Insights from the initial stage of a nation-wide environmental relicensing of hydropower facilities: a biologists' perspective on court verdicts

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Abstract

Hydropower, utilized for centuries, is promoted globally as renewable energy. The perceived socio-economic benefits have often outweighed environmental concerns, as reflected in operational permits. In 2022, Sweden began re-licensing approximately 2000 hydroelectric facilities under the National Plan for Modern Environmental Conditions. We extracted data from 33 completed court cases, all involving relatively small hydropower facilities, with 22 resulting in withdrawal and dam removal, and 11 receiving decisions for remedial measures. The primary focus of measures was longitudinal connectivity; other environmental aspects received less attention and monitoring requirements were almost non-existent. We recommend measures using adaptive design, prioritizing functionality and monitoring over detailed technical specifications. Greater attention should be given to habitat in affected reaches; addressing e.g. flow, and water levels. In conclusion, this nation-wide process provides a unique opportunity to implement measures that could benefit the whole riverine ecosystem.

Keywords: Dam removal, Ecological rehabilitation, Environmental law, Fish migration, Hydroelectric production, River connectivity

INTRODUCTION

Hydropower facilities and their associated dams and reservoirs have existed for centuries (Almeida et al. 2022). Hydroelectricity is globally promoted as a renewable resource, but ecological costs are often high (He et al. 2024). Impoundments upstream of dams turn river rapids into lake-like reservoir environments and downstream sections have altered flow-, sedimentation-, and physiochemical dynamics impacting the river ecosystems (He et al. 2024). For mobile organisms like fishes, dams block up- and downstream movements, in effect fragmenting both habitats and populations, leading to population decline or even local extinction of migratory species (Jonsson et al. 1999; Limburg and

Waldman 2009). Importantly, similar issues can apply to relatively resident species, which need to move in relation to changed environmental conditions and disperse to maintain genetic diversity (Jones et al. 2021; Schiavon et al. 2024). Dams are considered to be a threat to almost 4000 aquatic, semi-aquatic, and terrestrial species worldwide (He et al. 2024).

A variety of measures have been implemented to mitigate the ecological effects of hydropower. This includes various fish passage solutions (Katopodis and Williams 2012; Silva et al. 2018) which initially were focussed mainly on aiding upstream passage of salmonids, but later also cover two-way passage of whole fish communities (Mallen-Cooper 1999; Calles et al. 2013a). Other measures relate to flow regulation effects, which can be mitigated by implementing multifaceted natural flow variability (environmental flows, or e-flow) (Poff et al. 2010; Richter et al. 1997; Acreman et al. 2014). A main concern related to environmental flow is lost power production, but models indicate that the annual loss need not be substantial (Widén et al. 2022), although regulatory capacity might be reduced. In practice, however, regulation on minimum flow is more commonly applied than environmental flows (Arthington et al. 2006; Malm Renöfält et al. 2010), despite the riverine ecosystems' dependence on natural and seasonal variation in flow magnitude, rate of change, frequency, duration, and timing (Poff et al. 2010; Acreman et al 2014). For temperature-, oxygen-, and gas supersaturation effects, remedial measures are available but seldom implemented (Poole and Berman, 2001; Li et al., 2022). Relating to all mitigation measures at hand, continuous monitoring of the applied measures in combination with adaptive management is required for successful mitigation performance (Birnie-Gauvin et al. 2017; Nyqvist et al. 2017).

In Sweden, the usage of dams for water-powered energy generation dates back many centuries in the form of e.g., mill dams (Swedish National Heritage Board 2021). The first Swedish hydroelectric plant was constructed in 1882; a small-scale private plant at Rydal in the river Viskan (Perers et al. 2007). Large-scale production plants were inaugurated in the 1910's (*Olidan* in river Göta älv in 1910, *Porjus* in river Luleälven, in 1915, and *Älvkarleby* in river Dalälven in 1917; Ödmann et al. 1982; Perers et al. 2007). The main construction period lasted between 1910 and 1970's, with a culmination from 1940's to 1960's in association with the development of the national power grid which made production in the north accessible to the rest of the country (Ödmann et al. 1982; Perers et al. 2007; Lindström and Ruud 2017). Construction levelled off when the potential for further large-scale development became limited without causing deterioration to the last few free-flowing large rivers, with associated critique from environmentalists (Arheimer and Lindström 2014; Köhler and Ruud 2019). This hydroelectric development has resulted in a present-day state where Sweden has around 2000 dams associated to hydroelectricity production (Lindblom and Holmgren 2016).

Historically, the perceived socio-economic benefits of increased energy production outweighed environmental concern, which is reflected in the legally bound operational permits, or the lack thereof in some cases (Ödmann et al. 1982; Schäfer 2021; Lindström and Ruud 2017). Hydropower plants often operate under original permits that have remained valid without re-evaluation under modern environmental laws (Svensson 2004). Consequently, hydroelectric production has historically faced fewer environmental mitigation requirements than other industries (Schäfer 2021). Even if history writers have claimed that no serious criticism was raised against the negative environmental effects until the mid-1900's (Ödmann et al. 1982; Jakobsson 2002), this perspective likely overlooks silent or silenced opposition to river regulation; not the least the experiences and opinions of the Sámi, who endured land appropriation, forced relocations, loss of water access, destruction of reindeer grazing lands, and other major environmental changes in their homelands associated to with early large-scale hydropower development (Össbo 2023a, b).

In 2019, Swedish environmental law was updated to require hydroelectric plants to comply with modern environmental legislation (SFS 1998:808, chapter 11, §§27-28, updated by SFS 2018:1407). Importantly, an EU directive (2000/60/EC) establishing a water policy framework was implemented in 2000. Based on this directive, and the legal update, the Swedish government tasked the Swedish Agency for Marine and Water Management (SwAM) with coordinating efforts to modernize environmental conditions at hydropower facilities. A National Plan for Modern Environmental Conditions for Hydropower (NAP) was later formulated to renegotiate the environmental permits of all hydropower facilities with permits older than 40 years (Swedish Government, M2019/01769). This plan involves re-licensing each plant through Environmental Court negotiations, preceded by a collaborative process including powerplant owners, authorities and interest groups, to align with current national and EU legislation. To safeguard electricity production and grid balance, key facilities will face less stringent requirements (Swedish Government, M2019/01769). Operators who find modernization too costly may choose to cease operations and remove associated dams (Swedish Government, M2019/01769). This large-scale process, covering around 2000 hydropower plants and dams, commenced in 2022 and is estimated to take approximately 20 years. In December 2022, however, the Ministry of Environment decided to pause the process, initiating a 12-month suspension on January 30, 2023 (Ministry of Environment, M2022/02251). The Ministry of Climate and Enterprise has since extended the pause several times, with the latest extension lasting until July 1, 2025 (SFS 2024:285). Due to Sweden's non-compliance with the Water Framework Directive, the European Commission launched an infringement procedure in December 2024, issuing a formal notice [INFR(2024)2236].

Fewer than 40 re-licensing court trials have been completed so far. Nonetheless, several issues have already emerged, including conflicts between electricity production and environmental considerations, fairness in trials, and uncertainties around water-body definitions and classification, ensuring best-practice measures, and monitoring of measure functionality and effects (e.g. County Administrative Boards 2022; Levin 2022; Government Offices of Sweden 2024; Pettersson and Bladh 2024; Sandberg 2024). This underscores the significant need for information and knowledge ahead of the remaining retrials.

Here we evaluate the court verdicts completed so far, focusing on those with a legally binding requirements for remedial measures. We summarize the listed measures and monitoring obligations, with particular attention to the critically endangered European eel, *Anguilla anguilla* (Pike et al. 2020). Gaps in the requirements are identified, and we provide recommendations for measures and monitoring to be included in future retrials.

MATERIALS AND METHODS

In Sweden, all court decisions are public due to the principle of public access to information (SFS 2009:400; Riksdag of Sweden 2009). The court decisions on the re-licensing of the environmental legal conditions for hydropower plants can hence be requested and accessed by anyone. We identified completed retrials via the web application “Strömmen”, provided by the Swedish Agency for Marine and Water Management (SwAM, 2024). For the 33 retrials that have been completed until the start of 2025 (i.e., decisions that cannot be overruled, in Swedish: *har vunnit laga kraft*), the court decisions were obtained by requesting them from the respective courts. The decisions were requested and received via email in pdf format (by BJ). From Strömmen, the following information was extracted (by BJ and DN): name of hydropower facility, river, court case number (if applicable supreme court number), court name, decision (retraction of permission – i.e., removal of facility, or granted to continue with modern environmental conditions). From the court verdicts and related discussion in the document, BJ and DN extracted the following information: water flow of the hydropower plant (Q), effect of the hydropower plant (in kW), mean annual flow of the river (MQ), mean low flow of the river (MLQ), upstream passage solutions, downstream passage solutions, requirements concerning type of guidance, maximum angle of rack (in cases where the type of guidance was an alfa or beta rack), maximum gap width of rack (in cases where the type of guidance was an inclined or angled rack), amount of water discharge through bypass, eel ramps, type of fishway, required slope of fishway, flow in fishway, minimum flow in fishway, hydropeaking, flow requirements, and monitoring requirements. To obtain specific data related to the European eel, the words “ål”, “ålen” and “ålyngel” (i.e., eel, the eel and eel elvers in Swedish) was searched for in the court verdicts (by BJ). In what context eel was mentioned was noted, and other relevant comments in relation to context were also noted (by BJ). Information was extracted from the court verdicts or the comments on the court verdicts, and, while sometimes complemented by information provided elsewhere, the discussions leading to verdict were not taken into account.

RESULTS

Of the 33 completed cases, 22 resulted in permit withdrawal and dam removal (typically at the owner's request) (Fig. 1). In the remaining 11 cases, the court allowed continued hydropower production, contingent on meeting modern environmental conditions (Fig. 1). Ten of these are small-scale plants (<1.5 MW), and one is a regulation dam for downstream hydropower (Table 1). All verdicts emphasize longitudinal connectivity and fish passage, requiring downstream fish passage solutions; 10 of 11 also mandate improved upstream passage (Table 2, and see “passage” subheading). Environmental flow received less attention, though most verdicts include minimum flow requirements through fishways and some restrict hydropeaking (Table 2, and see "flow" subheading).

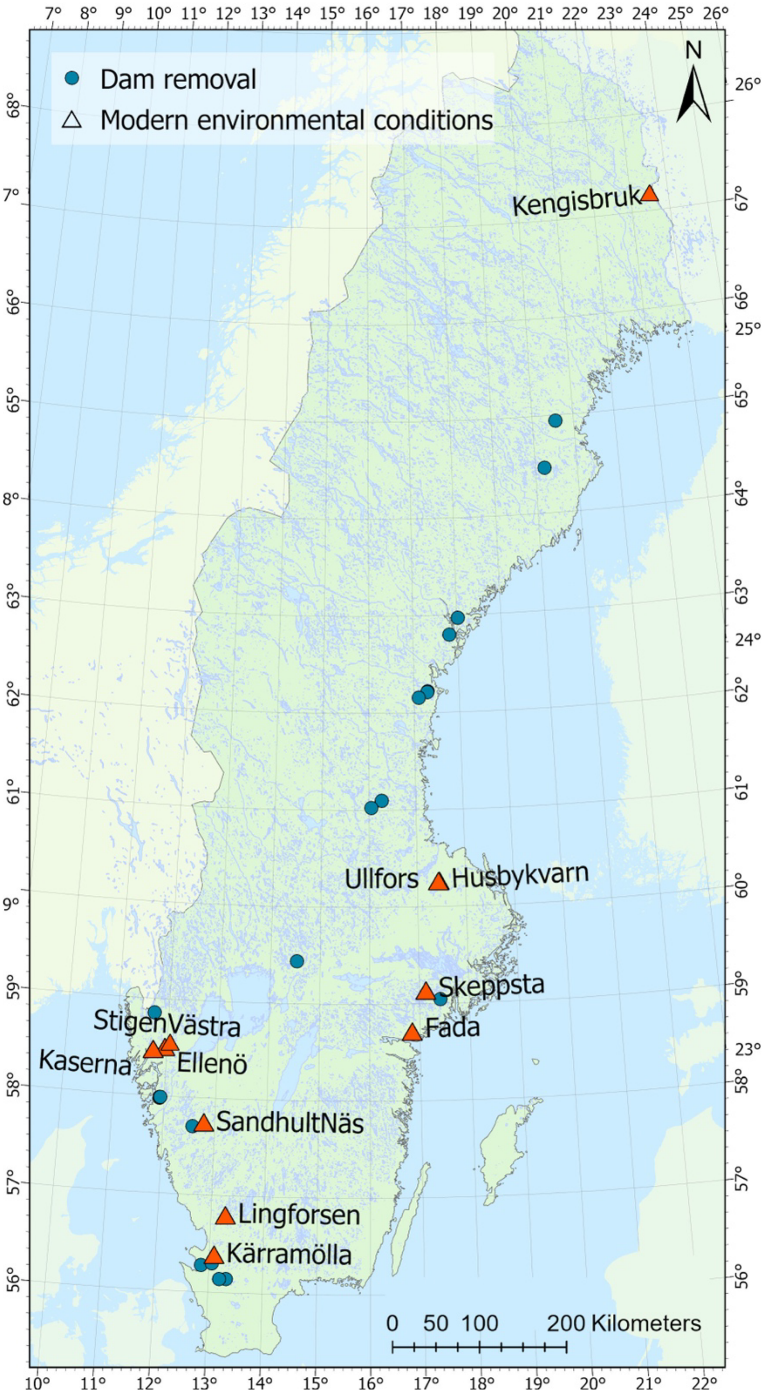

Fig. 1. Map of Sweden showing all 33 completed court case locations. The 22 facilities with withdrawn permits (dams to be removed) are indicated with blue points. The 11 facilities granted continued hydropower production (conditional on meeting modern environmental standards) are indicated with red triangles, with each facility labelled by name.

Table 1. Descriptive data for the 11 facilities granted continued hydropower production (conditional on meeting modern environmental standards), detailing name of the facility, river catchment, court, court case number, water flow of the hydropower plant (Q), effect of the hydropower plant (in kW), mean annual flow of the river (MQ), and mean low flow of the river (MLQ). Missing information in the court decisions is denoted not provided (NP). Note that Kaserna is a regulation dam and not a hydropower facility (hence, water flow and effect is not applicable (NA) at this site.

				Hydropower plant		River	
Facility	**Catchment**	**Court**	**Court case**	**Q (m^3/s)**	**Effect (kW)**	**MQ (m^3/s)**	**MLQ (m^3/s)**
Husbykvarn	Tämnarån	Nacka	M 593-22	6.00	340	6.12	1.03
Ullfors	Tämnarån	Nacka	M 611-22	5.00	80**	6.12**	1.03
Fada	Kilaån	Nacka	M 628-22	1.10	NP	0.03	0.01
Skeppsta	Trosaån	Nacka	M 629-22	0.80	55	NP	0.05
Kengis bruk	Torneälven	Umeå	M 2448-22	6.80	220	157	22.6
Kärramölla	Stensån	Vänersborg	M 332-22	1.10	16	1.04	0.18
Lingforsen	Fylleån	Vänersborg	M 3419-22	1.10	NP	1.58	0.13
Sandhult Näs	Rolfsån	Vänersborg	M 3466-22	0.15	15	0.07	0.01
Ellenö	Örekilsälven	Vänersborg	M 351-22	9.80	360	7.30	NP
Stigen Västra	Örekilsälven	Vänersborg	M 395-22	2.50	120	0.66	0.10
Kaserna	Örekilsälven	Vänersborg	M 415-22	NA	NA	10.00	1.70

**Provided by the County Administrative Board.

Table 2. Descriptive data for the 11 facilities granted continued hydropower production (conditional on meeting modern environmental standards), detailing name of the facility, and requirements concerning type of guidance, maximum angle of rack (in cases where the type of guidance was an alfa or beta rack), maximum gap width of rack (in cases where the type of guidance was an inclined or angled rack), amount of water discharge through bypass, eel ramps, type of fishway, required slope of fishway, flow in fishway, minimum flow in fishway, and hydropeaking. Missing information in the court decisions is denoted not provided (NP). Note that Kaserna is a regulation dam and not a hydropower facility (hence, water flow and effect is not applicable (NA) at this site.

	Downstream passage				**Upstream passage**				**Flow**		
Facility	**Guidance**	**Angle**	**Gap width (mm)**	**Bypass (l)**	**Eel ramp**	**Fishway**	**Slope**	**Flow (l/s)**	**Min. flow (l)**	**No peaking**	**Reduced rate**
Husbykvarn	Inclined rack	35	18	90	No	Nature-like**	2,5%	330	NP	X	
Ullfors	Inclined rack	35	18	150	No	Vertical slot	7%	NP	NP		
Fada	Rack (undefined)	45*	18	NP	Yes	No	NA	NA	26	X	
Skeppsta	Inclined rack	30	18	NP	No	Nature-like	1,2%	50	50	X	
Kengis bruk	Large spill + shutdown	NA	NA	NA	No	River	NA	NA			
Kärramölla	Rack (undefined)	35	13	80	No	Nature-like	4%*	NP	180		
Lingforsen	Rack (undefined)	35	15	70	Yes	Nature-like	3%	170	170	X	X
Sandhult Näs	Rack (undefined)	35	15	30	Yes	No	NA	NA	5		
Ellenö	Inclined rack	35	18	NP	Yes	No	NA	NA	220	X	
Stigen Västra	Angled rack	30	18	100	Yes	No	NA	NA	100	X	X
Kaserna	Spill (no turbine)	NA	NA	NA	Yes	Vertical slot**	5%	NP	1000		

*Provided in comment to the court decision (in Swedish: *domskäl*). ** Provided by the County Administrative Board.

Downstream passage

Guidance screens and associated bypasses are required at nine of the 11 facilities (Table 2). Among the required guidance screens, four are inclined (alfa-rack), one is angled (beta-rack), and four are undefined (Table 2). Maximum angles against the flow are 30° (*n*=2), 35° (*n*=6), and 45° (*n*=1), while maximum gap widths are defined as 13 mm (*n* = 1), 15 mm (*n* = 2), or 18 mm (*n* = 6) (Table 2). Bypass pipes leading fish downstream are required together with the rack except at *Fada*, where eels are to be trapped in a traditional eel trap (in Swedish: *ålkista*) and transported downstream past the dam (transport of other species is not mentioned). One facility requires an overlay plate for velocity refuge by the end of the rack (*Lingforsen*). At one facility, the lack of such plate is explained by low water velocity making it redundant (*Ellenö*). For six facilities where guidance racks were required, bypass discharge is defined to 30-150 L s^{-1}. Based on turbine capacity stated in the verdicts, this corresponds to a median of 5.2 % (range = 1.5% - 20 %, n = 6) of the maximum flow through the rack itself. Two facilities did not require guidance screens, *Kaserna* (the regulation dam) and *Kengis bruk*. The facility *Kaserna*, being a regulation dam, does not have a turbine but regulates flow for downstream hydropower plants and therefore the court presumably assumes that fish will safely pass through the only route available. At *Kengis bruk*, the dam does not cover the full width of the river, and remedial measures to improve downstream passage include reducing the width of a temporary dam, closing the power plant for two weeks during peak salmonid smolt migration (closure triggered by either temperature increases or peak flow), and running the power plant with open sluice gates next to the turbine intake through the bulk of the smolt run. Other fish species are not mentioned.

Upstream passage

At all facilities except Kengis bruk (where the dam does not span the full river width), some type of upstream passage solution is required (Table 2). This includes fishways that allows the entire fish community to pass, or at least a large part of it (*n* = 6), or eel ramps for juvenile eels (*n* = 6) (Table 2). Two verdicts require both an eel ramp and a technical fishway (Table 2). Where only eel ramps are required, this is based on assumptions that naturally, this reach would only be passable for eel.

Among the required fishways, four are nature-like and two vertical slot fishways, (Table 2). Slopes for nature-like fishways range from 1.2% to 4% (Table 2), while the vertical slot fishway has a maximum drop of 15 cm and a slope of 5-7%. Where specified (*n* = 4), water discharge to the fishways ranges from 50 to 330 L s^{-1} (Table 2), or 5% to 17% of the river's mean annual flow (MQ) in the three cases with available data. One of the eel ramps requires the downstream bypass pipe to exit near the ramp to provide additional attraction water.

The operation period is defined for three fishways and five eel ramps. Fishways must function year-round, except one site where winter conditions (e.g., ice cover) exempt operation. Eel ramps are mandated to operate from May (*n* = 4) or June (*n* = 1), to end of September (*n* = 2) or mid-October (*n* = 3). For three facilities (*Lingforsen, Ellenö,* and *Stigen Västra*), operation periods may be adjusted in consultation with the County Administrative Board (i.e., the supervisory authority). For the facility *Stigen Västra* it is further specified that based on climate change and/or new knowledge, operation period adjustments may be needed. In addition, for three facilities (*Ellenö*, *Stigen Västra*, *Kaserna*), it is specified for what eel sizes the ramp shall function for (10-40, or 0-70 cm), and the facility *Stigen Västra* specifies that the eel ladder substrate should accommodate eel in many sizes, from 0-70 cm.

Fishway placement is detailed in some verdicts, while others require the final setup to be determined in consultation with the County Administrative Board or a fish passage specialist. At one facility (*Lingforsen*), a chain barrier is prescribed to guide fish from the tailrace to the bypassed river where the fishway is located. At another facility (*Husbykvarn*), an additional fishway is required to connect the tailrace to the area downstream the spillway, where the primary fishway is situated. At one site (*Kärramölla*), the power plant must shut down one day per week from September to October to facilitate upstream migration (attraction to the fishway) of salmonid spawners.

Flow and habitat

Hydropeaking (i.e., short term shifts in turbined discharge to track electricity demands or prices, in Swedish: *korttidsreglering*) is explicitly prohibited in six verdicts, while two verdicts mandate reduced rates of change in spilled or turbined flow. Despite most dams having bypassed river reaches of different lengths, minimum flow is typically just a consequence of discharge in the fish passage solutions. Mandated minimum flow range from 5 to 610 L s^{-1} (Table 2) or the current river discharge. Mean annual flow (MQ) and mean low flow (MLQ) are available in the verdict background material for nine facilities. For these, the median environmental flow constitutes 10 % (range: 3% - 17%) of the mean MQ, or 100% (range: 50% – 131 s%) of MLQ. Dynamic or adaptive environmental flows are not mentioned in any verdicts. Downstream habitat restoration to facilitate fish movement is required in three cases (*Lingforsen, Kärramölla, Ellenö*). No other habitat measures are mentioned in any verdicts.

Monitoring

Monitoring requirements in the court verdicts for actions implemented to fulfil modern environmental conditions are limited. For most facilities, monitoring requirements only concern registration of water discharge, or confirming water discharge in fish passage solutions. Evaluation of the function of remedial measures is only required in a few verdicts (*Fada*, *Skeppsta*, *Kaserna*, *Kärramölla*). At the facility *Fada*, the functionality of up- and downstream passage facilities should be confirmed using the best available monitoring technique during the first three years post-implementation. This verdict also allows adjustment if conservation status targets (Swedish: *bevarandestatus*) or environmental quality standards (Swedish: *miljökvalitetsnorm*) are not met. At the facility *Skeppsta*, a statement of functionality from an expert is required, but the basis for the statement is not defined. At the facility *Kaserna* (the regulation dam), evaluation of the functionality of the fish passage solution is also required, again without specifying what the evaluation should contain. For the facility *Kärramölla*, the regulatory authority should advise on the evaluation of passage solutions. Regarding eel ramps, monitoring is only mentioned for one facility (*Lingforsen*) where the eel ladder should be checked weekly, no additional information is given in the verdict.

Withdrawal of permit and dam removals

Of the 33 retrials completed so far, 22 led to dam removal (typically at the owner's request). These cases fall outside of the main scope of this study, however, monitoring post-removal-effects is important to understand ecosystem responses, and we therefore present data on dam removals in short. Seven facilities were small scale (effect below 1.5 MW), and the remaining 15 were listed as having “unknown” effect (some of which were dams, not hydropower plants). One dam, not even remains, could be found (*Damm vid Småvatten* M 580-20). All verdicts list some form of restorative and/or habitat enhancing measures, and most mandate monitoring efforts.

Table 3. Descriptive data for 22 facilities where the retrial led to dam removal, detailing name of facility, river catchment, court, court case number, effect of hydropower plant (unknown or small scale < 1.5 MW). Note that some facilities are dams and not hydropower plants.

Facility	River catchment	Court	Court case	Size
Mölnbokvarnsdammen	Trosaån	Nacka	M 630-22	Unknown
Bäckland Kraftverk	Ångermanälven/Gådeån	Östersund	M 286-22	Small scale
Fansendammen	Testeboån	Östersund	M 2697-22	Unknown
Grössjö kraftverk	Grössjöån	Östersund	M 284-22	Unknown
Torringens*	Ljungan	Östersund	1523-23	Unknown
Ovansjö Kraftverk	Ljungan/Stångån	Östersund	M 107-23	Unknown
Skärsätts Kraftverk	Ljungan/Stångån	Östersund	M 1521-23	Unknown
Torrsjö kraftverk	Ljungan/Stångån/Torrsjöån	Östersund	M 1522-23	Unknown
Kölsjödammen	Testeboån	Östersund	M 2699-22/M 545-24	Unknown
Storfallets kraftverk	Kågeälven	Umeå	M 1957-22	Unknown
Forslidens kraftverk	Rickleån	Umeå	M 3634-20	Small scale
Damm vid Småvatten	Örekilsälven	Vänersborg	M 580-22	Unknown
Damm vid Ålevatten	Örekilsälven	Vänersborg	M 578-22	Unknown
Stora Holmevatten	Örekilsälven	Vänersborg	M 582-22	Unknown
Jordals kraftverk	Örekilsälven	Vänersborg	M 368-22	Unknown
Hultafors kraftstation	Rolfsån	Vänersborg	M 3476-22	Small scale
Loviseholms kraftverk	Enningdalsälven	Vänersborg	M 16-22	Small scale
Stockforsens kraftverk	Gullspångsälven	Vänersborg	M 2093-23	Small scale
Ebbarps kraftverk	Rönne å	Vänersborg	M 505-22	Small scale
Rössjöholms kraftstation	Rönne å	Växjö	M 5011-21	Unknown
Söndraby kraftverk	Rönne å	Växjö	M 509-22	Unknown
Västra kvarn	Rönne å	Växjö	M 495-22	Small scale

DISCUSSION

Since the initiation of the National Plan for Modern Environmental Conditions for Hydropower in 2000 to the first pause in 2023, a total of 33 cases have been completed. Of these, 11 facilities were granted continued hydropower production, conditional on fulfilling modern environmental conditions. The remaining 22 cases resulted in permit withdrawal and dam removal (typically at the owner's request). All verdicts focus on longitudinal connectivity and fish passage and are based on present species distribution and environmental conditions. When mentioned, monitoring requirements focus mainly on abiotic factors (e.g., flow in fishway), with only a few verdicts formulating requirements based on function or ecological effects.

Downstream passage versus guidelines

Given the historical relative absence of downstream passage solutions in Swedish rivers (Calles et al. 2013), it is encouraging that most verdicts include specific protection and guidance systems to allow downstream passage of fish. Nine verdicts require low sloping racks with small gap-widths to hinder fish from passing through turbines and guide them to a safe route. Versions of such solutions have proven effective for eel (Calles et al. 2021; Tomanova et al. 2023) and juvenile and adult salmon (Nyqvist et al. 2017, 2018; Tomanova et al. 2021). Gap width (Harbicht et al. 2022) and angle (Albayrak et al. 2020) are important characteristic of the guidance rack function. In the assessed verdicts, gap-widths and sloping angle ranged between 13-18 mm 30-45°, respectively. Calles et al. (2013) defines best available technique as gap-widths of 10-13 mm and angles ≤ 30°, but do not exclude good performance at slightly higher values. Indeed, good guidance has been reported for gap widths of 15-20 mm, and angles of 26-30° (Calles et al. 2021; Tomanova et al. 2023). Passage performance also depends on features like overlay plates and bypass entrance design (Albayrak et al. 2020), and low passage performance is still possible (de Bie et al. 2018). Also, fish sizes up to 20-times the gap-width can pass through these racks (Knott et al. 2023). Therefore, given the technical specifications defined in the verdicts, good passage performance is possible but should not be assumed.

Upstream passage vs guidelines

Upstream passage solutions adapted for the entire fish community are only required where such passage historically existed. Described slopes in the verdicts aligns with some guidelines (FAO/DVWK 2002; SwAM 2020) but partially breach recommendations in others (Calles et al. 2013; Schmutz and Mielach 2013). Importantly, fish passage success is the product of multiple steps as the fish must approach, enter, pass through, and exit the fishway (Castro-Santos et al. 2009). While slope-recommendations focus on ensuring that the fish can pass through the fishway, the attraction (i.e., finding and entering the fishway) is typically an important source of failure (Bunt et al. 2012). Attraction efficiency depends on water discharge proportion and entrance placement, and positions close to the barrier and main flow, and discharges of at least 5%, is recommended for small rivers (Calles et al. 2013). Placement is typically considered in the verdicts, and for the three facilities where fishway discharge and mean annual discharge of the river was available, proportions ranged from 1%–10%, aligning somewhat with the guidelines. The ideal fishway position, however, depends on discharge composition. For example, a fishway may have high attraction when most water is turbined, and low attraction when much water is spilled (Hagelin et al. 2019). As placement and water allocation often conflict with electricity production, obtaining good passage conditions typically require data on functionality followed by adaptive designs (Nyqvist et al. 2017).

Some locations are considered naturally passable only by juvenile eels, and hence only requiring an eel ramp. Design and placement of the eel ramp is important for its performance (Fjeldstad et al. 2018). Other parameters that may affect the function of eel ramps include longitudinal and lateral slope, climbing substrate, conveyance flow, flow direction, and crest shape, and concerns have been raised that many eel ramps may function poorly (e.g., Watz et al. 2019; Williamson et al. 2025). Very few verdicts specify design or placement, except the facility *Fada*, where the eel ramp should be 300 mm wide, and the facility *Stigen Västra*, where the ramp substrate should work for fish of many sizes (however, without specifying type of substrate). It is also worrying that the operation period varies, since no reasoning is provided. In Sweden, eel migrate upstream outside the periods specified in the verdicts. For example, glass eel are trapped in the cooling water intake at the Ringhals nuclear power plant already by January/February (Westerberg and Wickström 2016; Jaktén Langert et al. 2025) and migrate upstream in river Viskan throughout October (Sjöholm and Käll 2024). Functioning eel ramps are crucial not only for river connectivity but also for monitoring of recruitment (ICES WGEEL 2024). Notably, the longest European eel recruitment series (1900-2017) comes from such monitoring at the *Olidan* facility in river Göta älv (ICES WGEEL 2024, unfortunately, the data collection was discontinued 2018). Only one verdict requires regular checks of the eel ramp (*Lingforsen*), but no information is given on what the checks implies, or if data on eel counts should be collected. To ensure the function of eel ramps and data collection on recruitment, guidelines regarding operation period, placement, design, and monitoring will be needed in future verdicts.

Flow, habitat, and other impacts

All facilities receiving verdicts of modern environmental conditions are small run-of-the-river hydropower plants with very limited water storage capacity. This likely explains the strong focus on passage solutions and the relative omission of habitat and flow related measures, with these restricted to fishway flows, prohibition against hydropeaking or restricted ramping rates. Nevertheless, several of the dams have bypassed river reaches that are most likely degraded (compared to their original lotic state) by water abstraction for hydropower production (Kiernan et al. 2012; Poff et al. 2010). Despite this, environmental flows are only a consequence of flow through the fishway (i.e., all flow goes through turbines or the fishway, there's no additional environmental flow), and habitat concerns in bypassed stretches are largely restricted to downstream passability. Importantly, hydropower mitigation is related to broader ecological functions beyond passage (He et al. 2024), even if impacts on fishes often dominate media and stakeholder attention. Given the high frequency of damming, and hence the lack of lotic river reaches, ignoring flow and habitat effects may be an opportunity lost for Swedish rivers (Göthe et al. 2019).

The apparent focus on fish passage solutions in the verdicts also implies that other environmental impacts are largely overlooked. For example, few non-fish related measures are mentioned. While nature-like fishways can facilitate passage for other animals (e.g., invertebrates: Streib et al. 2020), the same is not true for eel ramps. Moreover, flow conditions unrelated to passage, and issues like temperature and gas supersaturation are ignored (Zaidel et al. 2021; Li et al. 2022; Poff et al. 2010). As a result, even with modern environmental conditions, downstream habitats and non-fish species (e.g. birds, semi-aquatic animals, and riparian plants) may remain as impacted as before (e.g., Nilsson et al. 1997; He et al. 2024; Altanov et al. 2025). Even though the re-licensed facilities are relatively small dams and short bypassed river reaches, this oversight may have significant national implications for ecosystem values at risk. This is particularly relevant in Sweden, where the absolute majority of hydropower facilities are small (approximately 1900 plants contribute 6% to the total Swedish hydroelectricity, including $n \approx 1030$ micro-powerplants with effects under 125 kW, Lindblom and Holmgren 2016), with only 208 power plants having an effect over 10 MW, producing approximately 94% of the Swedish hydroelectricity (Lindblom and Holmgren 2016).

Lack of monitoring requirements

Given the inherent compromise between energy production and function, fish passage design is not an exact science. A fishway may follow all guidelines yet still perform poorly due to issues with attraction, entrance, or conditions after passage (Nyqvist et al. 2016; Hagelin et al. 2019). Hence, bypasses can become mortality traps instead of safe passage routes (Nyqvist et al. 2016), and even well-functioning fishways can cause delays due to low attraction efficiency (Hagelin et al. 2019). It is therefore worrying that most court verdicts gloss over post-construction monitoring, with only three explicitly requiring evaluation of function. Additionally, the empirical evidence for many mitigation measures is relatively vague, making detailed design requirements without corresponding functionality requirements, problematic (Rogosch et al. 2024). Monitoring, evaluation, and adaptation are key for successful restoration in general, particularly for fish passage solutions (Rogosch et al. 2024). Some verdicts allow adaptive passage solution adjustments if conservation status targets or environmental quality standards are not met. This is, in general, a sound approach that inevitably rely on monitoring. It is however important to consider that environmental indices, used in e.g. ecological status assessment, are indicative, not definitive, with respect to ecological status assessment, and carry substantial uncertainties and in some cases flaws (Löfgren et al. 2009; Näslund et al. 2022). Hence, clear monitoring objectives are necessary for proper evaluations.

The hydropower facilities that have completed re-licensing so far are small, making substantial monitoring appear costly relative to production values. Instead of being a potential argument against monitoring and evaluation, however, this can be seen as an incitement for an industry-wide approach: coordinated monitoring across sites could be more productive than isolated efforts. For example, studying fish passage efficiency and environmental flows at multiple locations could inform on what works under specific conditions (Weber et al. 2018). Such an approach would evaluate specific mitigation effort types while also expanding our knowledge on mitigation solutions in general. Results could suggest adaptations for existing solutions and inform future court processes. Requiring functionality and monitoring appears fundamental for a successful re-licensing process, and it´s omission a lost opportunity to the detriment of our rivers.

Dam removals – opportunities from a wider management perspective

Of the 33 retrials, 22 led to permit withdrawals and dam removals, typically at the owner's request. Given that dam removal eliminates environmental issues related to longitudinal connectivity and natural flow dynamics (provided sufficient post-removal river channel restoration), this is encouraging from a river ecology perspective. It is also noteworthy that dam removals present an opportunity to contribute to the 25000 km of free-flowing river sections mandated (at the EU-wide level) by the recently implemented EU Nature Restoration Regulation (EU 2024/1991). This, however, requires consideration of additional environmental measures in terms of restoring lateral river connectivity in reaches up- and downstream of the removed dam, likely by other actors than the dam owners. Synchronized planning and a holistic approach at larger spatial scales could benefit river- and riparian ecosystems and create synergistic positive effects on ecosystem services (Stoffers et al. 2024). Taking the opportunity to monitor ecological effects of the dam removals, from a central agency perspective, could also inform future restoration- and hydropower mitigation projects, including insights on ecosystem recovery rates.

Conclusion

We conclude that while fishways (and/or eel ramps) are covered in most verdicts where continued hydropower production was granted, the focus on a few design components rather than actual functionality risks poor passage efficiency. The lack of monitoring requirements means that even if passage efficiency is high, it will be undocumented. We propose that fishways should enable passage for the entire fish community, which typically requires site specific adaptive design and monitoring of functionality (Nyqvist et al. 2017; Silva et al. 2018). For eel ramps, guidelines on placement, design, and monitoring should be followed (e.g., Fjeldstad et al. 2018; Watz et al. 2019; Williamson et al. 2025), and the operation period should cover the entire migration period (Westerberg and Wickström 2016; Sjöholm and Käll 2024; Jaktén Langert et al. 2025). Beyond passage, other parameters should be covered, inducing but not limited to habitat restoration, ensuring flow and avoiding dry stretches, avoidance of warming and gas supersaturation, and inclusion of non-fish organisms (e.g., Nilsson et al. 1997; Zaidel et al. 2021; He et al. 2024; Altanov et al. 2025). We emphasize that dam removals represent an unprecedented chance to contribute to improved ecological integrity in our waters, as well as to the mandated goals within the recently implemented EU Nature Restoration Regulation (EU 2024/1991). The vast nation-wide Swedish retrial process provides a unique opportunity to implement measures and monitoring to improve not only connectivity, but the whole riverine ecosystem.

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CRediT and MeRIT author contributions

In this manuscript, methods are reported using the author's initials to clarify contributor roles for reproducibility and replicability using the Method Reporting with Initials for Transparency (MeRIT) guidelines (Nakagawa et al. 2023). Additional author contribution roles are listed here according to the Contributor Role Taxonomy (CRediT) guidelines (https://credit.niso.org): Conceptualization: JS, DN, JN, PJ; Data curation: BJ, DN; Visualization: BJ; Writing - original draft: JS, DN, JN; Writing - review & editing: all authors.

Conflict of interest statement

The authors declare no conflict of interest. Note that this paper is an academic contribution and should not be seen as explicit legal advice.

Ethical statement

All data in the paper was extracted from court decisions that are publicly available due to the principle of public access to information in Sweden (SFS 2009:400).

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