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Analysis of Fish Migration Potential Through the Seminatural Fish Pass on an Example the Skórka Barrage on the Głomia River

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1. Introduction

River valleys are very valuable landscape elements that, through the formation of ecosystems, create habitats for multiple organisms (Mazur et al. 2016, Walczak et al. 2013). Negligence in their protection can lead to a decrease in the population of some species living there. It is also worth mentioning that inappropriate actions aimed to regulate rivers and facilitate water management may have similar effects (Bombač et al. 2014). For instance, a result of the construction and impoundment of a river with a hydropower plant or water barrage is the interruption of fish migration routes (Marschall et al. 2011, Szoszkiewicz et al. 2016). Facilitating fish passage in fragmented river systems has been commonly focused on commercially important migratory species (e.g. salmonids) (Norrgård et al. 2013) and concerned popular technical solutions (e.g. vertical slot fishway) (Bermúdez et al. 2010, Marriner et al. 2014). Early fishway constructions targeted only a few fish species with strong swimming abilities, such as adult salmonids (Laine et al. 2002), but recent trends are directed at making fishways available for the passage of all species in all life stages (Bunt et al. 2012). The ecosystem-based approaches to river rehabilitation have been increasingly adopted and fishways are progressively being designed for fish assemblages.

From among the various types of fishways, nature-like ones are constructed with boulders, large wooden debris, and riparian vegetation to imitate natural environments, instead of concrete or steel, thus producing hydrodynamic and morphological properties similar to those of natural rivers (Eberstaller et al. 1998, Tymiński and Kałuża 2013). Owing to these characteristics, unlike other fishways, those that are nature-like can be used by fish species with a wide range of sizes and swimming abilities (Calles and Greenberg 2005). Best-suited for the original purpose of fishways, nature-like ones are being constructed across the world in increasing numbers (DVWK 2002, Castro-Santos et al. 2009). In Poland too, nature-like fishways have attracted increasing attention.

These fishways, in contrast to the technical fish passages, are poorer described, and they are more difficult to design and build. Especially untypical solutions make a lot of trouble. The solution is continuous monitoring of fish behaviour in fishways and systematic hydraulic measurements in fish passages (Kim et al. 2016, Kasperek and Wiatkowski 2008, Hämmerling et al. 2016). By regularly monitoring the use of a fishway after its installation, not only its attraction and passage efficiencies can be checked, but useful data for its efficient management can also be obtained to better address fish movement issues (Knaepkens et al. 2006).

The study analysed hydraulic and geometric parameters of the fish pass at the Skórka barrage on the Głomia river in the context of its possible use by aquatic organisms for migration. This study is aimed to obtain accurate data necessary for evaluating the efficiency of a untypical nature-like fishway constructed on a small, lowland river.

2. Materials and methods

2.1. Fish pass efficiency

Technical parameters of a fish pass depend not only on hydraulic conditions of the riverbed, but also on migratory fish species present in a particular river. The key parameters that have to be taken into account to allow a given species pass through to the upper area of the barrage are: flow rate and water velocity, bottom slope of the fish pass, difference in the water level between adjacent chambers, minimum width of slots between chambers, length and width of chambers, minimum water depth.

It is very important to remember that, on the one hand, a fish pass is designed having in mind the requirements for the weakest organisms, and on the other hand – the largest individuals.

2.2. Requirements of fish

In order to systematise the above recommendations guidelines for designing fish passes have been devised. They include the characterization of main species of migratory fish, limiting values of dimensions for chambers and slots, and maximum velocity values that the fish are able to exceed. Depending on the species of fish (DVWK 2002, Mokwa 2010, Zgrabczyński 2007), two groups of different preferences regarding the topology and geometric dimensions of a fish pass are distinguished (Tab. 1).

Table 1. Dimensions of fish pass depending on fish species (DVWK 2002)
Tabela. 1. Wymiary przepławek w zależności od gatunku ryb (DVWK 2002)

Dimensions of fish pass		Grayling, bream, chub and others	
		Brown trout	Huchen, Trout
Slot width	s [m]	0.15-0.17	0.30
Chamber width	b [m]	1.20	1.80
Chamber length	l_b [m]	1.90	2.75-3.00
"Hook" length	c [m]	0.16	0.18
Deflector displacement	a [m]	0.06-0.10	0.14
Deflector width	f [m]	0.16	0.40
Maximal difference water level	Δh [m]	0.20	0.20
Minimum water depth	h_{min} [m]	0.50	0.75
Water flow rates in chambers [a)]	Q [$m^3 \cdot s^{-1}$]	0.14-0.16	0.14
Maximum velocity	v [m/s]	1.50	2.00

2.3. Fish species found in the Głomia river

The biodiversity of species in the Głomia river depends on the section of the river. The greatest biodiversity was observed in the lower section of the river, while the largest number of fish was recorded in the middle of its run. In the Głomia river the most abundantly occurring fish are common roach and European perch, also frequent are Eurasian minnow (*Phoximus phoximus*), riffle minnow (*Alburnoides bipunctatus*), European chub (*Squalis cephalus*), gudgeon (*Gobio gobio*), stone loach (*Barbatula barbatula*) grayling (*Thymallus thymallus*), brown trout (*Salmo trutta fario*) and European bullhead (*Cottus gobio*) (Penczak et al. 2008).

2.4. Research facility

The research facility is located in Wielkopolska, in the district of Złotów, Krajenka (commune), Skórka (locality). The barrage is located on the Głowia river. The barrage "Skórka" consists of four elements: weir, power plant, kayak crossing and fish pass.

The fish pass consists of two sections. Its upper part is a technical pass (Fig. 1b). The fish pass is located directly at the weir and separated with a retaining wall built of reticular-stone gabions. The water inlet (fish outlet) is a reinforced concrete dock structure with a profiled rectangular bed having a bottom width equal to 2.0 m. The technical part of the fish pass consists of three chambers. Then the fish pass becomes a semi-natural structure (Fig. 1a) consisting of 11 chambers with a length of approx. 3.50 m each and a bottom width of approx. 1.50 m. This part of the fish pass built with a 4% slope and a total decrease of 1.60 m and 39.0 m length. Its slots have a width of approximately 0.30 m and are located in baffles of wooden structure. The designed difference in levels of the water level between baffles is 0.15 m, and the depth of water in the fish pass ranges from 0.6 to 0.8 m.

At the design stage it was assumed that the amount of water needed to supply the fish pass was $Q = 0.30\ m^3 \cdot s^{-1}$, and the maximum speed was $v = 1.43\ m \cdot s^{-1}$. The escarpment of the fish pass constructed with a slope of about 1:1.5 is reinforced by grass. The bottom is strengthened with natural stone of different diameters, arranged irregularly. The fish pass at the "Skórka" barrage operates on the whole-year basis.

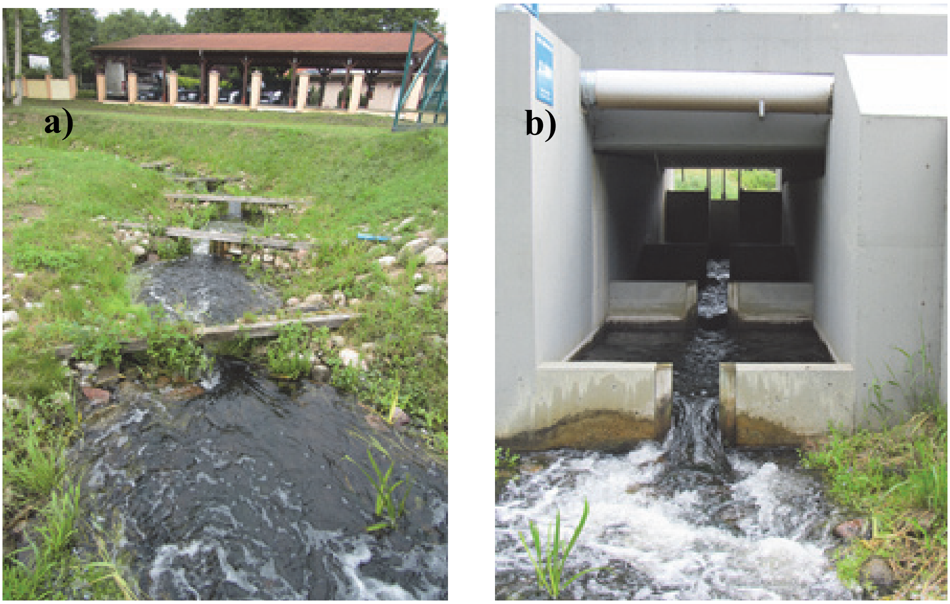

Fig. 1. The seminatural a) and technical b) parts of the fish pass at the Skórka barrage on the Głomia river
Rys. 1. Widok części seminaturalnej a) i technicznej b) przepławki na stopniu wodnym Skórka na rzece Głomi

The study was carried out in 2013 and 2014. The scope of the study included the levelling of the water level topology, velocity measurement in slots between chambers of the fish pass, velocity measurement in chambers of the fish pass and geometry measurement of the fish pass.

The water level results obtained from field tests in 2013 were compared to the theoretical model describing the difference between water levels in chambers of the fish pass:

$$\Delta h = \frac{H}{n+1} \quad (1)$$

where:
Δh – difference in water levels in chambers, m
H – difference in water levels between the inlet and outlet of the fish pass, m
n – number of fish pass chambers.

3. Results

3.1. Levelling and geometry measurement of the fish pass

During field measurements the ordinates of the water level in particular chambers and the differences between them were determined. Water surfaces elevation in 2013 was measured at the discharge Q = 0.096 $m^3 \cdot s^{-1}$ and in 2014 it was measured at the discharge Q = 0.030 $m^3 \cdot s^{-1}$ (table 2).

Table 2. Differences between the ordinates in chambers of the fish pass measured in 2013-2014
Tabela 2. Różnice pomiędzy rzędnymi zwierciadła wody pomierzonymi w komorach przepławki w latach 2013-2014

Number of chambers	Differences between ordinates in chambers	
	2013	2014
	Δh [m]	Δh [m]
1	–	–
2	0.110	0.012
3	0.015	0.030
4	0.015	0.020
5	0.028	0.020
6	0.027	0.010
7	0.070	0.100
8	0.004	0.060
9	0.091	0.100
10	0.060	0.080
11	0.132	0.100
12	0.266	0.270
13	–	0.230
14	–	0.060
15	–	0.180

The results obtained from levelling and geometry measurements are shown schematically in Figure 2. The above figure illustrates an uneven distribution of the water level topology in the fish pass. The water table measurements in the fish pass system were performed twice.

The greatest difference in water levels in 2013 was 0.266 m between chambers 10 and 11, and the smallest difference was between chambers 6 and 7, and reached the value 0.004 m. In 2014, the smallest difference between the water level was noted between chambers 4/5 and was 0.01, while the greatest one was 0.27 m between chambers 10 and 11. Significant differences in the water level between chambers 10 and 11 result from a steep slope of the fish pass bottom.

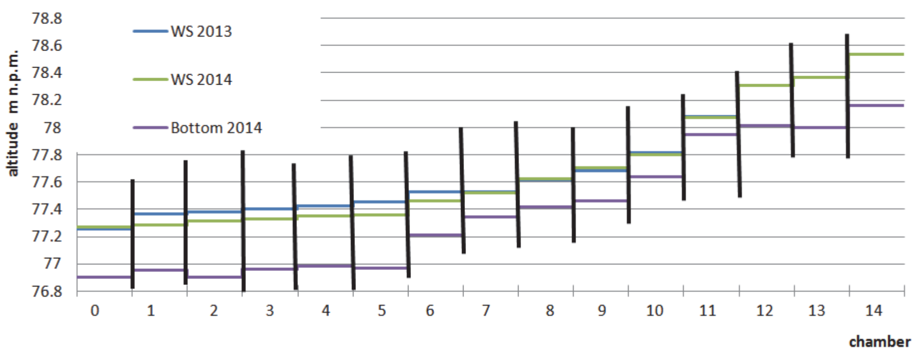

Fig. 2. Diagram of the water level topology of the fish pass semi-natural part in 2013 - 2014

Rys. 2. Schemat układu zwierciadła wody w części seminaturalnej przepławki w latach 2013 - 2014.

The differences between water levels in the chambers obtained from field research in 2013 were compared to the theoretical model describing the difference between water levels in chambers of the fish pass:

$$\Delta h = \frac{78.416 - 77.258}{15+1} = 0.072 \text{ m} \quad (2)$$

In the case of the analysed fish pass, the above formula (1) allows calculating an average difference in the water level between individual chambers, which does not exceed the limit value and amounts to 0.072 m (in 2013), and 0.066 m (in 2014).

3.2. Measurement of the water flow rate

On the basis of the water flow rate results obtained in the field measurements, the velocity curves were drawn for particular vertical measurement points. Because of low water levels in the fish pass chambers, the analysis of vertical velocity distribution of flow rate was often based on measurements at 2-3 measuring points, assuming that at the bottom the flow rate was zero. From the point of view of fish migration possibility, the maximum values of flow rate are important. The results of examples flow velocity rate measurements in the fish pass (at the fish pass inlet and in chamber 6 – vertical measurement points on the left and right sides at a distance of 0.5 m from the central vertical measurement point) are presented below in Table 3. The flow rate analysis carried out in chamber 6 showed that the migration conditions were favourable even for the weakest individuals present in the river.

Table 3. Compilation of water flow rate measurements in the fish pass
Tabela 3. Zestawienie wyników pomiarów prędkości przepływu wody w przepławce

Measurement point in chamber 6 in 2013	Velocity [$m \cdot s^{-1}$]
The left vertical	0.14
The middle vertical	0.57
The right vertical	0.41

Table 4 presents the velocity values in the fish pass at all vertical points of measurement.

Table 4. Average water velocity values in the fish pass (no data available)
Tabela 4. Średnie prędkości przepływu wody w przepławce (brak danych)

No.	Section	Mean velocity 2013 year	Mean velocity 2014 year	Maximum velocity 2014 year
		$m \cdot s^{-1}$	$m \cdot s^{-1}$	$m \cdot s^{-1}$
1.	1.7 m down from partitions 1	No data available	0.06	0.18
2.	partitions 1	–	0.19	0.29
3.	partitions "2"	–	0.29	0.36
4.	partitions "3"	–	0.30	0.36
5.	partitions "4"	–	0.36	0.45
6.	partitions "5"	–	–	–
7.	partitions "6"	1.16	0.40	0.63

Table 4. cont.
Tabela 4. cd.

No.	Section	Mean velocity 2013 year	Mean velocity 2014 year	Maximum velocity 2014 year
		$m\cdot s^{-1}$	$m\cdot s^{-1}$	$m\cdot s^{-1}$
8.	partitions "7"	0.79	–	–
9.	partitions "8"	–	0.463	0.76
10.	partitions "9"	–	–	–
11.	partitions "10"	–	0.47	0.63
12.	outlet part of the concrete	0.36	0.31	0.41
13.	inlet part of the concrete	1.74	1.61	2.70

The average water velocity at the vertical point of the technical part outlet was 0.31 $m\cdot s^{-1}$, and the maximum value was 0.41 $m\cdot s^{-1}$. The average water velocity the vertical point of the concrete part outlet of the fish pass, due to its compact size, was 1.61 $m\cdot s^{-1}$ and the maximum was 2.70 $m\cdot s^{-1}$. These velocities far exceed the limit values, which may hinder fish migration.

4. Discussion

The principles of good design of fish passes have been established assuming that a fish pass should be efficient at all water levels enabling fish migration. Other additional conditions ensuring the optimal work of the fish pass should also be met, such as: proper filling, not exceeded velocity values admissible in slots and creation of an alluring stream in the lower area of the fish pass. Fish pass efficiency tests should be accompanied by some geometry measurements, and then compared to standards contained in DVWK (2002). According to the field tests, the chamber length varies from 3.08 m to 4.73 m, while the slot width in baffles changes from 0.2 m to 0.35 m. The total length of the semi-natural part of the fish pass is 39.87 m. The geometrical dimensions of chambers and slots provide the possibility of migration to all organisms present in the Głomia river.

The analysed fish pass within the Skórka barrage on the Głomia river is effective but to certain limits. Because of different slopes of the bottom for which the fish pass was designed and constructed, the conditions of water flow during the vegetation season in multiple locations constitute a serious impediment to fish. The most unfavourable conditions are present at the interface between the technical and semi-natural part of the fish pass because the maximum difference in water elevations between the chambers is up 20 cm. For example, due to the differences between the ordinates in chamber 12 where Δh is up 27 cm, migration of small specimens can be significantly impeded (Marriner et al. 2014). This level difference also exceeds the recommendations of DVWK (2002). In contrast, in the semi-natural part of the fish pass the level differences are very small (in the order of a few centimetres). This translates into low flow velocities and no luring current.

The water velocities at slots are within the accepted range. The maximum water velocity at all studied points in semi-natural structure does not exceed 0.8 $m \cdot s^{-1}$. The flow rate right at the inlet to the concrete part of the fish pass is equal to 2.7 $m \cdot s^{-1}$, which makes an insurmountable barrier for most fish that use the fish pass. Similar problems have been studied by Bartnik et al. (2010) and Wierzbicki (2013). A separate issue is to provide an alluring stream in the lower area of the fish pass, where the fish pass joins the river. Based on observations and velocity measurements carried out in this area, the fish pass is hardly tempting to fish as the average water velocity value is there approx. 0.3 $m \cdot s^{-1}$. The stream of water flowing out of the fish pass cannot perish in the stream of the river, i.e. the water velocity in the fish pass should be much higher than in the river (alluring stream). The impact of alluring stream has been also considered by Bartnik et al. (2010) and Wyżga et al. (2014). Bartnik has shown the results of numerical modelling of 400-meter part of a river that includes coated weir, small hydroelectric power station and a fish pass. The action taken concentrated on such a formation of the water discharge in the ladder and modification of the bed configuration in the hydromouth that would make an alluring stream. Similarly as for the Skórka Barrage, the study by Bartnik et al. (2010) have shown that the velocity of water flowing out of the fish pass depends on the water velocity in the pass but also on the conditions of water movement in the main river bed.

The problem of semi-natural fish pass is to prepare a good project and its correct implementation (Zgrabczyński 2007). Another issue are the exploitation problems. The reason for such high water velocity rate may be the fact that on the day of field measurements (07.09.2014) the valve regulating water supply to the fish pass at the upper area of the barrage was lowered to 0.10 m. With the valve being almost closed, it contributes to the phenomenon of water throttling. Therefore, high velocities are being generated preventing the fish from passing through the barrage. The measurements in 2013 indicate that water velocity values at the inlet slot exceeded the value admissible for the Trout family (Brown trout), which according to Mokwa (2010) is 1.5 $m \cdot s^{-1}$. Functionality of the fish pass would improve if the valve at the fish pass inlet was larger. This would result in reduction of water flow rate at the inlet, increase in the water level, as well as increase in depth and flow rate of the fish pass.

5. Summary

Analysis of the results of field measurements carried out in 2013 and 2014, has shown that the designed flow rate is not ensured during use. Increase in the flow rate would result in increase in the depth of water in the fish pass thereby increasing its water t ordinates and deepening the fish pass. The analysis of field data has indicated that differences in the water level between chambers are not significant except for the difference between chambers 10 and 11. The averaged difference between water levels in individual chambers is approx. 7 cm respectively. Analysis of geometry of the fish pass has indicated that all organisms present in the river may migrate if the opening of the inlet valve is larger. On the basis of the analyses it can be concluded that velocity values in the fish pass according to 2014 measurements oscillate within values that allow the free fish migration. The maximum velocity takes values allowing fish migration over the entire depth of tested hydrometric points.

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Analiza możliwości migracji ryb przez przepławkę seminaturalną na przykładzie stopnia wodnego Skórka na rzece Głomii

Streszczenie

Gospodarowanie wodą poprzez m.in. piętrzenie rzek powoduje zmiany w środowisku przyrodniczym. Jedną z nich jest ograniczenie możliwości migracji ryb i innych organizmów wodnych. W celu ułatwienia ich przemieszania buduje się przepławki. W pracy przedstawiono wyniki badań terenowych dotyczących parametrów hydraulicznych przepławki dla ryb zlokalizowanej w obrębie stopnia wodnego Skórka na rzece Głomii. Celem badań było rozpoznanie warunków przepływu wody w poszczególnych komorach przepławki seminaturalnej. Na podstawie wyników badań terenowych określono warunki hydrauliczne przepływu wody przez przepławkę, odnosząc uzyskane rezultaty do optymalnych parametrów pracy przepławki. Uzyskane wyniki stanowią podstawę do dyskusji na temat możliwych problemów budowy i eksploatacji „bliskich naturze” konstrukcji przepławek dla ryb.

Abstract

Water management by artificial water level increasing in rivers, results in environmental changes. One of them is the constraint on migration of fish and other aquatic organisms. In order to facilitate the passage, fish passes are built. The study analysed many parameters related to proper work of the fish pass. The article presents results of a field study of the fish pass located within the Skórka barrage on the Głomia river. The aim of the study was to identify water flow conditions in particular chambers of the fish pass. On the basis of results of the field study, the hydraulic conditions of water flow through the fish pass were determined and referred to the optimum performance parameters of the construction. The results obtained make a basis for discussion of possible problems related to construction and operation of the fish passes resembling „close to nature” structures.

Słowa kluczowe:
seminaturalna przepławka dla ryb, pomiary terenowe, rzeka Głomia

Keywords:
semi-natural fish pass, field measurement, Głomia river