NATURAL LIKE OR TECHNICAL FISH WAY FACILITIES – WHICH ONE IS BETTER?

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The only weir on the German side of the river Elbe was built in 1960 next to the City of Geesthacht (Germany), 30 km upstream of Hamburg for navigation purposes. It creates an artificial separation between the meta-potamon and the tidally influenced hypo-potamon, resulting in very variable differences in water level with a maximum drop between headwater and tailwater of 4.5 m. In 1998, a natural-like fish pass channel was installed along the left bank of the Geesthacht weir. 12 years later, on August 1st, 2010 Europe's biggest fish pass, designed as a double vertical slot pass, was opened at the opposite bank. Both fish passes provide fish migration past the barrier for about 580 km up the river course without further obstacles. The goal in equipping the Geesthacht weir with two fish passes was to guarantee migration for big species like Atlantic sturgeon (*Acipenser sturio*) and Atlantic salmon (*Salmo salar*), which are subject to resettlement programs, as well as for poor swimmers like ruff (*Gymnocephalus cernuus*) and bleak (*Alburnus alburnus*). Since the new double-slot fish pass has gone into operation, a continuous, daily long-time monitoring with similar methods for counting all upstream migrators takes place at both sites. During 2011, more than 430,000 specimens of 40 species used the two fish ways. This huge data base allows a detailed comparison of the natural-like constructed fish pass to the technical facility in terms of traceability and passability.

1 INTRODUCTION

Interruptions of the up and downstream passability of rivers have contributed decisively to the extinction of many anadromous fish species which depend on a change in fresh water for spawning and salt water in their food habitats. Indeed, all the other native species also perform long-distance migrations. Particular examples are feeding, overwinter, drift, compensatory countercurrent as well as spawning migration [1]. Hence, all fish species profit from the up and downstream migration in rivers, not least on account of the genetic exchange of different populations. In many German rivers the presence of several dams affects the up and downward migration of fish. For example, there are 27 dams on the river Neckar and 34 weirs on the river Main [2]. As opposite to that, the river Elbe is free-flowing upstream the Geesthacht weir for a length of 580 km to the border of Czech Republic. Therefore, the up and downstream migration via the Geesthacht weir has a particular importance for the aquatic fauna of the whole middle Elbe and sections of the upper Elbe. Since 1998, a natural-like bypass channel, which already is the third facility at this location, exists on the right bank of the Geesthacht weir. Both previous fish ladders were not functioning properly [3]. 12 Years later, on the opposite shore, the new vertical slot pass, Europe's biggest fish pass facility, financed by the Vattenfall Europe Generation AG as an environmental protection measure within the framework of constructing the Moorburg thermal power plant in Hamburg, was put into operation in August, 2010. The construction time was about 16 months [4].

2 RESEARCH AREA

2.1 The river Elbe and the Geesthacht weir

From its spring in the Giant Mountains (Czech Republic) up to the mouth in the North See nearby Cuxhaven/Friedrichskoog (Germany), the river Elbe with a total length of 1,094 kilometers is Europe's fourth longest stream and Germany's second longest stream. Currently, there are 24 dams on the Czech part of this river. The Geesthacht weir, installed to maintain shipping traffic on the middle Elbe, is located about 140 km above the North Sea estuary. The catchment area of the Elbe in this location encloses 135.013 km². The weir severs the current from the tidally-influenced lower Elbe and the tide-free middle and upper Elbe. Two fish passes provide upstream fish migration at this location: the old natural-like bypass channel (1998) on the left bank (undercut bank) and the new double slot pass (2010) on the right bank (slip-off bank) (figure 1).

Figure 1. Position of the natural-like bypass channel on the left bank (undercut bank) and the double vertical slot pass on the right bank (slip-off bank) (source: Google earth 2012)

2.2 The two fish pass facilities at the Geesthacht weir

The old fish pass was built in 1998 as a close to the nature bypass channel (figure 2). The entrance with an angle of 90° is located in a side bay of the river about 70 m downstream of the weir. Modeled like a mountain torrent, the alternating stream bed is divided in several sections: three riffles equipped with massive perturbation bolders, and two pools with a maximum depth of 1.2 m. The bypass channel has an average slope of 1:30 and a discharge of 6.3 m³/s [3]. The 216 m long, slightly curved channel was constructed with a trapezoidal profile with a width of about 8 to 10 m. Bottom and banks are compounded of massive broken stones to create differentiated flow conditions. In addition, the shores are protected by sheet pile walls. The riffle structures cause a very high turbulence with a volumetric power dissipation of more than 200 W/m^3; the maximum flow velocity reaches 2.3 m/s.

The new fish pass facility was constructed as a vertical slot pass with two slots in each cross wall (figure 3). The aim of this building is to significantly improve the passability of the river Elbe for all autochthones fish species including the currently extinct Atlantic sturgeon (*Acipenser sturio*). All requirements formulated in the German guideline DWA 509 [1] were strictly adhered to. The total length of the fish pass with its 49 basins is about 550 m with a slope of 1:93. Every pool has a length of 9 meters. The width, measured from sheet pile wall to sheet pile wall, is 16 meters. The slots have a width of 1.2 m [5]. The entrance is situated in the immediate vicinity of the weir. Thus, creating a potential dead-end between the fish way's entrance and the weir is avoided. The attracting flow leaves the fish pass entrance with an angle of 30°. In addition to the regular discharge of the fish pass, five irrigating gutters have been sliced into the weir. Discharging 10 cubic meters of water per second, they generate a rectified current, to help the fish orient themselves and enter the fish pass faster. To implement the functionality of the new fish pass independent of permanently fluctuating tail water levels due to the tidal range, the discharge automatically increases from usually 4.6 m³/s up to 11 m³/s. For this purpose, six additional dotations coupled to the tidal level are installed at different positions within the course of the fish pass. The hydraulic conditions in the channel were laid out to allow maximum differences in water levels of 9 cm between each pool. With regards to the swimming capacity of the weakest fish species the maximum flow velocity near the slots is 1.5 m/s. The volumetric power dissipation amounts to 20 W/m³ of pool volume. The depth of the basins amounts to at least 1.75 m and increases up to 5 m in the entrance area of the fish pass in relation to the tide level. The bottom of the fish pass is covered with water-rounded stones of approximately 20 cm in diameter [6].

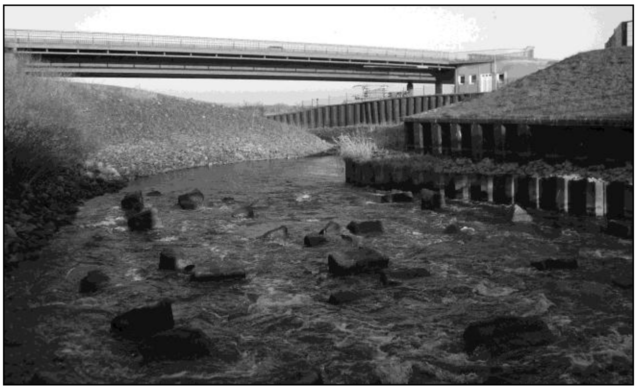


Figure 2. The natural-like bypass channel on the left bank of the Geesthacht weir

Figure 3. The double slot pass on the right bank of the Geesthacht weir

3 FISHERY MONITORING

Since the new double slot pass has gone into operation, a continuous daily long-time monitoring with similar methods to count all upstream migrators takes place at the old and the new fish pass [7], [8]. However, in periods of high water and ice drift no monitoring takes place for security reasons. Also, maintenance work on the fish passes can cause interruption. A simultaneous monitoring on both fish passes was done on 267 days in 2011. Only the database of those days was used in the following analysis.

3.1 Monitoring at the natural-like bypass channel

A conventional fish trap is installed immediately upstream the water intake of the old fish pass. The cross section of the pass is completely blocked off. After successful passage of the total length of the facility, two nets fixed on both banks lead upstream-migrators into the trap. The bag-shaped trap is made of fyke net with a mesh size of 11 mm. Three narrowing's inside avoid the escape of trapped fish. Depending on the quantity of migrating fish, the removing of the animals from the trap takes place once or twice a day. All fish are put into water-filled tanks. Their biometric parameters, such as species, total length and weight are documented. Following this operation, all animals will be released into the headwater. Finally the fish trap is maintained and exposed again [9].

3.2 Monitoring at the double slot pass

The controlling station in which all migrators traversing the double slot pass are collected, is situated upstream the final pool [7]. Two screens with a clear spacing between their horizontal racks of just 9 millimeters, lead fish to a capture chamber. The frames of the screens are sealed with several rows of robust brushes to close them off against the bottom and vertical structures of the fish pass. The screens are arranged at a 30° angle to the centrally located capture chamber. Drawn by the current, the fish are guided parallel along these impassable structures and swim to the entrance of the capture chamber. Via a funnel, the migrating fish are herded inside, where they are held in a huge fish trap box.

The trap box is 3 m wide, 4 m long, and 1.25 m high. The volume is sufficient to hold fully-grown Atlantic sturgeon, as well as significant numbers of smaller fish. Its interior is spacious enough to keep the captured animals from feeling undue stress and from possibly injuring themselves by attempting to escape. The trap box inside the capture chamber is placed outside of the fish pass discharge. The benefit of this construction is the avoidance of high flow velocities and turbulence inside the trap. Therefore, the fish remain uninjured and healthy throughout the trapping and keeping. Two pumps supply the discharge for the capture chamber to provide a sufficient velocity of the attraction flow leaving the entrance of the trap and to fill the trap with fresh, oxygenized river-water. In this way, turbulence and flow velocity inside the trap has cut down dramatically to less than 0.1 m/s. Usually, the fish are getting removed for monitoring purposes once or twice a day. During periods of mass migration, more control cycles are added as necessary during the night. When emptying the trap box, the water and fish are released through a chute in a collection tank of 3.5 m^3 on the bank opposite the controlling station.

4 COMPARISON OF BOTH FISH PASSES

In 2011, a total of 496,551 specimens from 40 species were detected at both fish pass sites. The most frequent species were stickleback (*Gasterosteus aculeatus)* with 150,239 specimens and river lamprey (*Lampetra* *fluviatilis)* with 125,744 specimens. Also among the more frequent ones were bleak (*Alburnus alburnus)* with 94,943 specimens, silver bream (*Blicca bjoerkna*) with 49,968 specimens and 28,973 bream (*Abramis brama*).

At the double slot pass about 7 times the number of fish was detected compared to the natural-like fish pass. For example: 149,151 sticklebacks traversed the double slot fish pass, but only 1,088 specimens traversed the natural-like construction. A similar result is indicated by the number of river lamprey *(Lampetra fluviatilis)*: With 120,012 specimen, about 20 times more specimens were detected in the double slot pass than in the natural-like bypass channel. Also, 6,819 smelt (*Osmerus eperlanus*) traversed the new facility, while just one single individual traversed the older one. The burbot (*Lota lota*) was documented with 3,316 specimen at the double slot pass which equals 15 times more specimens than in the natural-like bypass channel.

However, particularly larger-sized species like the European catfish (*Silurus glanis)*, the ide (*Leuciscus idus)*, the Atlantic salmon (*Salmo salar*), or sea trout *(Salmo trutta f. trutta)* preferred the old fish pass to the new one and twice as many Atlantic salmon traversed the natural-like bypass channel. This phenomenon is also shown by analyzing the three most frequent species on both fish passes. The double slot pass was mostly traversed by the weak species stickleback, river lamprey and bleak, whereas nevertheless two of three species, which belong to species with high swimming performance, became one of the three most frequent species in the natural-like fish pass. The pikeperch (*Sander lucioperca*) is an exception from the larger-sized fish species, because 2,081 specimens, resp. 8 times the number of specimen passes the new facility than the older one.

Table 1. Total number of all detected migrators during the simultaneous monitoring

species	Latin name	double slot pass	natural-like channel	total
stickleback	*Gasterosteus aculeatus*	149,151	1,088	150,239
river lamprey	*Lampetra fluviatilis*	120,012	5,733	125,744
bleak	*Alburnus alburnus*	77,588	17,355	94,943
silver bream	*Blicca bjoerkna*	40,298	9,670	49,968
bream	*Abramis brama*	21,837	7,136	28,973
blue bream	*Abramis ballerus*	4,071	7,915	11,986
smelt	*Osmerus eperlanus*	6,819	1	6,820
eel	*Anguilla anguilla*	1,173	4,830	6,003
roach	*Rutilus rutilus*	4,191	1,397	5,588
burbot	*Lota lota*	3,316	222	3,538
perch	*Perca fluviatilis*	2,392	228	2,620
ide	*Leuciscus idus*	767	1,736	2,503
pikeperch	*Sander lucioperca*	2,081	256	2,337
ruff	*Gymnocephalus cernuus*	1,501	133	1,634
Northern	*Romanogobio belingi*	704	101	805
asp	*Aspius aspius*	129	447	576
barbel	*Barbus barbus*	344	205	549
Atlantic salmon	*Salmo salar*	119	294	413
sea trout	*Salmo trutta f. trutta*	140	226	366
chub	*Squalius cephalus*	189	63	252
lamprey	*Petromyzon marinus*	120	66	186
gudgeon	*Gobio gobio*	96	51	147
nase	*Chondrostoma nasus*	46	42	88
European catfish	*Silurus glanis*	16	38	54
whitefish	*Coregonus oxyrhynchus*	49	0	49
prussian carp.	*Crassius gibelio*	18	25	43
common roach	*Scardinius erythrophthalmus*	23	2	25
dace	*Leuciscus leuciscus*	18	4	22
common carp	*Cyprinus carpio*	5	11	16
vimba	*Vimba vimba*	8	4	12
rainbow trout	*Oncorhynchus mykiss*	7	4	11
brown trout	*Salmo trutta f. fario*	4	6	10
Grass carp	*Ctenopharyngodon idella*	4	2	6
pike	*Esox lucius*	5	0	5
flounder	*Pleuronectes flesus*	0	4	4
prucian carp	*Carassius carassius*	2	2	4
vendace	*Coregonus albula*	3	1	4
Siberian sturgeon	*Acipenser baerii*	2	1	3
tench	*Tinca tinca*	2	0	2
striped bass	*Morone saxatilis x Morone chrysops*	1	1	2
brook charr	*Salvelinus fontinalis*	0	1	1
total number of individuals		**437,250**	**59,301**	**496,551**
total number of species		**38**	**37**	**40**

4.1 Length frequencies

Altogether, 94,943 bleak *(Alburnus alburnus)* were collected at both fish pass facilities (figure 4). With a number of 77,588 specimens, the majority was collected at the double slot fish pass. Curve characteristics showing the fish length frequencies for both fish passes are very similar with a peak at 12 cm. There is no significant difference in the size selectivity equivalent for both fish passes. However, bleaks with a length smaller than 7 cm were recorded only in very small numbers.

A total number of 11,986 blue bream specimens was recorded (figure 5). With 7,915 individuals, the majority traversed the natural-like bypass channel. Blue breams were collected with length classes between 4 and 47 cm. It should be emphasized that the majority of the animals smaller than 30 cm passed the double slot pass, whereas animals longer than 30 cm preferred to pass the natural-like facility.

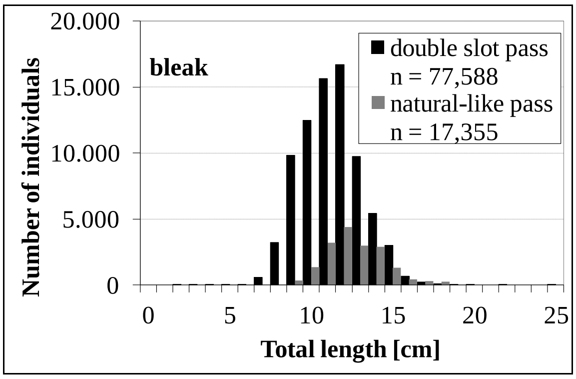


Figure 4. Length frequency of all detected bleak *(Alburnus alburnus)* in comparison of both fish passes in 2011

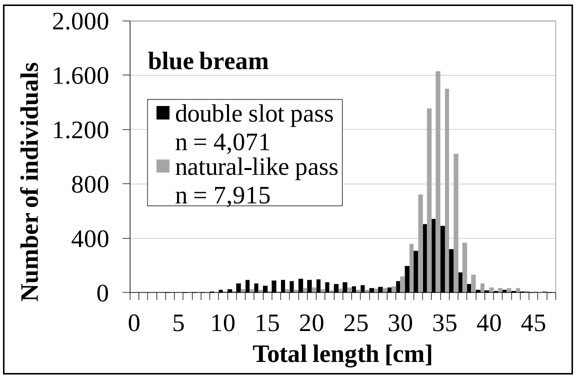


Figure 5. Length frequency of blue bream *(Abramis brama)* in comparison of both fish passes in 2011

During the parallel monitoring in 2011, a total of 413 Atlantic salmon (*Salmo salar*) was collected at both fish pass facilities (figure 6). With a number of 294 specimens, about 3/4 of all salmon used the old fish pass. On the basis of length frequency, different age groups can be determined. Animals with a total length between about 55 and 73 cm can be distinguished as grilse, which spend only one winter in the sea. 2-seawinter-fish are classified with a length between 74 and 100 cm and specimen larger than 100 cm are so called multi-seawinter-fish. However the length frequency gives no indication of the size selectivity equivalent of one of the fish pass facilities.

Altogether, 2,502 ide (*Leuciscus idus*) were documented (figure 7). 1,735 specimens, which amount to a share of 69 %, traversed the old fish pass. The body length of the collected fish was between 3 and 59 cm. One fact is that ides smaller than 15 cm preferred to use the new double slot fish pass, while specimens with body lengths between 15 and 20 cm divide equally between both facilities. However, ides with a total length of more than 30 cm traversed primarily the natural-like fish pass channel with a percentage of 90% of the total catch.

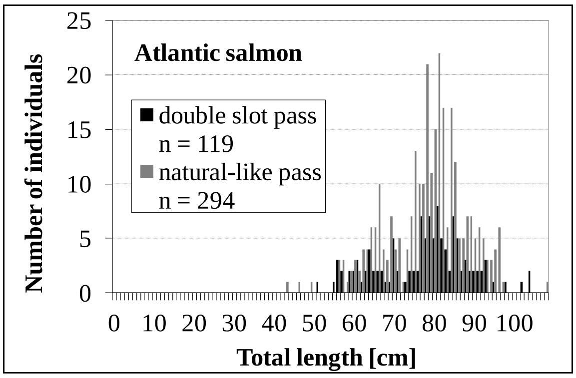


Figure 6. Length frequency of Atlantic salmon *(Salmo salar)* in the comparison of both fish passes in 2011

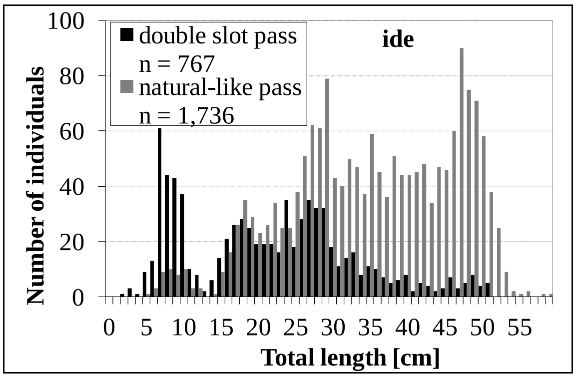


Figure 7. Length frequency of ide *(Leuciscus idus)* in the comparison of both fish passes in 2011

4.2 The influence of water temperature on the upstream migration of fish at both facilities

The course of water temperature at the river Elbe near Geesthacht is presented in figure 8. The days with a simultaneous monitoring at both fish pass facilities are marked by a grey background. The number of monitoring days based on a water temperature interval of 5°C is presented in figure 9. During the periods of water temperatures between 15 and 20°C, parallel monitoring was possible most frequently with a number of 95 days. During periods when the water temperature was lower than 5°C, parallel monitoring at both fish passes took place on 28 days. The results of these days can be ignored, because just single specimens passed the upstream migration facilities.

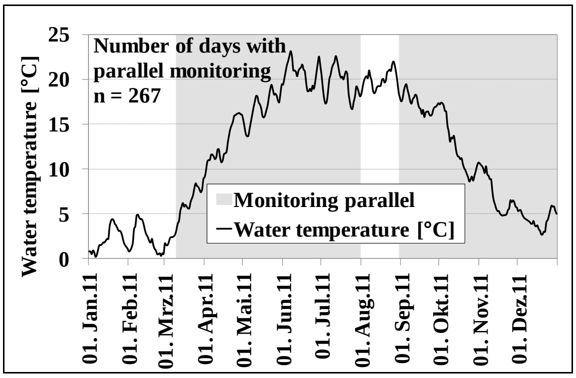


Figure 8. Water temperature of the river Elbe near Geesthacht and periods of a parallel monitoring at both fish passes in 2011

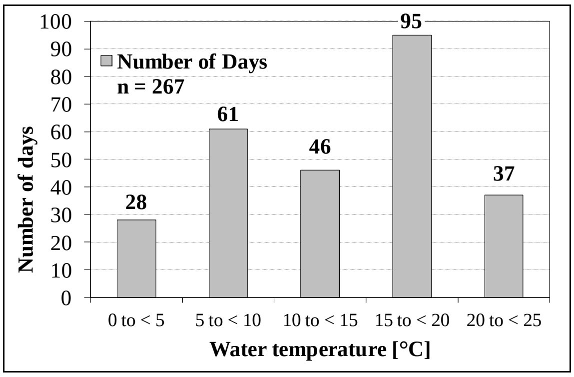


Figure 9. Number of monitoring days during a water temperature less than 5°C

A total number of 1,634 ruff *(Gymnocephalus cernuus)* was counted at both fish passes (figure 10). During the periods of water temperatures between 5 and 20°C, 95% of ruff traversed the fish pass facilities. The number of specimens collected during these temperature intervals is roughly equal. However, at water temperatures higher than 20°C only 62 specimens could be monitored. Figure 11 indicates a clear connection between increasing water temperature and the rising percentage of ruff traversing the natural like bypass channel. 90% of ruff traversed the double slot fish pass on the right bank.

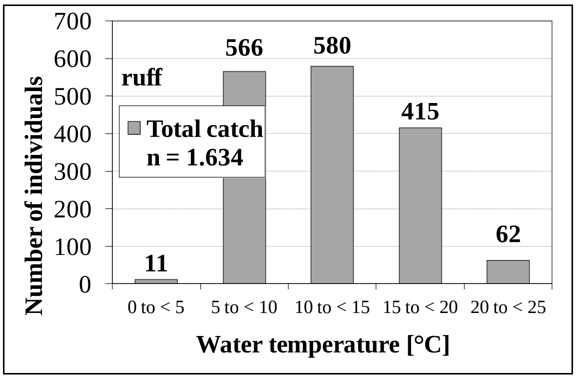


Figure 10: Number of collected ruff (*Gymnocephalus cernuus*) during a water temperature interval between 0 and 25°C

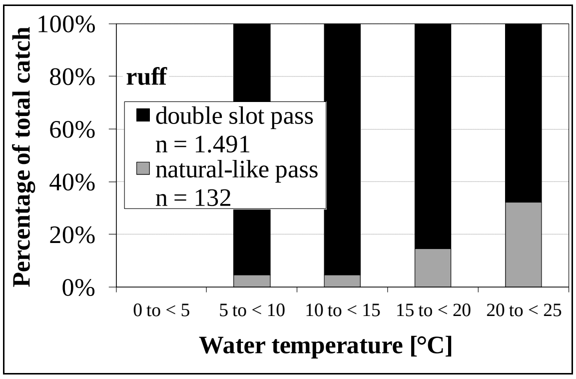
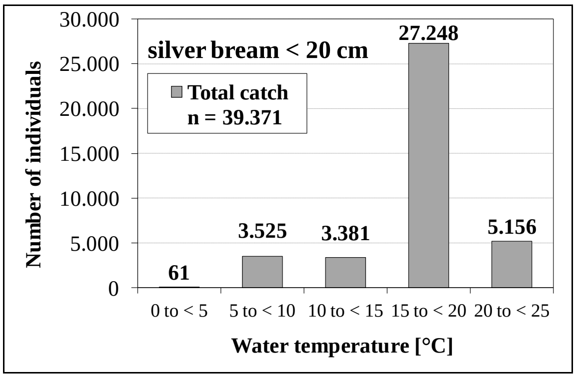


Figure 11: Comparison of the total catch of ruff (*Gymnocephalus cernuus*) on both fish pass facilities in relation to water temperature

A total number of 34,733 silver bream *(Blicca bjoerkna)* was collected at both fish passes. Almost 90 % of them passed the new double slot pass at the right river bank. Figure 12 shows the number of collected silver bream with a length of less than 20 cm while water temperatures between 0 and 25 °C: Most of them passes the double slot pass during periods of water temperatures between 15 and 20°C. As already indicated and with respect to the results of the migration of ruff, the percentage of small silver bream *(Blicca bjoerkna)* (< 20 cm) using the natural-like bypass channel increases with rising water temperature (figure 13). A similar phenomenon can be observed amongst other species, for example bleak *(Alburnus alburnus)* or roach *(Rutilus rutilus)*.



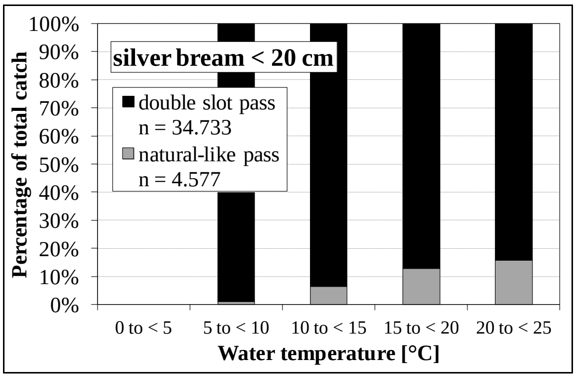


Figure 12: Number of silver bream *(Blicca bjoerkna)* smaller than 20 cm, migrating during a period of water temperature interval between 0 and 25 °C

Figure 13: Comparison of the total catch of silver bream *(Blicca bjoerkna)* smaller than 20 cm at both fish passes in relation to water temperature

5 DISCUSSION

Even a simultaneous long term monitoring was done the question which of the two fish pass constructions is the best, is not easy to answer. Surely the number of 437,250 specimens, which traversed the new double slot pass is much higher than the number of only 59,301 migrators, which used the natural-like bypass channel. But a closer look at the results offers, that several species and/or specific length classes prefer the natural-like fish pass channel. Particularly the relation of specimens with high swimming performance to weaker fish such as juveniles or small sized species shows important disparities:

- The extremely high number of specimens which traversed the double slot fish pass is caused by poor swimmers like stickleback (*Gasterosteus aculeatus)*, bleak (*Alburnus alburnus)*, juvenile silver breams (*Blicca bjoerkna)* and bream (*Abramis brama)* < 20 cm. Furthermore, a huge number of river lamprey (*Lampetra fluviatilis*) preferred the double slot fish pass.
- However, species with a greater swimming capacity show a tendency to prefer the natural-like bypass channel. In particular, this concerns adult blue bream (*Abramis ballerus)*, ide (*Leuciscus idus)*, asp (*Aspius aspius)*, as well as sea trout (*Salmo trutta f. trutta)*, Atlantic salmon (*Salmo salar*) and European catfish *(Siluris glanis)*.
- The three most frequent species traversing the double slot fish pass where poor swimmers, whereas two of the three most frequent species traversing the natural-like bypass channel were species with greater swimming capacity.

These results underline that the number of migrators have to be analyzed species and size-specific to evaluate the functionality of fish passes. The example of Geesthacht points out that there are species like bleak, pikeperch and Atlantic salmon whose length frequency allows no conclusion regarding a potential length selectivity of one of the monitored facilities. However, the natural-like bypass channel shows significant size selectivity against small species and weak juvenile fish. The main reasons for this undoubted severely limited passability of the close to the nature structured facility are the riffle sections with heavy turbulence caused by perturbation boulders [10]. A further proof that flow velocity and turbulences inside the natural-like bypass channel places to high demand on the physical swimming capacity of weak fish is the increasing percentage of successful migrators with rising water temperature: as higher the temperature, as greater the physical ability to pass the channel [11].

On the other hand the length frequencies of ide and asp point out, that just a small percentage of fish larger than 30 cm traverse the double slot fish pass. There is no doubt about that this effect can´t be explained with to narrow dimensions of the construction, which is Europe´s largest facility. In this manner it has to be taken into account, that at the site of Geesthacht the natural-like bypass channel is located at the point bar bank and accordingly optimal connected to the main current in the river. The new double slot fish pass, which had build at the undercut bank in opposite lays apart from the main corridor of the stream. Upstream migrating fish with high swimming capacity usually follow the higher flow velocity of the main current [1]; therefore they can find the natural-like bypass channel more easily due to the more suitable hydraulic conditions in the tailwater of the weir.

6 CONCLUSION

The massive number of fish, especially hundreds of thousands weak species, juveniles and river lamprey traverse successfully the new double slot fish pass at the right bank of the Geesthacht weir, are an undoubtful proof of precise geometric and hydraulic demands for fish passes, which are documented in German guidelines as the state of art. There exists no other fish pass in Germany, not even the natural-like bypass channel on the left river bank, with an approximately high number of migrators from different species and a roughly similarly length size-spectrum. The design of the entrance, the additional discharge over the weir field next to it, and the attracting flow which guides fish independently of the tidal range to the entrance, ensures a reliable traceability. The sturgeon-fitting dimensions, the limited maximum current of 1.5 m/s and the ensuring of a continuous attractive flow path with sufficient current inside this facility, guarantee an efficient passability. However the results of the monitoring indicate that the unfavorable position on the undercut bank cannot be compensated.

On the other hand, without placing the double slot fish pass on the undercut bank, thousands weak swimmers such as juveniles, smaller sized species and river lamprey would have massive problems reach the headwater of the Geesthacht weir. The huge number of migrators (capture. 4) traversing the double slot fish pass at the undercut bank impressively demonstrate that broad rivers like the river Elbe, two fish passes – each at one river bank - are necessary to guarantee the upstream migration past insurmountable obstacles.

Building a technical fish pass at the Geesthacht weir with its specific hydraulic conditions and general navigation requirements was the only possibility to comply consequently the state of art, especially with an optimal entrance situation in the tailwater and an always suitable attraction flow and stream path [1]. But technical constructions are not generally better than so called natural like ones: However, the image of a wild creek-like bypass channel at the Geesthacht weir led to heavy turbulences and high flow velocities. The results of the monitoring demonstrate that poor swimmers have massive problems traversing this facility especially during periods of lower water temperature.

The bottom line of the monitoring results is, that always a site-specific careful consideration has to be done in order to define the most suitable construction type to fulfill the dimensional and hydraulic demands of the site specific fish fauna: Compromises or cuts to the state of the art carry out species- and size-selectivity, whether it's a technical or a natural-like fish pass facility.

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