MOKSLAS – LIETUVOS ATEITIS 2009, 1 tomas, Nr. 4
SCIENCE – FUTURE OF LITHUANIA 2009, Vol. 1, No. 4

Aplinkos apsaugos inžinerija
Environmental Protection Engineering

IMPACT OF SMALL HYDRO-POWER PLANTS ON SALMONID FISHES SPAWNING MIGRATIONS

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Abstract. In 2000 and 2005, fish ladders were built in Vilnia and Siesartis rivers providing fish access to another 10 and 25 km of the rivers respectively. The analysis of redd distribution and abundance in both rivers revealed that the construction of fish ladders significantly increased the number and share of redds above dams, however, a significant increase in redds above the dam occurred 2-4 years after fish ladders construction supporting homing behaviour as one of the most important factors for the recolonization of the newly accessible habitats. The tracking of radio tagged salmon and sea trout revealed that statistically, significantly more time, fishes spent in the middle part of fish ladders. Assessed fish ladders efficiency for migrating salmonids made 66 %. Minor construction defects and lack of protection were the main factors reducing fishway efficiency. Based on radio tracking data, recommendations are given for minor changes in fish ladders construction and operating schedule to increase the efficiency of fish ladders.

Keywords: radio telemetry, fish ladders, Baltic salmon, Sea trout.

Introduction

The development of renewable energy – particularly energy from wind, water, solar power and biomass – is a central aim of the European Commission's energy policy. The main reason is to reduce Carbon Dioxide (CO_2) emissions, enhance sustainability and improve the security of energy supply by reducing Community's growing dependence on imported energy sources. Therefore, the development of various sources of renewable energy has substantially increased over the recent years. However, there are many risks involved with developing hydropower plants. Due to the effects of global warming, change in precipitation pattern posses a great threat to any projects as decreased stream and river flows can threaten hydroenergy resources. The other 'side effect' of hydropower projects is a negative impact on the river ecosystems, especially for migratory fishes. The hydropower industry has, since the early 1900s, radically altered the longitudinal connectivity of many ecosystems in running waters precluding migrations of many different aquatic organisms. Longitudinal movements along rivers are crucial for the life cycles of many diadromous fish species (Lucas, Baras 2001), e.g. Atlantic salmon (*Salmo salar* L.), sea trout (*Salmo trutta* L.), Baltic vimba (*Vimba vimba* L.) and European eel (*Anguilla anguilla* L.) (Backiel, Bontemps 1996; Cowx, Welcomme 1998; Lucas Baras 2001; Northcote 1998). The underlying reasons for these movements are generally associated with shifts to areas with better conditions for growth, survival and reproduction (Northcote 1998). Even if fish pass turbines, they can be seriously injured or killed. Therefore, the development of small hydropower plants in Lithuania triggers fierce discussions among the environmentalists and supporters of small hydropower plants as the use of the energy potential of Lithuanian rivers is low and mainly restricted by environmental regulations (Jablonskis *et al.* 2007).

Anadromous and catadromous fish species in Lithuania are among the most valuable economically and very popular angling catch. Particularly these migratory fishes were most dramatically affected by human activity in the past centuries (Turner 1990) and the main impact was the construction of dam that completely or partially affected the majority of migration routes in Lithuania (Kesminas *et al*. 2000; Lietuvininkas 2001). According to historical data, the construction of Kaunas hydropower plant on the main Lithuanian river Nemunas in 1949 decreased a total area of the natural spawning grounds of salmon and sea trout by half and by 70 % for vimba (Žiliukas 2006).

On 16th January 2003, due to the drastically decreased populations of migratory fishes, Environmental and Agriculture Ministries issued an order to prevent and protect the routes of migratory fishes in Lithuanian rivers. A recent list contains 169 rivers of ecological and/or cultural heritage. However, in Lithuania, the hydroenergy potential of the above mentioned rivers could be as high as 128.1 mln. kWh (Jablonskis *et al.* 2007), and therefore this fact is widely used as the main argument put forward by hydropower supporters.

Though a negative impact of small hydropower plants on migratory fishes is obvious, however, studies on long term adaptation and changes in migration and spawning patterns together with studies on possible mitigation measures have been absent in Lithuania.

The current study reveals changes in spawning grounds distribution influenced by the impact of dams. Short and long term effects of fish ladders, their efficiency and the major defects of construction and design are also discussed in the present study as despite substantial economic investments in constructing fish ways, the functionality of those is rarely evaluated (Calles, Greenberg 2005).

Study area, Material and Methods

Studies on salmon and sea trout redds were performed at the very end of salmonid spawning season (October – December) for the best possible assessment of salmonid nests (Moir *et al.* 2002). The monitoring of salmonid redds was carried in the Vilnia River and the Siesartis River in 2005–2008. Both rivers are very similar: the Vilnia River (the left tributary of the Neris River, river length – 79,6 km, the average annual water yield – 5,63 m^3/s) and the Siesartis River (the left tributary of the Šventoji, river length – 64,1 km, the average annual water yield – 5,13 m^3/s) (Gailiušis 2000). Those two rivers were chosen because of constructing dams ceasing migration routes for migrating salmonids, however, later constructed fish ladders in both rivers benefited for the partial reoccupation of upstream spawning grounds. In the Vilnia River, fish ladders were constructed in 2000 and in the Siesartis in 2005. Before, Siesartis dam was too high to pass and partially ruined dams in the Vilnia River were hardly suitable to passage for adult salmonids. To assess the impact of fish ladders on salmonid redd distribution and the abundance total number and occupied area of redds, mean per 1 km of the same monitoring river stretch together with the average redd size were compared downstream and upstream from the constructed fish ladders in both rivers.

The assessment of redds was undertaken visually using polarised glasses. Spawning ground measurements were undertaken with the accuracy of 0.1 meter. Redds were determined as a raised mound of clean gravel or dome under which most of the eggs were located and upstream depression or 'pot' (Schlunke, Vonlanthen 2002; Kesminas 2008).

The efficiency of fish ladders built in Valtūnai small hydropower plant were assessed using radio telemetry. Valtūnai fish ladders is a typical cascade type fish passage with 14 pools the average width and length of which were 6,3 m and 4,6m respectively. The total length of fish ladders was 66,7m. Fish ladders and the river were connected with a 15 meters long channel (Stakėnas *et. al.* 2007).

In September-October 2007, 18 specimens of salmonids were captured by electro-fishing single run depletion in the Siesartis River for radio telemetry studies. Upon capture, the selected salmon and sea trout were anaesthetised by immersion in a 0.4–0.5 ml L-1 solution of 2-phenoxy ethanol and then fitted with radio tags inserted manually via a ≈ 25 mm incision made in the central area between pelvic fins and anus. The incision was closed using 3 – 4 sutures of coated Vicryl® (Lower *et. al.* 2005). Anaesthesia and surgery lasted 5–6 minutes. The sutured wound was treated with Orahesive® and Cicatrin® mixture as described in Moore *et al.* (1990). Fish was allowed to recover and then released at the point of capture. Tag-fish body weight ratio did not exceed 0.9 %. Tagged fish was manually tracked using portable Biotrack Ltd. Sika® receivers with a directional Yagi antenna (flexible elements). Simultaneously, automatic listening stations Lotek SRX-400® with directional antennas were deployed close to fish ladders to monitor fish movements in different parts of fish ladders. Pre study tests with loose radio tags revealed that fish position in the ladder could be located with 5 m accuracy using tag output signal power readings in automatic listening stations.

Results

During 10 years period, in the Vilnia River, the total number of redds varied from 16 to 118 or 1,68 – 12,2 (mean = 5.8; SE = 1.1) redds per 1 km of river stretch. The total area of reds varied from 38,1 to 573,9 m^2 or 4,04 – 60,41 m^2/km (mean = 16.1; SE = 5.6). The mean size of redds was 2.5 m^2 (SE=0.4).

During 4 years period, in the Siesartis River, the total number of redds varied from 33 to 144 or 1,24 – 5,42 (mean = 3.0; SE = 1.0) redds per 1 km of river stretch. The total area of reds varied from 146,4 to 478,64 m^2, or 5,51 – 18,03 m^2/km (mean = 11.2; SE = 3.1). The mean size of redds was 4.1 m^2 (SE=0.5).

Table 1. The mean and SE (given in brackets) of the number and area of redds per 1 km of the river with mean redds size in the Vilnia and Siesartis rivers bellow and above dams

River		Number of redds per 1 km	Area of redds per 1 km	Mean redds size
Vilnia	Above dam	7.3 (1.7)	24.5 (9.1)	2.7 (0.4)
	Bellow dam	4.3 (0.8)	11.0 (4.1)	2.0 (0.4)
Siesartis	Above dam	3.9 (1.6)	15.6 (7.7)	4.1 (0.8)
	Bellow dam	3.0 (0.8)	10.8 (1.7)	4.0 (0.4)

The distribution of redds bellow and above the dam in the Vilnia River varied significantly over the monitoring area. The biggest increase in redds above the dam was in 2004, which is 4 years after constructing fish ladders (Fig. 1). Since 2004, the relative abundance of redds above the dam has been significantly greater than that bellow the dam (Fig. 1) and the mean values of relative redd abundance, the area and mean size over all monitoring period were also greater for river stretch above the dam (Table 1.). However, differences were not statistically significant (Mann-Whitney U test, p>0.05).

In the Siesartis River, the distribution of redds bellow and above the dam also significantly varied over the monitoring area. The biggest increase in redds above the dam was in 2007-2008, 2-3 years after constructing fish ladders (Fig. 2). In 2008, the relative abundance of redds above the dam was significantly greater than that bellow the dam (Fig. 2) and the mean values of relative redd abundance, the area and mean size over all monitoring period were also greater for river stretch above the dam (Table 1.). Nevertheless, differences in the Vilnia River were not statistically significant (Mann-Whitney U test, p>0.05).

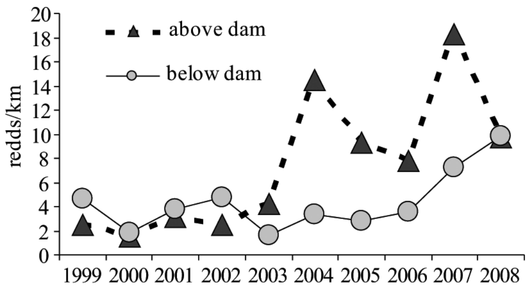

Fig. 1. Dispersion of redds in Vilnia

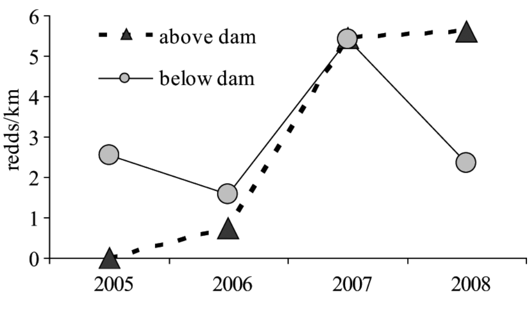

Fig. 2. Dispersion of redds in Siesartis

From radio-tagged 18 salmonid specimens in the Siesartis river, 13 (10 females and 3 males) were registered as very close (<50 m) to fish ladders. The registered 9 fish ascended fish ladders and 6 of them passage. One fish was illegally caught at the very top of fish ladders, one big male salmon (15,8 kg) did not manage to pass through the screen bars of fish ladders and the last one failed to passage in 12 attempts.

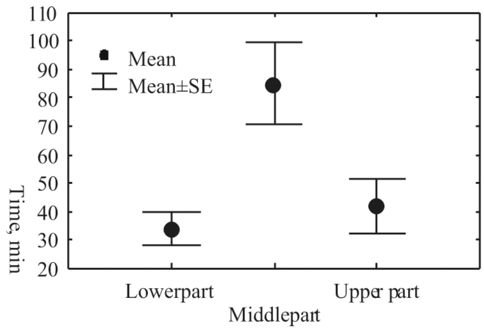

Fig. 3. Mean time (in minutes) spent in different parts of fish ladder by salmonids in Valtūnai hydropower plant

Discussion

The analysis of redd distribution and abundance in both rivers revealed that the construction of fish ladders significantly increased the number and share of redds above the dams, however, it takes from 3 to 4 years. Though anadromous salmonids have been shown to rapidly colonize newly accessible habitats (Bryant *et al.* 1999), in the present study, dealing with recolonization rather than the colonization distribution of redds below and above the dam is mainly the result of homing behaviour, i.e. the tendency of salmonids to return to their natal areas for spawning (Heggberget *et al.* 1986; Heggberget *et al.* 1988; McDowall 2001). In both rivers, the restocking programme with salmonids started in the same year as the construction of fish ladders and first adult salmonids returned to the same rivers 3-4 years later which is obviously reflected in redd distribution (Fig. 1, 2). Thus, the homing factor was the most significant.

Table 2. Biological data on radio-tagged fish and migration through fish ladders

No.	Length TL, cm	Weight Q, g	Sex	Passed fish-ladder	Number of attempts	Passing while for every third of fish ladders (hour:min:sec)		
						Lower part	Middle part	Upper part
1	63.5	2938	♀	no	2	00:48:30	02:14:41	–*
2	65.0	2706	♀	no	0	–	–	–
3	41.3	794	♂	yes	1	00:19:32	01:13:24	00:32:29
4	72.0	3567	♀	no	0	–	–	–
5	75.0	4660	♀	no	0	–	–	–
6	78.0	4726	♀	no	12	–	–	–
7	73.5	3303	♂	yes	1	00:46:13	01:45:47	01:14:01
8	71.0	3300	♀	yes	2	00:11:43	00:39:20	00:40:50
9	69.0	3296	♀	yes	1	00:49:06	02:01:18	01:12:38
10	64.5	2860	♀	yes	1	00:32:09	01:06:29	00:38:19
11	66.5	4777	♀	yes	1	00:48:05	01:57:11	01:02:29
12	77.,0	4889	♀	no	0	–	–	–
13	119.0	15780	♂	no	1	00:13:15	00:21:27	00:12:06**

*Fish illegally caught in the upper part of fish ladders

**Tagged fish failed to pass screen at the very top of fish ladders.

However, an increase in the share of redds above the dams was notable during the next spawning season and this could be only explained as natural dispersion driven by seeking more suitable spawning grounds and to avoid inter-specific and intra-specific competition.

During the monitoring period, recolonization rate (the share of redds above the dam) is expected to be further accelerated when individuals born in this stretch come back to spawn as this tendency has already been obvious in a short term (Fig 1, 2).

Analysing the efficiency of Valtūnai fish ladders revealed that the main reasons for the failed attempts were a lack of protection during the migration season (for example, radio tagged fish caught while passing) and construction mistakes impeding fish passage. According to Lithuanian regulations, the owners of hydropower plants must ensure the functioning of fish ladders from the 1st of October, however, radio tracking studies revealed, that a substantial share of tagged fish shoaled close to the dam from the mid of September. Few specimens never ascended fish ladders. Therefore, the main recommendations were to improve the protection of fish ladders (the construction of protective screens, fencing hydropower plants and fish ladders area), pro-longing the functioning period of fish ladders and the elimination of construction defects (screen). We also recommended changing construction in cascade type fish ladders with installing the so called 'rest zone' for fishes in the middle of fish ladders (a prolonged or curved pool with additional current inhibitors). Those recommendations will definitely benefit to increase the efficiency of fish ladders to the level of the reported nature like fish ways (Calles, Greenberg 2005).

Even if fish ways are ascendable, fish may have difficulty finding entrances, i.e. attraction efficiency is low (Larinier 2002; Northcote 1998). Our attraction efficiency was 62 % as 8 fishes of 13 were recorded close to the entrance of fish ladders and tried to pass fish way. The remaining fish either returned downstream or spawned nearby. In comparison with other fish ladders, it is slightly better attraction (Aarestrup *et al.* 2003, Calles, Greenberg 2005). The problems of poor attraction efficiencies for Atlantic salmon and brown trout have been related to insufficient attraction flows (Aarestrup *et al.* 2003; Arnekleiv, Kraabøl 1996; Jensen, Aass 1995; Laine *et al.* 2002; Linlokken 1993; Rivinoja *et al.* 2001; Thorstad *et al.* 2003) and to the inappropriate design or location of the entrances of the fish ways (Gowans *et al.* 1999; Laine *et al.* 1998; Laine *et al.* 2002). For our study, we cannot be certain why attraction is low as flows were normal and the design and location of the entrance were well designed, however, few fishes that approached fish way before the 1st of October (the beginning of fish ladders functioning), migrated downstream after the shoaling period close to the dam. The delayed start of fish ladders functioning therefore could be a reason for lower attraction levels as other studies revealed that delays between first approaching, the dam and the ascent of the ladder were greater for fish that had approached the dam earlier (Gowans *et al.* 1999). Our study showed the majority of fishes migrated through fishway in the dusk which is 1-2 hours before the sunset and in dark time, contrarily as reported by Calles and Greenberg (2005), Gowans *et al.* (1999), where the most of migrations were recorded during daylight; nevertheless, other studies suggest that a major part of fish enter fish ways during dark time (Aarestrup *et al.* 2003). The majority of the tagged salmonids ascended fish ladders in the first attempt as the other studies revealed that the most of salmonids visited the ladder entrance more than once before ascending (Gowans *et al.* 1999).

This study confirms that a substantial proportion of the spawning migrants of both anadromous sea trout and Atlantic salmon successfully passed Valtūnai fish way, even though attraction efficiency and fish ladders efficiency was not high. The majority of individuals that passed fish ways were also observed to use fish ways for downstream migration. An increase in redd density upstream dams indicates that fish ways have re-established connectivity for salmonids in Vilnia and Siesartis rivers. In a short period, both fish ways had a substantial effect on the reproduction of salmonids as well as it is likely that the downstream migration of smolts in spring will have to be more successful with functioning fish ways which in long term, will have significant benefit for the populations of salmonids in the investigated rivers.

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MAŽŲJŲ HIDROELEKTRINIŲ ĮTAKA LAŠIŠINIŲ ŽUVŲ NERŠTO MIGRACIJAI

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Santrauka

Siekiant sukurti palankias žuvų migracijos sąlygas ir atverti migracijos kelius į upių aukštupius Vilnios ir Siesarties upėse 2000 ir 2005 m. atitinkamai buvo pastatyti kaskadinio tipo žuvitakiai. Abiejose upėse atlikti lašišinių žuvų nerštaviečių tyrimai parodė, kad įrengti žuvitakiai padarė didelę įtaką lizdų sklaidai upėje – jų labai padaugėjo praėjus 2–4 metams po žuvitakių įrengimo aukščiau patvankos. Tai galėtų būti aiškinama „homingo“ ir naujų nerštui tinkamų plotų atradimu. Valtūnų žuvitakio efektyvumo tyrimai, taikant radijo telemetrinius metodus, parodė, kad didžiąją dalį laiko, įveikdamos žuvitakį, žuvys sugaišta vidurinėje jo dalyje. Nustatytas žuvitakio efektyvumas siekė 66 %. Straipsnyje pateikti pagrindiniai nustatyti žuvitakių trūkumai, kurių esmė – nedideli techniniai statinio trūkumai ir menka žuvitakių apsauga žuvų migracijos metu. Pateiktos rekomendacijos žuvitakių efektyvumui pagerinti.

Reikšminiai žodžiai: radijo telemetrija, žuvitakiai, *Baltic salmon*, *Sea trout.*