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Emerging mitigation measures and strategies are needed for riverine ecology to ensure sustainable hydropeaking production in Norway

Jo Halvard Halleraker[1], Mahmoud S. R. Kenawi[2], Jan Henning L'Abée - Lund[3], Anders G. Finstad[4], and Knut Alfredsen[1]
[1]Norwegian University of Science and Technology (NTNU), Department of Civil and Environmental Engineering, S.P. Andersens veg 5, 7491 Trondheim, Norway
[2]Norwegian Environment Agency (NEA), P.O. Box 5672 Torgarden, 7485 Trondheim, Norway
[3]Norwegian Water Resources and Energy Directorate (NVE), P. O. Box 5091, Majorstua, 0301 Oslo, Norway
[4]Centre for Biodiversity Dynamics (CBD), Department of Natural History, Norwegian University of Science and Technology, (NTNU) 7491 Trondheim, Norway

Riverine biodiversity is threatened with severe degradation from multiple pressures worldwide. One of the key pressures in European rivers are hydromorphological alterations. Rehabilitation of river habitats is accordingly high on the political agenda at the start of UN decade of ecological restoration (2021-2030).

Water storage for hydropower production (HP) has severe impacts on aquatic ecology in Norway, with more than 3000 water bodies designated as heavily modified due to hydropower. Norway is the largest hydropower producer in Europe with a huge amount of high head storage schemes. Ca 86 TWh of this is storage hydropower, which constitutes more than 50% of the total in Europe. This makes Norway a potentially significant supplier of hydropeaking services. Flexible hydropower operations are crucial for EUs Green Deal in balancing electricity from renewable intermittent power generation such as wind and solar.

Many Norwegian **HP licenses** were issued before modern environmental requirements evolved. Few are re-licensed with emerging strategies to mitigate hydropeaking. Still, there seems to be a common understanding of relevant mitigation strategies emerging between many large hydropower producers. For example, flow ramping from hydropower tailrace water with direct outlet into fjords or other lake reservoirs may be less environmentally harmful than outlet into riverine habitat.In this study, we have assessed the Norwegian hydropower portfolio of more than 1600 HP facilities constructing a national database focusing on the knowledge base for assessing potential downstream hydropower ecological impacts. The ecological severity of such flow ramping and the restoration/mitigation potential, may depend on;

About 51 % of the HPs (ca **80TWh**) have tailrace into shorter rivers (<1 km) or directly into fjords or lake/reservoirs. Many of the largest HPs are in this category (e.g 50 HP> 500 MW). Close to 800 HP might have downstream impacts on rivers (> 0.5 km; about 49 % of all HP, in total of ca **56 TWh**). Probably **> 3 000 km of regulated rivers** in Norway therefor might need more ecosystem-based mode of HP operation. **Flow ramping analysis:** Ecosystem-based HP operational rules are established in a selection of sustainably managed Norwegian rivers, still with significant baseload production (0.35-0.76 - TWh annual prod). However, eco-friendly mode of operation seems to be rare as our analysis indicate that flow ramping with potential ecological degradation seems widespread in many rivers. Surprisingly, even in many with operational ramping restriction as required mitigation.Our database may be further improved and updated (with e.g. more flow ramping data and biological indicators) and serve as a basis for a national hydropeaking strategy, and hence make more of the Norwegian hydropower portfolio in line with the EUs sustainability taxonomy.