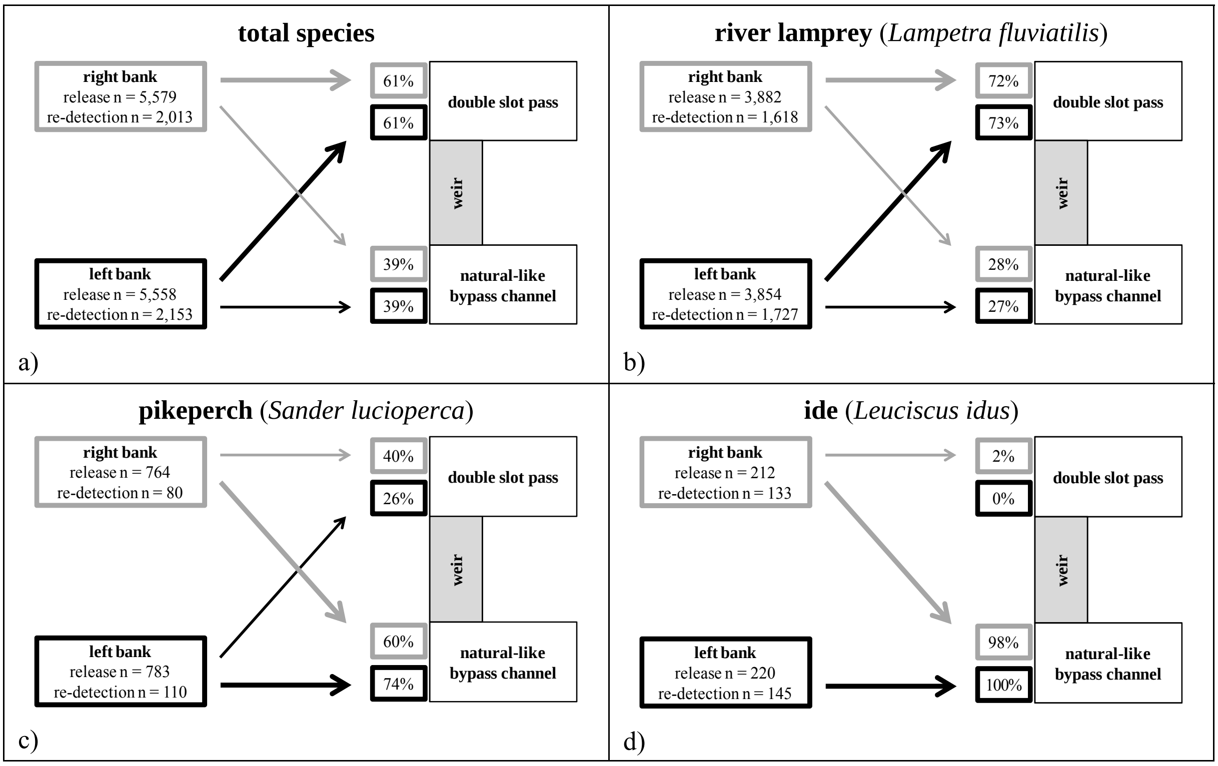

Figure 4. Species-specific rate of re-detection at each of the both fishways with respect to the point of the releasing site.

As shown in Table 2 exemplarily for river lamprey and pikeperch for which there were actual the most adequate data to enable comparable analyses, median time from release until re-detection (re-detection delay) was species-specific.

Table 2. Median re-detection delay of river lamprey and pikeperch with respect of the river bank of release and the fish pass of re-detection.

	median re-detection delay [d]			
	river lamprey (*Lampetra fluviatilis*)		**pikeperch** (*Sander lucioperca*)	
river bank of release	**double slot pass**	**bypass channel**	**double slot pass**	**bypass channel**
right	3	11	25	16
left	3	19	27	13

Furthermore, within each species re-detection delay was highly different between the fish pass used for re-ascent and this was always irrespective of the river bank of release. Half of all re-detected river lamprey at the double slot pass needed up to 3 days to trace this fishway, whereas the bypass channel was traced on median after approximately 2 weeks. For the double slot pass, pikeperch median re-detection delay amounted 25 d after release on the right river bank, respectively 27 d after release on the left bank. In contrast, 50% of pikeperch needed up to 13 d (left bank release), respectively 16 d (right bank release) to trace the old fishway located on the cut bank (Table 2).

For the bypass channel some individuals, regardless of the species, traced the entrance without passing this fishway successfully. In particular, this was true for pikeperch (Figure 5). Only 27 out of 129 pikeperch re-detected at the old fish pass at the antennas were caught in the upstream located trap, thus reaching the headwater. After first re-detection and leaving the bypass channel downstream into the tailwater, 11 individuals were caught within a few days later at the double slot pass. After leaving the bypass downstream, altogether 91 pikeperch were not re-detected a second time during the study period.

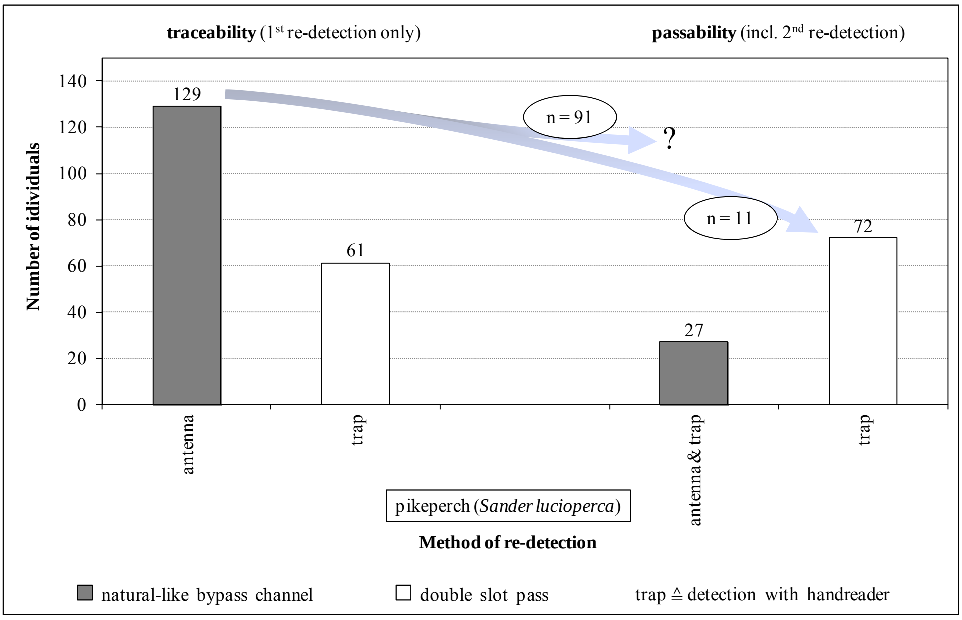

Figure 5. Pikeperch - traceability versus passage success and fishway change after passage failure.

Out of 11,137 individuals marked between 1th August 2010 and 30th November 2011 in total 53 external re-captures, respectively re-detections comprising 5 species were reported by anglers, fishermen and scientific institutes to the Institute of Applied Ecology within this entire evaluation period. With 30 individuals pikeperch was the most external caught species followed by seatrout (n = 12), Atlantic salmon (n = 7) and 2 specimens of river lamprey, respectively burbot. All Atlantic salmon were re-detected at their spawning grounds in Brandenburg and Saxony, 150 km, respectively 600 km upstream the Geesthacht weir. This was also true for the most of seatrout which spawn in the River Stepenitz/Brandenburg, indeed one individual which was first re-detected during upstream migration at the Geesthacht weir and finally, 226 days later re-caught at the River Eider which drains into the North Sea, 210 km far away from Geesthacht. Most of the potamodromous pikeperch were re-caught downstream along the course of the Elbe up to the city of Hamburg (migration-range 0 - 35 km). However, 3 individuals of this species migrated 94 to 182 km upstream until re-catch. One pikeperch was recorded near the city of Dessau, 326 km upstream the Geesthacht weir. After migrating 157 km upstream, one burbot was recorded at the River Havel/Quitzöbel weir, a tributary of the Elbe.

4 DISCUSSION

Without any doubt, with more than 11,000 marked individuals the scope of the use of HDX-transponder technology in the field is unprecedented, at least by German standards. With respect of a large-scale field trial, the exceptionally high total re-detection rate of 37% leads to an increased validity of the results, although some of the 11 species tagged were quantitatively underrepresented in the sample size (e.g. houting and chub). Rate of re-detection was highly variable among species (range 10% - 64%). Especially remarkable are the high proportions of re-detected potamodromous ide (64%) and asp (53%), which clearly exceed those of anadromous species like Atlantic salmon or river lamprey (each 43%).

Gaumert et al. [5] assumed pronounced bank fidelity for migratory fish on their way upstream until reaching the weir. According to this authors, bank fidelity would lead to a 50% division of the "migratory population" without considerable cross-over migration between the banks. With respect of this assumption, assessing the extent of bank fidelity for upstream migrating fish was a crucial aim of the entire HDX-monitoring. Results so far indicated a remarkable cross-over migration between both river banks of release, thus pronounced bank fidelity does not matter with regard of the fishway use to overcome the Geesthacht weir. In total, equal parts of 61% of individuals released at the left bank as well at the right bank used the double slot pass for upstream migration, whereas 39% of all individuals entered the bypass channel, regardless of the river bank of release. In contrast to the new fishway which is located at the point bank, the bypass channel was built at the cut bank. Subsequently to this positioning, hydraulic conditions in the tailwater always differ between the river banks and thus leading to a different large scale traceability of the two facilities which determines fish migration route.

Also regardless of the river bank of release, the results clearly point out species-specifically preferred migration corridors. As shown for river lamprey, but also for sea lamprey most specimens of this species were re-detected at the double slot pass. Species with greater swimming capacity, e.g. ide and salmonids seem to prefer migrating upstream along the cut bank, since most individuals of these species were re-detected at the bypass channel. During high incoming tide, the drop between head- and tailwater was markedly diminished at a few days within the study period. Such events may have enabled an unknown number of powerful individuals to traverse the Geesthacht weir via the 5 irrigation gutters of the double slot pass and thus evading re-detection. With respect to control this periodic passage opportunity, additional antennas will be installed in the future, resulting in more valid information concerning species-specific migration corridors.

In addition to quantify preferred migration corridors the time span from release until re-catch (re-detection delay) also provides species-specific information about attraction efficiency, e.g. traceability of the two fish pass facilities. As shown for river lamprey, the above-mentioned exceptional attraction efficiency of the new fishway was confirmed, since 50% of individuals of this species only needed up to 3 days to traverse the weir and this again regardless of the river bank of release. In contrast, re-detection delay of pikeperch stressed the species-specific character of this parameter.

For several species passability, e.g. passage efficiency of the natural-like bypass channel must be deemed as restricted. Only 21% of preadult and adult pikeperch (≥ 30 cm) which passed the entrance of this fishway and were re-detected by the antenna array successfully reached the headwater. Upstream migration seems to be restricted by the lack of suitable hydraulic conditions especially in the upper part of the bypass channel, which is characterized by high turbulence level between the numerous perturbation boulders [12]. According to Larinier [13], passage success for certain species like northern pike and pikeperch just can be obtained with power dissipation obviously less than 100 W/m^3. The new double slot pass is characterized by maximum power dissipation of 20 W/m^3 and maximum flow velocities of 1.5 m/s along short distances within the slots. Quantitative and qualitative results of the conventional monitoring (trap box) confirm these optimum hydraulic conditions since all species and size-classes were recorded, regardless of the species [10; 11]. For example, as shown by means of HDX-technology, pikeperch prefers migrating along the cut bank towards the bypass channel. In contrast to this finding, conventional monitoring revealed an eight-fold higher number of recorded individuals of this species successful passing the double slot pass comprising all size-classes (range 3 - 90 cm; median 51 cm). A more detailed and valid comparison of species-specific passage efficiencies between the two completely different constructed fishways will be enabled after starting up automatic detection at the new fish pass by means of 18 antennas distributed along the 550 m long course of the facility. The installation of additional antennas at the direct entrance and exit of the bypass channel would be preferable.

Besides the short scaled HDX-results obtained at the Geesthacht weir, evaluating species-specific migration distances with the help of the informed public revealed quite surprising insights into the migration behaviour of some species. Especially this was true for pikeperch, in general assumed to migrate only short distances, since some individuals were reported over 100 km upstream of Geesthacht. These unique results stress the importance of unrestricted longitudinal connectivity of flowing waters, even for potamodromous species.

Collectively, HDX-technology was successfully implemented on a large scale field monitoring at the Geesthacht weir on the River Elbe. Already the first results of the long-term monitoring provide unique insights into the fish migration behavior downstream the obstacle. The results stress the significance of using HDX-transponder technology within fish migration studys in particular with the aim to reliable assess traceability and passability of fishways. In addition, the results concerning species-specific large scale traceability of both of the fishways at the Geesthacht weir pointed out the need of a second fish pass facility at broad rivers like the Elbe to maximize overall passage efficiency. In contrast to recommendations made by DWA guideline [1], on the Geesthacht weir the 4 submersible gates are exclusively managed accordingly WSA requirements. Since some species express partially high re-detection delay regardless of the fishway, a practical consequence of the results would be to alter the discharge management above the 4 gates to optimize the linkage between attraction flow and the main current of the Elbe, e.g. to enhance traceability.

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