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A low cost, flood-resistant weir to monitor fish migration in small- and medium-sized rivers

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A reliable method to count migrating fish at different sites was required within a Danube-tributary system in Austria to assess the efficiency of connectivity measures (Zitek, Schmutz & Jungwirth 2008). Fish needed to be monitored over a maximum time frame of about 4 months per site during their spring/summer spawning migrations, when flood events are expected in Austrian rivers. Due to a high number of different monitoring sites distributed over the whole project area, and expected debris and wood-loaded high floods, a low cost and flood-resistant highly transportable, modular weir for counting migrating fish was developed (Mühlbauer, Traxler, Zitek & Schmutz 2003). The construction was based on the concept of the resistance board weir (Tobin 1994; Stewart 2002), which is an alternative to other weir types, e.g. portable rigid weirs, and has been typically used in Alaskan rivers (Holmes 1992). Portable rigid weirs are usually made of wood or metal, but are vulnerable to washout and downstream losses during high water periods (Anderson & McDonald 1978; Clay 1995). In contrast, resistance board weirs temporarily submerge when pressure created by water volume and debris loading reaches a point that might wash a rigid weir downstream, so demolition and washout are generally avoided. Unfortunately, existing resistance board weir constructions are complex and expensive (Tobin 1994; Stewart 2002). This paper describes a simple design and construction that overcomes these limitations.

The system developed consists of panels and traps built in a modular design providing flexibility. The weir consists of a linked array of picket-fence-like panels made of PVC tubes closed at both ends by commercially available end caps. The upstream end of each panel is fixed to concrete lattice girders at the river bottom by shackles mounted on the lowest transverse PVC tube by synthetic ropes; the downstream end is lifted above the water surface by Styrofoam floats (Fig. 1a, b). Lattice girders are anchored in the substratum across the whole river cross section using iron pins (Ø 2 cm) at approximately 1-m spacings.

Two sizes of weir panels were constructed, one with 1-cm and one with 2-cm spacing, 6 and 3 m long, respectively. The weir panels are constructed from rectangular PVC tubes with regularly spaced drill holes through which tubes are pushed and glued to form a picket-type fence. Each panel consists of 29 pickets (Ø 2.5 cm, 2-cm spacing) or 43 pickets (Ø 2 cm, 1-cm spacing) and has a width of about 130 cm. Transverse PVC pipes/tubes have diameters of 40 and 50 mm. Styrofoam floats (120 × 20 × 10 cm) are fixed at the

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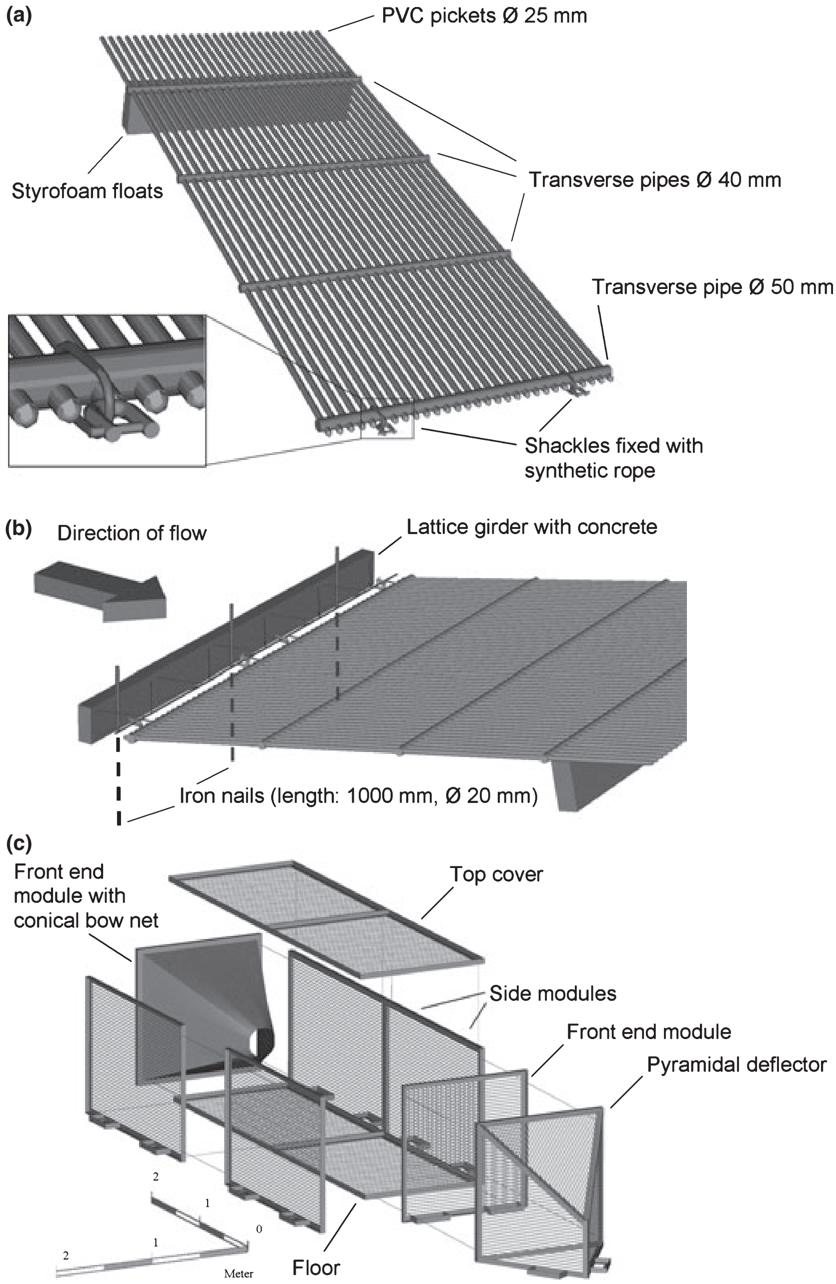

Figure 1. Construction details of the flood resistant weir and trap system with details on panel construction (a), fixation of the panels to the concrete lattice girders anchored to the river bottom (b) and the modular trap design (c).

downstream end of each panel which float the panels on the surface even in situations, when the increased water level causes back eddies with a loss of flow velocity. The panels are linked with rubber cords to maintain flexibility in construction. A bulkhead is installed on each shoreline to allow the adjacent panel to move up and down with falling and rising water levels. Unwanted fish passage at these bulkheads is avoided by fixing synthetic fibre brushes on the left and right panel-ends. Fish passage between the bulkhead and the shoreline is further prevented by a rigid 1.5-cm mesh plastic fence. In addition, sandbags are used to fix holes in the construction and to repair washout of substrate. The traps provide the only opportunity for fish to migrate up- or downstream. They are constructed in a modular way and equipped either with a

1- or 2-cm lattice spacing created by horizontal iron staves (Ø 0.8 cm) (Fig. 1c). Side modules are 1.3 m high and 2 m long, and front end modules a size of 1.3 × 1.3 m. One of the front modules is equipped with a 1-cm mesh conical bow net directing the fish into the trap. Floor and top covers (1.2 × 2 m) are made of L-sections and iron lattice (15 × 15 cm) and covered by a 1-cm mesh plastic fence. A pyramidal deflector is positioned at the upstream side of the trap to avoid accumulation of large woody debris and demolition of the trap. Finally a 1-cm mesh net or some upright weir panels are used to close the gaps between the weir panels and the trap on both sides of the trap. The entrances of the traps are positioned around the expected migration pathways of fish to minimise delays to migration. The modular design of the trap allows for easy handling and flexibility, and the length of each trap can be easily changed. Fish are removed by entering the trap and capturing them with a hand net, preferably with a net having approximately the width of the trap to facilitate emptying the trap. The trap was found to be not effective for capturing downstream migrants, but capture was improved by fixing a conical fyke net to some lowered panels.

The design of the panel length and picket spacing at specific river sites depends upon the volume of water that must pass through the fence without submerging it. The differential head between upstream and downstream of the weir, or head loss (Clay 1995), was used to calculate the potential discharge transported through the weir without submerging it (Mühlbauer *et al.* 2003). The discharge capacity of a specific weir can be related to the hydrology of the river to determine the approximate time of year when a weir will be submerged. Suitable sites for a resistance board weir should be uniform, relatively shallow, river cross sections with depths around 50–100 cm, and stable substrate. A minimum water depth of 50 cm is required to avoid escapement of bottom orientated fishes from the traps and to provide enough space in the traps. The maximum depth of 1 m limits the possibility of a simple installation of the weir. Laminar flow is important and only a small amount of angular flow is tolerable. Ideally, flow should be evenly distributed over the total river width, avoiding excessive pressure on individual parts of the weir.

The installation of a 27-m long weir with panels of 3 m length and two traps was done by four persons within 3 days, and dismantling by four persons at 1 day. The estimated cost (2003 prices) of materials was approximately 3500€ for a 27-m long weir (2-cm picket spacing, 3 m panel length) and two traps (each with a length of 4 m).

The life of the construction is relatively high because of the use of durable materials and its resistance to floods, allowing for both a long-term deployment and repeated deployment of the same weir at different sites. The use of cheap materials, the low maintenance needs and its resistance to floods keep the total costs low. The weir was found to be widely resistant to washout and virtually self-cleaning during increased water levels. Several high flood events proved the construction to be resistant against downstream loss, although manual cleaning of the device was needed after each flood to remove sediment and debris from the panels. Cleaning at lower water levels, when woody debris and other materials accumulated at the lower end of the panels, was done by submerging the panels at their downstream end with a hand or a foot, sometimes with the aid of a rake. However, for successful application of the system and to guarantee migrating fish pass through the traps requires constant service, and washout of substrate should be compensated regularly by sand bags.

The main advantage of the weir, beside its flood resistance and transportability, is its flexibility of use. It provides an relatively inexpensive and flexible way to monitor fish movements in certain different types of streams and can be used to cover small to medium-sized rivers with widths > 20 m, but might also be used in relatively narrow situations, e.g. at natural fish ladders, especially nature-like rock ramps and natural bypass channels. Furthermore, the system allows the temporal deployment at multiple sites and can be used by a small number of persons to monitor a large number of stream sites simultaneously. The construction has been successfully deployed at about 20 sites in Austria and Germany, and data on a total catch of 15 952 fish of 46 species from 14 sites (11 sites with 1-cm spacing, and at three sites with 2-cm spacing) were available for analysis (Table 1). Highest numbers of species and individuals were typically captured at sites near river mouths with low distances from source populations in the downstream habitats. Barbel, *Barbus barbus* (L.), and nase, *Chondrostoma nasus* (L.) were the most abundant species caught (Table 2). Typical small-sized species like bleak, *Alburnus alburnus* (L.), bullhead, *Cottus gobio* L., gudgeon, *Gobio gobio* (L.), and spirlin, *Alburnoides bipunctatus* (Bloch) and juveniles of other species < 150–200 mm were primarily caught with traps with 1-cm spacing, whereas a certain proportion of fish with sizes below 100 mm could have also entered the trap from upstream through the 1-cm iron lattice. A spacing of 2 cm only allowed capture of fish exceeding 150–200 mm long (Table 2). This is in accordance with Holzner (2000)

Table 1. Description of sites and information about deployment of the weir

Site ID	River	MAF (m^3 s^{-1})	Situation of the trap	Distance from mouth (km)	Date of deployment	Spacing of weir pickets (cm)	No. days deployed	No. species	No. individuals	No. individuals per day	Data and information source
1	Pielach	12.2	River mouth/main channel	0.2	02/04–14/07/2001, 15/02–27/06/2002	2	237	26	7083	29.9	Mühlbauer & Traxler (2002); Tscharnuter & Pichler (2003); Zitek *et al*. (2004, 2008)
2	Pielach	12.2	Nature like bypass channel	1.6	30/09–17/10/2002, 05/03–04/07/2003, 11/03–24/06/2004	1	246	17	375	1.5	Köck & Schreyer (2004); Zitek *et al*. (2004, 2008)
3	Pielach	12.2	Nature like rock ramp/ main channel	5.5	27/03–23/06/2003	2	89	12	189	2.1	Köck & Schreyer (2004); Zitek *et al*. (2004, 2008)
4	Pielach	12.0	Nature like bypass channel	8.3	06/06–26/06/2003	1	21	8	60	2.9	Köck & Schreyer (2004); Zitek *et al*. (2004, 2008)
5	Pielach	8.9	Nature like bypass channel	17.5	03/04–07/06/2002	1	66	9	51	0.8	Tscharnuter & Pichler (2003); Zitek *et al*. (2004)
6	Pielach	8.9	Main channel	17.5	03/04–07/06/2002	1	66	5	275	4.2	Tscharnuter & Pichler (2003); Zitek *et al*. (2004)
7	Melk	2.5	Nature like rock ramp	0.2	07/03–26/06/2003	1	112	33	2092	18.7	Köck & Schreyer (2004); Zitek *et al*. (2004, 2008)
8	Melk	2.5	Main channel	2.0	23/02–07/06/2002	1	105	19	583	5.6	Tscharnuter & Pichler (2003)
9	Melk	2.5	Nature like rock ramp, main channel	7.0	29/05–09/07/2001	1	42	14	115	2.7	Mühlbauer & Traxler (2002); Zitek *et al*. (2004, 2008)
10	Melk	2.5	Pool type fish pass	9.5	19/04–22/06/2003	1	65	15	352	5.6	Köck & Schreyer (2004); Zitek *et al*. (2004, 2008)
11	Melk	2.5	Nature like rock ramp, main channel	12.2	18/05–09/07/2001	1	53	10	71	1.3	Mühlbauer & Traxler (2002); Zitek *et al*. (2004, 2008)
12	Mank	1.6	Nature like rock ramp, main channel	20.0	28/03–14/06/2003	1	79	9	38	0.5	Köck & Schreyer (2004); Zitek *et al*. (2004)
13	Große Tulln	1.2	Nature like rock ramp, main channel	8.0	13/03–13/06/2007	1	93	12	562	6.0	Pinka & Eberstaller (2008)
14	Mondsee Ache	9.2	Main channel	0.1	16/04–16/06/2004	2	62	18	4106	66.2	Siligato & Gumpinger (2005)

Table 2. Total number of fish captured at the 14 sites described in Table 1 for the most abundant species according to 50 mm total length (TL) classes, divided into fish captured with 1- and 2-cm spacing (S) (Ab-br, *Abramis brama*; Al-al, *Alburnus alburnus*; Ba-ba, *Barbus barbus*; Bl-bj, *Blicca bjoerkna*; Ch-ch, *Chalcalburnus chalcoides*; Ch-na, *Chondrostoma nasus;* Co-go, *Cottus gobio*; Hu-hu, *Hucho hucho*; Le-ce, *Leuciscus cephalus*; Le-le, *Leuciscus leuciscus*; Pe-fl, *Perca fluviatilis*; *Rutilus meidingerii*; Ru-ru, *Rutilus rutilus*; Sa-tr, *Salmo trutta*; Th-th, *Thymallus thymallus*; Vi-vi, *Vimba vimba*; Zi-zi, *Zingel zingel*)

TL (mm)	Ab-br		Al-al		Al-bi		Ba-ba		Bl-bj		Ch-ch	Ch-na		Co-go		Go-go		Hu-hu		Le-ce		Le-le		Pe-fl		Ru-me	Ru-ru		Sa-tr		Th-th		Vi-vi		Zi-zi		Total (*N*)		Total (%)	
S (cm)	1	2	1	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
0–49														3		1				4																	8		0.2	
50–99			1		85		9							51	1	23				27		1		4	1		3		2				4				210	2	4.9	0.02
100–149			117	2	128	4	8	1	8		1	20		17		203	6	1		26	1	14	1	24	19		51		2		1	3	1				621	38	14.4	0.3
150–199			475		2		26	9	42		357	56	2			2		9		59	9	120	30	20	18		54	10	5	2	22	24	1	1			893	462	20.7	4.1
200–249	2		12				25	7	37		1351	49	3					4		76	18	73	26	10	6		12	10	12	1	20	6	4	1	8	73	344	1502	8.0	13.5
250–299	3	2	1				37	47	17	3	33	10	1					1		36	25	11	17	1	3		2	4	8	7	3	4	2	7	3	29	135	182	3.1	1.6
300–349		2					65	150	4	2	1	4								17	36			1					17	13	1	7	1	23		8	110	242	2.5	2.2
350–399	11	5					96	288	1			4	10							23	61								2	17	4	3	4	11		1	145	396	3.4	3.6
400–449	60	18					210	996		1		32	144							40	76					1				3	2	2	7	1			351	1242	8.1	11.1
450–499	83	11					452	2007				84	471							28	112					27							9				656	2628	15.2	23.6
500–549	58	4					354	1082				19	91							9	45					1536			1				2				443	2758	10.3	24.7
550–599	14	3					249	858											1	1	8					405											264	1275	6.1	11.4
600–649							120	371										1	2							16											121	389	2.8	3.5
650–699							15	27										1								1											16	28	0.4	0.3
700–749								1										1	2																		1	3		0.03
750–799																			2																			2		0.02
800–849																			1																			1		0.01
850–899																			1																			1		0.01
900–949																																								
950–999																																								
1000–1049																			1																			1		0.01
> 1050																																								
Total	231	45	606	2	215	4	1666	5844	109	6	1743	278	722	71	1	229	6	18	10	346	391	219	74	60	47	1986	122	24	49	43	53	49	35	44	11	111	4318	11152	100	100

who described that bream, *Abramis brama* (L.), >205 mm, barbel >185 mm, chub, *Leuciscus cephalus* (L.), >170 mm, nase >170 mm, and roach, *Rutilus rutilus* (L.), >175 mm might be prevented from entering a hydropower turbine by a bar rack with 2-cm bar spacing, whereas smaller individuals might have to pass.

Catch efficiency of the traps in combination with the weir was generally high (assessed via visual observations and electric fishing below the weir), and more fish species were documented with the described trap system than by electric fishing (Zitek *et al.* 2008). However, some species seemed to be behaviourally impeded by the weir or did not enter the trap for other reasons. For example, spawning activity of barbel and nase was observed at suitable habitats below the weir at two monitoring sites. Some species, like chub and barbel, used the weir panels as cover. This species-specific behaviour to weirs needs further study. Using multiple traps at wider river sections or traps with wider entrance situations might reduce this problem. Increased water levels lead to larger numbers of fish in the traps, as long as the construction does not allow fish to pass at other places on the weir. The maximum numbers of fish caught at any one time in a 4-m long, 1.2-m wide trap at a water depth of 70 cm were around 400 barbel with a size range of 275–650 mm ranging from 0.18 to 2.3 kg, and about 320 *Rutilus meidingerii* (Heckel 1851) with a size range of 495–630 mm with weight between 0.95 and 2.2 kg. The largest fish captured was a pike, *Esox lucius* L., 1 m long and 7.2 kg weight, a carp, *Cyprinus carpio* L., 0.84 m long and 10.5 kg weight and a Danube salmon, *Hucho hucho* (L.) 1.05 m long and a weight of 12.6 kg.

As a result of its flexibility and high capture efficiency for a wide range of species, the system is increasingly being used for fish migration studies in Austria and Germany, and has great potential to become an important tool for monitoring fish migrations.

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