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Strategies for mitigating the impact of hydropower plants on the stocks of diadromous species in the Daugava River

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Abstract

The Daugava River is the largest river in Latvia. Daugava Hydro Power Plants built in 1939 – 1974 are Latvia's most important renewable resource in generation of electricity. The absence of fish passage structures excludes upstream migration of diadromous species. Compensatory stocking activities are introduced annually. The need for studying alternative or additional impact mitigation measures is based on biodiversity conservation aspects and possible changes in EU legislation. The case study of solutions for improving the Daugava River connectivity is introduced and further strategies for mitigating the impact of HPP are proposed in the paper.

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Keywords: hydropower; fish migration; fish passage; environmental impact; renewable energy

1. Introduction

From the ecological point of view hydropower plants significantly and sometimes irreversibly modify existing ecosystem. There are very few truly natural free flowing rivers left in the world [1]. The life cycle of diadromous species takes place partly in fresh water and partly in sea water. Dams and hydropower plants that prevent passage have a fundamental effect on migrating fish populations [2]. Dams can block or delay fish migration and thus

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contribute to the decline and even the extinction of species that depend on longitudinal movements along the stream continuum during certain phases of their life cycle. Mortality resulting from fish passage through hydraulic turbines or over spillways during their downstream migration can be significant. Habitat loss or alteration, discharge modifications, changes in water quality and temperature, increased predation pressure as well as delays in migration caused by dams are significant issues affecting diadromous fish stocks [3].

At the same time the use of hydropower is a significant contribution to mitigation of climate change and reduction of greenhouse gas emissions. 2030 Climate and Energy Framework agreed by EU leaders in 2014 aims to reduce greenhouse gas emissions by 40 % below 1990 levels as well as achieve 27 % share of renewable energy sources following 2020 targets (–20 % of GHG emissions and 20 % of RES). Latvia is one of the leading EU member states in the use of renewable energy. This achievement is mostly based on Daugava HPPs which produce at least 50 % of the total electricity generated in Latvia.

Co-existence of hydropower and river system biodiversity is always a challenge which requires complex sustainable solutions taking into consideration economic, social and environmental aspects. Two environmental science areas – biodiversity conservation and climate change mitigation come to a conflict at this point. Compromise should be found without neglecting the importance of the use of RES for electricity generation (thus reducing emissions of GHG) as well as preserving natural resources of the river system which have not only economic (commercial and recreational fishery), but also biological (rare, protected species) and social (keeping the nature as it is for the next generations) value.

The Daugava River is the largest river in Latvia and originates from the Valdaja plateau. It flows 1020 km through Russia, Belarus and finally empties into the Gulf of Riga, in the Baltic Sea. Within Latvia, the Daugava River flows 357 km before reaching the Gulf. The river basin is 24 700 km^2, including approximately 40 tributaries in Latvia [4]. The annual mean discharge in Daugava River is 601 m^3/s (1971–2014). The two major tributaries within the Latvian territory are the River Ogre and Aiviekste, situated about 50 and 120 km from the river mouth, respectively [2]. Daugava hydro power plants (HPPs) built in 1939 – 1974 and owned by power supply company Latvenergo AS are Latvia's most important renewable resource in generation of electricity with a total installed capacity of 1,56 GW.

The electricity generation capability of the Daugava HPPs depends on the Daugava River discharge. Therefore, with the exception of the spring flooding season, the Daugava HPPs operate on a cascading principle to cover peak loads. This allows the accumulation of water and generation of electricity during periods of increased demand (daytime peak hours). During the spring flooding season, which lasts for one to two months each year, the Daugava HPPs operate at full capacity. It is possible to satisfy the demand of all Latvian electricity consumers in this period [5]. The HPPs also perform the role of the power system's emergency reserves – they are able to quickly start electricity generation in the event of emergency, thus preventing electrical network overload and protect disconnection of consumers from power supply.

Plavinas HPP, located 107 km from the Gulf of Riga, forms the third stage of the Daugava HPP cascade. Plavinas HPP is the largest hydropower plant by installed capacity in the Baltics and one of the largest in the European Union. The power plant started operation in 1968 with ten Francis type hydropower units. The current capacity of the plant is 894 MW, maximum head 40 m.

Kegums HPP forms the second stage of the cascade. Located 70 km from the Gulf of Riga, it consists of two separate power plants on the left and on the right banks of the Daugava River. Kegums HPP is the oldest of the Daugava HPPs – it was constructed between 1936 and 1939. Currently the total capacity of Kegums HPP is 264 MW, maximum head 14 m, 7 Kaplan type hydropower units are installed.

Located 35 km from the Gulf of Riga, Riga HPP forms the lowest stage of the Daugava HPP cascade. Riga HPP was commissioned in 1974. Current capacity of the plant is 402 MW, maximum head 18 m, 6 Kaplan type units are installed [5].

Changes in the Daugava ichtyofauna have taken place as a result of natural as well as anthropogenic factors. The greatest impact on river ichtyofauna has been observed from the construction of the HPP cascade, determining an unpassable obstacle to fish migration and a change into a lentic system which substantially altered the distribution of some species in this river basin.

Before the construction of Kegums HPP Atlantic salmon, sea trout, vimba bream and other species migrated all over the Daugava and its tributaries, reaching Belarus [6]. Although the Kegums HPP was historically equipped with a fish passage facility, fish migration was significantly limited. Studies showed that a small fraction of fish at the dam, at best 1–2 %, migrated up the fish passage [4]. After the Pļaviņas HPP was built the fish that got over the Kegums HPP were searching for the spawning sites in the rapids near Jekabpils, other fish were spawning downstream Plavinas HPP, where their spawn had low efficiency due to the water level fluctuations. After Riga HPP was built without any fish passage facilities, Kegums fish pass had lost its initial meaning [6]. Since 1974, the Daugava has completely lost its role in natural reproduction of migratory species [4].

Nowadays overall, 42 fish and 3 lamprey species are attributed to the Daugava basin, including 37 species that have self-sustaining populations; some species (e.g. sturgeon) have become extinct in the Daugava and in all of Latvia. Salmon and sea trout populations in the Daugava are maintained artificially, while vimba and river lamprey reproduce naturally in other rivers [4].

The impact of HPPs is annually compensated by stocking of salmon, sea trout (600 thousands of smolt and fries annually) and other species: vimba, pike, pikeperch, river lamprey, whitefish (700 thousands of fries and 5 millions of larvae annually) with the total annual costs more than 1 million EUR. The stocked populations of salmon and sea trout significantly differ from the historical wild populations: the average age of the individuals decreased, the structure of population changed: late-run spawners dominate in the current population [4].

The Atlantic salmon is currently red listed by the IUCN organization and is classified as "least concern", which means there is a low risk for extinction of the species. The Baltic stocks of Atlantic salmon are genetically unique [7] having been isolated from North Atlantic stocks for about two thousand years [2]. Although once considered among the world's most productive salmon regions with high ocean survival, the vast majority of Baltic stocks have seen drastic declines in production, in part due to hydropower development. Furthermore, in [8] concerns are expressed that the genetic diversity of Baltic salmon is being negatively affected by compensatory releases of hatchery fish [2].

In 2011 European Commission published the proposal for regulation establishing a multiannual plan for the Baltic salmon stock. One of the proposed amendments states that stocking of salmon may only be conducted in wild salmon rivers when this is required to prevent extermination of the local stock [9]. Since the Daugava River is regulated by HPPs which are an obstacle for migrations of Baltic salmon, it cannot be considered as a wild salmon river, therefore according to draft regulation, compensatory releases should be interrupted within 7–10 years after regulation coming into the force. Due to these possible changes in legal acts existing model of HPP impact compensation will have to be revised. The aim of this paper is to introduce possible further steps and strategies of mitigating HPP impact by facilitating natural reproduction of diadromous species.

2. Methods

The case study was performed to analyze the Daugava River system and develop further strategies for improving the river connectivity. The study is based on analysis of ecological and technical aspects of possible re-opening the Daugava River for migratory species grounded by available historical data, HPP technical and operational data, review of fish passage technical solutions and recent studies aimed to explore the present condition of the Daugava River eco-system. In 2013 Latvenergo AS initiated the study "Fish migration and natural reproduction restoration in the Daugava River". This study divided in several stages was planned and organized by the authors. The planning of the study was performed by prioritizing the subjects of research and defining the methods and data necessary for initial evaluation and planning further steps of decision-making process: review of the literature, analysis of long-term data records, onsite observations, field works. At the 1st stage of the study the review of historical data and habitat survey was performed [4]. Possible fish passage technical solutions and other fish migration restoration options were analyzed as well in [10]. The 2nd stage of the study (2014–2015) included Atlantic salmon telemetry study in the Daugava River and its tributary the Ogre River [11].

2.1. Review of historical data and habitat survey

This study was the first step in investigating fish migration and natural reproduction restoration in the Daugava River. It was performed by Institute of Food Safety, Animal Health and Environment “BIOR” and the results are reported in [4]. The first report of this study is dedicated to review of available historical data reflecting the Daugava River system before anthropogenic modifications caused by construction of hydro power plants. It also summarizes available literature on scientific research performed during and after construction of the plants aiming to reduce or compensate the impact of the dams on fish resources. At the same time the report includes recent data, gained from fish population monitoring and fishery reporting. The second report reflected the results of spawning habitat mapping which covered the Daugava and its tributaries downstream and upstream Riga HPP.

2.2. Possible fish passage technical solutions and other fish migration restoration options

Following BIOR study, the analysis of technically feasible solutions for restoring fish migration and natural reproduction was performed by expert group from Politecnico di Torino (Italy) and Karlstad University (Sweden) in cooperation with Latvenergo AS specialists. The following options and solutions were evaluated: fish pass construction; trap and transport option; artificial spawning grounds option; downstream passage solutions.

2.2. Telemetry study in the Ogre River

The study was performed in cooperation with Karlstad University (Sweden), Politecnico di Torino and Flume srl (Italy) and the Institute for Environmental Solutions (Latvia). The study was aimed at testing if salmon trapped at the mouth of the Daugava will migrate upstream if released in the Ogre and possibly recognize a trap- and transport-approach as a suitable strategy for reintroducing wild-spawning Atlantic salmon to the Daugava River system. To evaluate the trap-and-transport approach, adult salmon returning to the mouth of the Daugava were radio-tagged and transported upstream to the Ogre River, and their migration behavior was monitored. The study design comprised of tagging and releasing three groups of ripe Atlantic salmon, which are transported upstream Riga HPP. Two groups were released in the tributary Ogre River upstream the lowermost HPP, and the third group was released in the Riga HPP reservoir in the Daugava River. The purpose of the third group was to see if fish tended to move upstream and also if fish was able to find the mouth of the Ogre River. The objectives were to determine if the fish would migrate upstream to suitable spawning areas along Ogre River, if upstream migration does not occur, will downstream passage through both Ogre HPP and Riga HPP be successful and how released salmon behave in the Daugava River [2].

3. Results

Historical data indicate that the Daugava lost its significance in reproducing salmon, sea trout and river lamprey stocks following construction of the HPP cascade. The main reason noted is the loss of spawning and rearing habitats. Habitats suitable for diadromous species have remained in smaller amounts in the Ogre River and few smaller tributaries flowing into the Riga HPP water reservoir. However, their biological potential is estimated as being much lower compared to the Daugava’s potential following construction of the HPP cascade. Three small HPPs have been built across the Ogre River since the 1990s at 5, 70 and 85 km from the mouth of the Ogre River [4]. The area of habitats suitable for migratory fish was investigated along a 70 km section of the river between the first two hydropower plants: 223 sites suitable for salmon, sea trout and river lamprey for a total surface of 29,6 ha have been mapped. According to [4] some of the upstream sections of the Ogre River also correspond to the ecological needs of salmonids in terms of its hydrological and morphological characteristics. Habitats survey and mapping in the Daugava and its tributaries upstream Kegums and Plavinas HPP have not been performed.

The Daugava reach on the other hand, thus significantly altered by the reservoir (lentic habitat) can be exploited by other species (e.g. vimba, eels); this element should need further investigation, especially with regards to eels. A potential limiting factor for eels, as reported in [4], could be the water level fluctuations in the reservoir, which could affect the exploitation of the shoreline by this species [10].

An analysis of data available for the 1970s showed that fish passage across the Riga HPP would not have an economic effect. The idea of maintaining small but natural populations of vimba in the Ogre River of the Daugava basin was never implemented (though experimental studies were performed). Stocking of the most economically important species had a considerable effect, particularly for salmon [4] and remained as the main instrument to mitigate the impact of HPP cascade.

Above mentioned EU regulation proposal [9] and recent studies represent different approach: evaluation of the impacts on fish resources do not limit to economic effects which could be achieved through compensatory releases, but take into account the aspect of biodiversity which means developing solutions for natural reproduction of the species. Therefore analysis of possible fish passage solutions at the first obstacles on the way from the Baltic Sea to the Daugava and its tributaries was performed using the data and conclusions reported in [4].

The construction of a fish pass shall take into account the needs and swimming abilities of all the present and potentially present migratory species and guarantee for all of them sustainable hydrodynamic conditions along the migratory periods and, in general, throughout all the year. Compared to other options, this can be theoretically considered optimal, since it would continuously provide a flow release and free movement through the dam and without the need for operating mechanical equipment or using personnel (e.g. required for trap and transport option).

The construction of a fish pass at Riga dam would allow the reopening of the fish migratory routes along a stretch of 34 km along the Daugava river, up to Kegums dam, and the access to the available reaches (i.e. not blocked by obstacles) along the related tributaries [10].

The study concluded that for Riga HPP construction of fish pass is technically feasible, but complex, related with high costs and requires further detailed studies. Taking into account existing infrastructure, relatively high water level fluctuations downstream and upstream Riga HPP an optimal type of fish pass is nature-like bypass channel in the central part of the fish pass (including suitable habitats and spawning grounds) combined with a “technical” part (single or double vertical slot) at upstream and downstream ends. In any case the downstream part of the fish pass would be required even to provide attraction to the entrance to alternative facilities (fish lift or collection chamber for trap and transport or artificial spawning grounds), due to the significant water level fluctuations at the HPP tailrace.

The choice of the optimal solution needs to be based on a more detailed knowledge of the involved fish species and should find an appropriate balance among the needs for providing free passage to all species, guaranteeing optimal hydrodynamic conditions and proper attractivity and keeping construction costs to an acceptable level (considering that the fish pass length could vary, depending on the design choices, from 800 to 1800 m) [10].

Fish pass attraction flow to be provided in the different periods of fish migration is shown in Tab.1.

Table 1. Riga HPP fish pass attraction flows in the different periods of the year.

Period	Mean discharges, m^3/s (1996-2011)	Fish pass attraction flow, m^3/s
September-November: salmon, sea trout, vimba and river lamprey	448	4.5 – 22.4
April: vimba and river lamprey	1830	18.3 – 91.5
July-August: yellow eel	331	3.3 – 16.6

Possible alternative of a fish pass at Riga HPP is a construction of artificial spawning grounds for salmon & sea trout (no passage) downstream Riga HPP; it would avoid most downstream migration issues and can be used as trapping site for trap and transport option, but should face similar technical issues as for the fish pass.

From a preliminary analysis of the existing fish passage facility at Kegums HPP, the limited efficiency should be caused by poor attraction due to low discharge and to the influence of tailrace water levels fluctuations. During high flows the total drop reduction (due to increased downstream water levels) reduces the flow passing through the fish pass orifices, further increasing the difficulty for fish to locate the entrances to the passage.

The evaluation of the technical, ecological and economic feasibility of the rehabilitation of Kegums HPP fish pass (including reconstruction of existing/constructing new the fish pass) shall be considered in a later stage, after having evaluated the feasibility of the fish pass at Riga dam. The next obstacle, Plavinas dam, represents a further technical challenge for building a fish pass, with its high head and relevant water levels fluctuations.

The turbine mortality was evaluated using a specific model and highlighted a low to intermediate impact on downstream migrants (silver eel was used as reference species) at Riga and Kegums HPP. Before basing any long-term management strategies on this predicted moderate turbine-induced mortality, a study validating the turbine-induced mortality should be conducted for the species and life-stages considered as most relevant [10].

Telemetry study reported in [2, 11] was the next step of the study aiming to gain evidence of theoretical Ogre river compliance with ecological criteria of diadromous species spawning and rearing habitats, highlighting problems to be solved and defining reintroduction strategy. During the study a significant flood occurred only surpassed by the 1930's flood event; in October 2014 water discharge in the Ogre River, whose mean annual discharge is 18 m^3/s, reached 185 m^3/s, with a higher extent than the common spring floods. All the radio-tagged fish released in the Ogre abandoned the study site, while about 40 % managed to move downstream Riga HPP and about 25 % moving upstream along Daugava approaching the unpassable Kegums dam. The study shall be repeated in order to obtain the result at more typical hydrological conditions.

4. Discussion

Analysis of the Daugava River reopening studies performed in the period from 2013 to 2015 and described above leads to the following concluding statements:

- The construction of the fish pass at Riga dam as a stand-alone measure would "only" reopen the main stretch of Daugava up to Kegums dam, where available lentic habitats are not optimal for salmon, and the accessible portions of the main tributaries. Therefore identification of suitable spawning grounds and optimal available habitats for the key target species upstream Kegums and Plavinas HPP is necessary. In any case the fish pass itself can be exploited as spawning ground and would reopen continuous access to the more significant tributary of the lower part of Daugava, river Ogre;
- Possible effective fish passage solution at Riga HPP is technically feasible, but complex and would result in significant investments;
- With reference to Ogre, it must be outlined that the most significant areas suitable for spawning are still blocked by the Ogre HEP (lowermost obstacle). At that obstacle a small fish pass must be provided in order to allow access to suitable sites, together with an appropriate solution to allow downstream migration (e.g. [12, 13]);
- Since the provision for restoring the longitudinal continuity by constructing fish pass at the three dams will need further detailed studies, the trap&transport option (trapping the spawners to transport them to the spawning sites upstream the obstacle) represents the recommended short-mid-term strategy.

Assessment of the data obtained in previous studies highlighted a number of necessary studies such as investigation of target species and factors impacting their reproduction effectiveness, habitat mapping, hydrodynamic modelling of HPP discharged flow at varying water levels and operation regimes, analysis of fish behavior using various methods including telemetry studies, physical-numerical modelling of a potential fish pass, modelling and testing fish mortality in turbines etc. These studies should be prioritized in accordance with short-term, medium-term and long-term action planning.

4.1. Short-term and mid-term actions

Short-term actions (1 – 3 years) should focus on investigating the critical issues for validating initial feasibility of further actions such as availability and effectiveness of spawning and rearing habitats, technical options and their complexity as well as helping to establish directions of the most appropriate further studies. Mid-term actions (3 – 5 years) should include implementation and/or testing of the prior activities resulting from the short-term activities, as well as extended investigations of relevant issues and developing basin-scale strategy of reintroducing diadromous species in the most appropriate sections of the Daugava River system. For the Daugava River short and mid-term planning, further steps should focus on implementation of trap and transport option for already mapped spawning sites in the Ogre. In line with this, extension of studies to other possible sites (upstream part of the Ogre, Kegums HPP, Plavinas HPP) is necessary.

4.2. Long-term actions

The long-term actions should include implementation of the strategy developed on the basis of short-term and mid-term activities. The long-term target is to improve longitudinal connectivity of the Daugava River by reopening access for migratory species to the most biologically appropriate, significant and effective spawning grounds in the Daugava and its tributaries. The provision for a fish pass at Riga HPP shall be considered only as the first of three main steps of a long-term strategy aimed at restoring the longitudinal continuity for upstream migration throughout the three dams system [10]. Alternatively, trap and transport option will have to be pursued and, in any case the downstream migration issues will have to be adequately addressed at every obstacle.

The ways and means of reaching this target should be evaluated with respect of available evidence of ecological, technical and economic feasibility. Therefore, at any stage of a planning process it is important to apply wider scale view putting together all the elements of the system. A number of aspects should be considered throughout decision making process.

5. Conclusion

Daugava HPPs play an important role in the use of renewable energy sources and achieving EU 2020 and 2030 climate and energy targets. At the same time the HPPs are an obstacle for diadromous species, the loss of these species is compensated by annual fish stocking. The recent studies initiated by Latvenergo AS were the first step to investigate the Daugava River reopening options. The mentioned study is in line with prospective European regulation which could potentially limit the stocking of the Baltic salmon, which is one of the valuable species both from ecological and economical point of view. The studies concluded that though the Daugava River and its tributaries met significant anthropogenic modifications, some areas of the habitats appropriate for diadromous species still exist. The mentioned areas have been investigated in the river section downstream and between two large-scale obstacles – Riga and Kegums HPP covering small part of the Daugava River potential. Three large-scale hydropower plants is a significant obstacle for diadromous species and possible fish passage solutions are complex and expensive. Therefore solving the problem of mitigation of HPP impact on fish resources and keeping the hydropower as one of the main renewable energy sources is complex and requires appropriate and well-considered planning. In this paper case study of potential solutions was introduced. Further steps and strategies were proposed in a short-term, mid-term and long-term view. The short and mid-term planning should be based on evaluating an option of trapping and transporting spawners to investigated appropriate habitats thus sustaining natural reproduction of diadromous species. Further the Daugava River connectivity improvements should be investigated using basin-scale approach for developing long-term strategy. Long-term target should remain as reopening the Daugava for migratory species in the most efficient and feasible way.

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