project. The other task relates to the building of models of the Iron Gate dams using hydrological and technical data (https://www.we-pass.org/).

In the area of the Gabčíkovo HPP, several LIFE projects that are currently running are focused on the interconnection of the inland delta or some side arms with the main Danube or old Danube channels. The LIFE + project "Restoration and Management of Danube Floodplain Habitats" aims to provide greater lateral connectivity. A newly submitted LIFE integrated project, "Implementation of the River Basin Management Plan in Selected River Sub-basins in Slovakia", will deal with complex and long-term proposals for restoration actions, particularly for the Danube River section in Slovakia, including fish migration and how to overcome barriers of the Gabčíkovo HPP.

Conclusion

The absence of fishways on the largest dams on the Danube River (Iron Gates and Gabčíkovo) make them mostly impassable for migratory fish species apart from the random passage of some fish via navigation locks. The negative impact on populations of migratory fish species is evident, especially on sturgeons. First steps in solving this problem were initiated in 2011. Since then, several projects have been completed and some are still ongoing, indicating a positive development in making the Iron Gates and Gabčíkovo dams traversable for fish. The construction of fishways would enable sturgeon to reach the majority of their historical spawning habitats.

References

Balon EK, Holčik J (1999): Gabčíkovo River Barrage System: The Ecological Disaster and Economic Calamity for the Inland Delta of the Middle Danube. Environmental Biology of Fishes 54, 1–17.

Banarescu P (1964): Fauna R.P.R., Pisces – Osteichthyes. Ed. Academiei R.P.R. Bucuresti, 962 pp.

Černý J, Copp GH, Kováč V, Gozlan R, Vilizzi L (2003): Initial impact of the Gabčíkovo hydroelectric scheme on the species richness and composition of 0+ fish assemblages in the Slovak flood plain, River Danube. River Research and Applications 19(7), 749–766.

Comoglio C (2011): FAO Scoping mission at Iron Gates I and II dams (Romania and Serbia). Preliminary assessment of the feasibility for providing free passage to migratory fish species. Mission report May 2011, 39 pp.

DDNI (2015): Fish behavior preparatory study at Iron Gate Hydropower dams and reservoirs. Project Report. Danube Delta National Institute for Research and Development, 64 pp.

De Bruijne W, Redeker M, Suciu R, van Herk J, Molnar P, Wanningen H, Manshanden G (2014): Fish migration at the Iron Gates I and II, Report, Arcadis NL. 81 pp.

Guti G (2006): Past and present status of sturgeons in Hungary. Proceedings Volume of the 36th Conference of the International Association of the Danube Research, 143–147.

Lenhardt M, Smederevac-Lalić M, Spasić S, Honț S, Paraschiv M, Iani M, Nikčević M, Klimley AP, Suciu R (2021). Seasonal changes in depth position and temperature of European catfish (Silurus glanis) tracked by acoustic telemetry in the Danube River. International Review of Hydrobiology. DOI: 10.1002/iroh.202002049

Pont D., Keskin E., Meulenbroek P., Ünal EM., Bammer V., Dejean T., Er A., Erős T., Jean P., Lenhardt M., Nagel L., Pekarik L., Schabuss M., Stoeckle B., Stoica E., Valentini A., Zornig H., Weigand A. (2021): Metabarcoding of fish eDNA samples. In: I. Liška, F. Wagner, M. Sengl, K. Deutsch, J. Slobodník, M. Paunović (Eds.): Joint Danube Survey 4 - Scientific Report: A shared analysis of the Danube River. ICPDR, Vienna. 133–144.

Reinartz R (2002): Sturgeons in the Danube River: Biology, Status, Conservation, IAD, 150 pp.

van de Kamp R, Yossef M, Buijs P, Hoving R (2014): Increasing the operational flexibility of the Gabcikovo dam water system: Pre-feasibility study. Acradis Nl. 139 pp.

Višnjić-Jeftić Ž (2012): Ecological and toxicological study of the Pontic shad (Alosa immaculate Bennett, 1835) in the Danube River in Serbia. PhD Thesis, Faculty of Biology University of Belgrade, 114 pp.

Mitigating ecological impacts of hydropower

Stefan Schmutz: *Institute of Hydrobiology and Aquatic Ecosystem Management, University of Natural Resources and Life Sciences Vienna, Austria, e-mail: stefan.schmutz@boku.ac.at*

Gerd Frik, *VERBUND Hydro Power GmbH, Vienna, Austria, e-mail: gerd.frik@verbund.com*

Introduction

Impacts on riverine ecosystems as a consequence of using rivers for hydropower (HP) production can be mitigated in various ways, whereby possibilities for gaining ecological benefits depend on many factors such as type and dimension of HP plant, river type of concern and other existing stressors. In principal, mitigating negative impacts is important throughout the entire HP planning as well as during pre- and post-implementation processes.

Mitigating impacts by strategic planning of HP

Mitigation starts at the planning stage, where dam siting decides in which way and to what extent catchments may become affected by HP use. Considering e.g. major fish migration routes, sensitive habitats and/or sites of high conservation value already during the dam siting safeguards environmentally-friendly implementation of HP. The ICPDR has developed a guidance document employing a number of economic and ecological criteria for classifying river sections from "favorable" to "non favorable" for HP use (ICPDR 2013). Following these guiding principles, new regulations for HP planning have been implemented in Austria at the provincial level and other countries (e.g. Bosnia and Herzegovina).

Mitigating impacts during and after HP implementation

Nowadays, a number of well-tested mitigation measures are available to improve the ecological conditions related to river continuity, sediment transport, hydrology, river morphology and water quality. Guidelines or guiding documents have been developed and are subsequently updated at national, European or international level supporting the planning and implementation of effective mitigation measures *(tab. 1).*

Potential ecological impacts	Mitigation measures	Examples of guidelines, guiding documents
Disruption of fish migration (upstream and downstream)	Upstream/downstream fish passes, fish screens, fish friendly turbines	Guidelines for building fish migration facilities (BMLFUW 2012)
Disruption of sediment transport	Sediment flushing/dredging, re-introduction of sediments	How-to Guide: Hydropower Erosion and Sedimentation (IHA 2019)
Impounded habitat – loss of fluvial habitat	Habitat restoration Habitat substitution	Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats (Roni & Beechie 2012)
Water abstraction	Release of ecological-flow	Ecological flows in the implementation of the Water Framework Directive: guidance document n°31 (EC 2016)
Reservoir water level fluctuation	Reduce water level fluctuations, manage shallow habitats	WG ECOSTAT report on common understanding of using mitigation measures for reaching Good Ecological Potential for heavily modified water bodies Part 1: Impacted by water storage (Halleraker et al. 2016)
Hydropeaking	Installation of a balancing reservoir, changing HP operational mode, diverting peak flows	
Downstream water quality deterioration incl. water temperature alteration and oversaturation	Flexible/multiple intakes, avoid air mixing into turbine intake	

Table 1: Potential ecological impacts caused by HP, mitigation measures and examples of guidelines

While there is comparably long tradition in implementing ecological flows and fish passes, improving the ecological conditions in "heavily modified water bodies – HMWB" sensu EU Water Framework Directive (WFD) is still challenging due to ecosystem degradation and potential impacts on use resulting from mitigation measures. This happens especially in case of large impoundments/reservoirs that fundamentally change the former fluvial habitat conditions and/or may

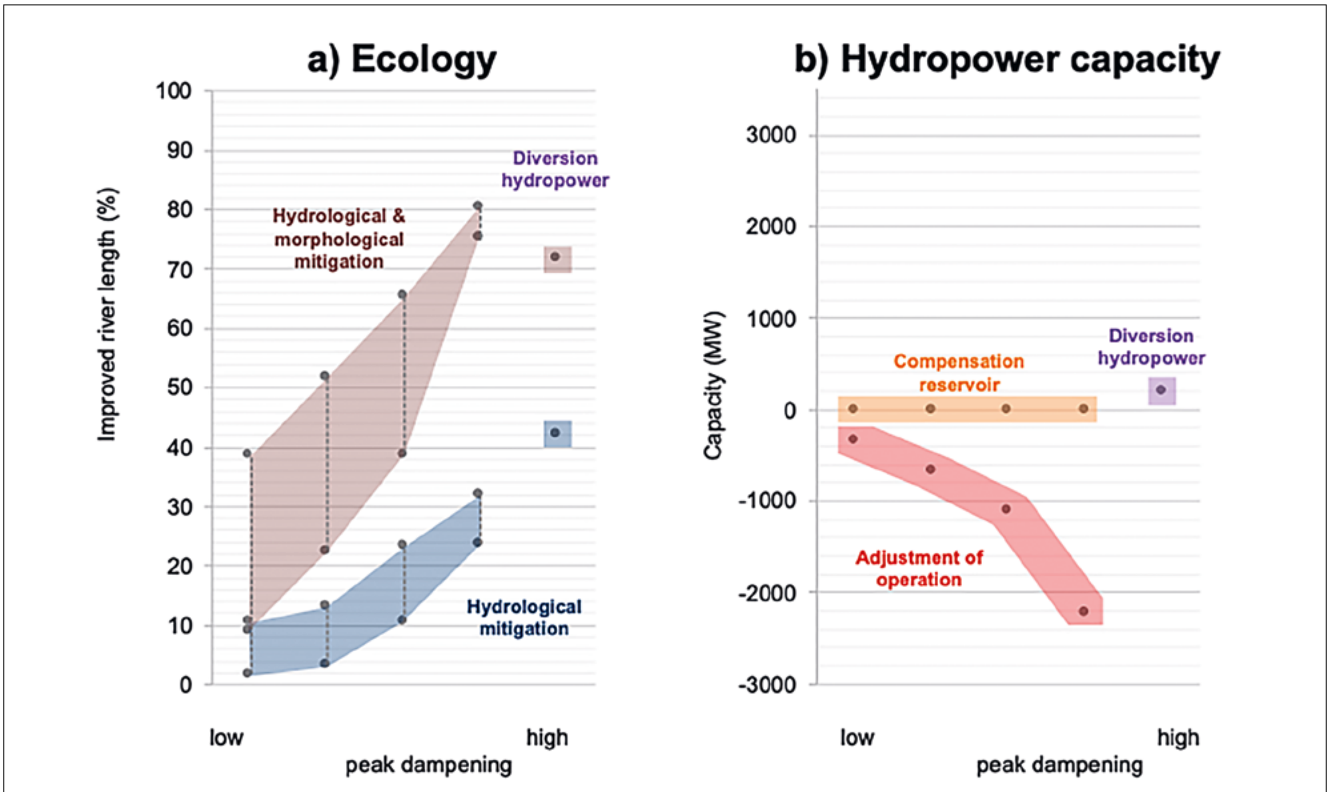

Figure 1: Ecological improvements (a) compared with impacts on HP use (exemplified by capacity) based on peak dampening scenarios from low to high by implementing mitigation measures, i.e. compensation reservoirs, diversion HP or adjustments of HP operation including morphological improvements (cumulated representation of analyzed case studies, adapted from Greimel et al. 2017).

Figure 2: *The 9.5 km long “New Traisen” was created by the 30 Mio Euro LIFE+ Traisen project financed by VERBUND Hydro Power with co-funding by EU and other donors, credits: VERBUND Hydro Power.*

impact downstream flows. Two examples given below show that even in those cases ecologically effective and technical/ economic feasible improvements can be achieved.

Case study mitigating hydro-peaking in Austria

HP plays an important role in balancing electricity production/consumption by storing water in reservoirs and delivering electricity when needed. As a consequence, rivers receive less (during storage) or more (during HP operation) water than naturally, a phenomenon called hydropeaking. Such rivers are exposed to rapid peak flows and dewatering events, often happening several times a day. Main consequences for river organisms could be increased drift during peak flows and stranding during dewatering. In Austria, more than 800 km of rivers are classified as HMWB due to hydropeaking. In HMWB, the objective is to achieve the “Good Ecological Potential” which is - in simple words - the status that can be achieved when implementing effective and technically feasible mitigation measures that do not significantly impact hydropower use or the wider environment (WFD). Within the frame of a number of research projects a new methodology was developed to monitor and assess the ecological consequences of mitigation measures and potential impacts on HP use such as installation of compensation reservoirs, altered HP operation and diversion HP (see Halleraker et al. (2016) for more details on mitigation options). The challenge was to define quantitative criteria and scenarios for the expected ecological improvements that could be directly related to the expected impacts on HP use. The latter was assessed by estimating the economic losses due to reduced HP production including impacts on energy safety and consequences for climate change (additional CO_2 emissions by substituting HP with fossil energy production). Based on a number of case studies analyzed in close cooperation among scientific institutions, HP companies and governmental administration the following main conclusions could be drawn: Highest ecological effects can be achieved by combining peak dampening or diversion HP with morphological improvements *(fig. 1a)*. While adjustments of HP operation results in significant impacts on HP use (loss of capacity) at already low peak dampening levels, compensation reservoirs and diversion HP do not impact HP use (fig. 1b), However, the latter may cause disproportionate costs or might be technically not feasible in specific cases. Based on these findings case-specific feasibility studies are now developed for affected river sections, ecological monitoring methods are adjusted to better assess mitigation effects and first implementation projects are scientifically monitored. The first mitigation project in form of a combination of a compensation reservoir and diversion HP is currently build at the river Inn and will be subject to scientific

Figure 3: Danube salmon (Hucho hucho) caught on 17.10.2018 in the "New Traisen" created by the "LIFE+ project Traisen", credits: T. Kaufmann.

monitoring and evaluation in the next years (www.gemeinschaftskraftwerk-inn.com). Results of the ongoing research project ÖkoReSch (forschung.boku.ac.at) will feed into an upcoming national guideline supporting hydropeaking mitigation in Austria.

Case study habitat restoration at Traisen river

During the implementation of the Danube HP Altenwörth in the mid 1970ies the mouth of the tributary Traisen was channelized, disconnected from the Danube and dislocated downstream to the tailwater of the HP Altenwörth. The aim of the "LIFE+ project Traisen" was to re-connect the Traisen to the Danube, re-create a natural river course of 9.5 km length and to improve terrestrial and aquatic floodplain habitats *(fig. 2)*. This 30 Mio € project was financed by VERBUND Hydro Power with co-funding by the EU and other donors and was implemented in 2012-2016. Endangered species such as the Danube salmon *(Hucho hucho)* and sterlet *(Acipenser ruthenus)* were stocked and the recovery process of the fish stocks were monitored within scientific projects (fig. 3). The ecological status of the "New Traisen" improved from pre-project "poor/moderate" to post-project "high" ecological status based on the fish fauna (fig. 4). The "New Traisen" now serves as spawning and nursery habitat not only for fishes of the Traisen but also of the Danube. Gravel spawners such as nase *(Chondrostoma nasus)* and barbel *(Barbus barbus)* use the Traisen for reproduction. The species richness increased from 20 to more than 30 species. The "New Traisen" provides habitat for rare, endemic and endangered species such as zingel *(Zingel zingel)* and streber *(Zingel streber)*. The newly created river course can be seen as a compensation measure for the lost fluvial Danube habitats and significantly contributes to achieving the "Good Ecological Potential" in the Danube HP cascade.

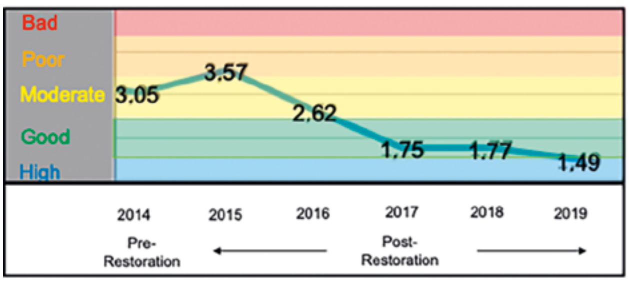

Figure 4: Improvement of the fish ecological status of the Traisen. Classification according to Fish Index Austria / WFD.

Conclusions

HP plays an important role in providing renewable energy but at the same time may cause significant impacts on aquatic ecosystems. Nowadays, a number of mitigation technologies are available or under development that can effectively improve the ecological conditions. Even in case of HMWB ecological improvements can be achieved without impacting HP use if mitigation measures are thoroughly planned and sufficient (co-)funding is provided. Recent experiences gained in Austria and exemplified here prove that the objectives of the WFD, i.e. to achieve the "Good Ecological Status/Potential" can be achieved if the required scientific foundation is sufficiently elaborated, solutions are developed together with stakeholders and adequate funding instruments are available.

References

BMLFUW (2012): Guidelines for building fish migration facilities, Fed. Ministry of Agriculture, Forestry, Environment and Water Management, Vienna, 102 p.

EC (2016): Ecological flows in the implementation of the Water Framework Directive: guidance document n°31. European Commission. 108 pp.

Greimel F, Neubarth J, Fuhrmann M, Führer S, Habersack H, Haslauer M, Hauer C, Holzapfel P, Auer S, Pfleger M, Schmutz S, Zeiringer B (2017): SuREmMa - Sustainable River Management - Energiewirtschaftliche und umweltrelevante Bewertung möglicher schwalldämpfender Maßnahmen. BMLFUW, Wien.

Halleraker, J. H., van de Bund, W., Bussettini, M, Gosling, R, Döbbelt-Grüne S, Hensman J, Kling J, Koller-Kreimel V, Pollard P (2016): WG ECOSTAT report on common understanding of using mitigation measures for reaching Good Ecological Potential for heavily modified water bodies Part 1: Impacted by water storage. European Commission, 104 pp.

ICPDR (2013): Sustainable Hydropower Development in the Danube Basin - Guiding Principles. International Commission for the Protection of the Danube River. Vienna.

IHA (2019): How-to Guide: Hydropower Erosion and Sedimentation. International Hydropower Association, London, 84 pp (Available from: www.hydropower.org).

Roni P, Beechie T (2012) Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats. Wiley-Blackwell. 316 pp.