

# Insights from a nation-wide environmental relicensing of hydropower facilities in Sweden: a review of court verdicts from a biological perspective

Josefin Sundin <sup>\*</sup>, Joacim Näslund, Philip Jacobson, Birgitta Jacobson, Johan Östergren and Daniel Nyqvist

Swedish University of Agricultural Sciences, Department of Aquatic Resources, Stångholmsvägen 2, SE-17893, Drottningholm, Sweden

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**Abstract** – Hydropower, utilized for centuries, is promoted globally as renewable energy. The many ecological costs associated with hydropower facilities can be mitigated, but the perceived socio-economic benefits often outweigh environmental concern. The EU Water Framework Directive (WFD), implemented in 2000, established a framework for community action in the field of water policy. It constitutes an instrument to compel hydropower facilities to align with environmental requirements. Based on the WFD and national law, a National Plan for Modern Environmental Conditions for Hydropower (NAP) was formulated in Sweden to renegotiate the environmental permits of around 2000 hydropower plants and dams. The NAP process commenced in 2022 and is estimated to last approximately 20 years. In this review, we assessed the 33 court cases completed until the end of 2024, out of which 22 resulted in permit withdrawal and dam removal, while 11 received decisions requiring remedial measures. The primary focus of remedial measures was re-establishing 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. In addition, greater attention should be given also to aquatic habitats in affected reaches: addressing *e.g.*, flow, water levels, and temperature. In conclusion, this nation-wide process provides a unique opportunity to implement measures that could benefit entire riverine ecosystems.

**Keywords:** Dam removal / environmental law / fish migration / hydroelectric production / river connectivity

## 1 Introduction

Hydropower facilities and their associated dams and reservoirs have contributed energy to human society for centuries, initially on a local scale in the form of *e.g.*, mills and later at much larger scales after the development of hydroelectric plants (Almeida *et al.*, 2022). Hydroelectricity is globally promoted as a renewable resource, but ecological costs are often high (He *et al.*, 2024; Nyqvist *et al.*, 2025). Impoundments upstream of dams turn river rapids into lake-like environments and downstream sections have altered flow-sedimentation- and physico-chemical 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, Algera *et al.*, 2020; Nyqvist *et al.*, 2025). 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). On a global scale, dams are considered to be a threat to almost 4000 aquatic, semi-aquatic, and terrestrial species (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 focused 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”) (Richter *et al.*, 1997; Poff *et al.*, 2010; Acreman *et al.*, 2014). A main concern related to environmental flow is lost power production, but

\*Corresponding authors: [josefn.sundin@slu.se](mailto:josefn.sundin@slu.se);  
[josefn@teamsundin.se](mailto:josefn@teamsundin.se)

models indicate that the annual loss need not be substantial (Widén *et al.*, 2022b), 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, monitoring and evaluation of the applied measures in combination with adaptive management based on such evaluations is required for successful mitigation performance (Birnle-Gauvin *et al.*, 2017; Nyqvist *et al.*, 2017).

In Sweden, the usage of water for energy generation dates back many centuries, supplying *e.g.*, mills, triphammers, and saws through waterwheels, often fed from small dams (Fryxell *et al.*, 1931; 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). A quick expansion of private and municipal hydropower plants followed in the late 1800's and early 1900's (Fryxell *et al.*, 1931). Large-scale production plants were inaugurated in the 1910's at the advent of state-owned hydropower (*Olidan* in the river Göta älv in 1910, *Porjus* in the river Luleälven in 1915, and *Älvkarleby* in the river Dalälven in 1917, Fryxell *et al.*, 1931; 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 existent (legally bound) operational permits, or the lack thereof in some cases (Ödmann *et al.*, 1982; Lindström and Ruud, 2017; Schäfer, 2021). Indeed, hydropower plants often operate under original permits that have remained valid without re-evaluation under modern environmental laws (Svensson, 2000). Consequently, in Sweden, hydroelectric production has historically faced fewer environmental mitigation requirements than other industries (Schäfer, 2021). Even if some 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 indigenous 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, the EU Water Framework Directive (2000/60/EC) was implemented in 2000, which established a framework for community action in the field of water policy. Based on this directive, and the legal update, the Swedish government tasked the Swedish Agency for Marine and Water Management (SwAM), the Swedish Energy Agency, and Svenska Kraftnät (the authority responsible for Sweden's electricity transmission system) with coordinating efforts to modernize environmental conditions of hydropower facilities (SwAM *et al.*, 2019). 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 yr (Swedish Government, M2019/01769). This large-scale process, covering almost all of Sweden's hydropower plants and dams, was decided upon by the government in 2020 and commenced in 2022 and is estimated to take approximately 20 yr. It 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). The NAP work has, however, not progressed undisturbed. In December 2022, 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 then extended the pause several times, with the latest extension lasting until July 1, 2025 (SFS 2024:285), and the process was restarted in August 2025. 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]. The NAP process hence constitutes an exceptional case study where energy production needs are weighted against environmental protection via national and international environmental law and directives.

Fewer than 40 re-licensing court trials had been completed within the NAP process until the end of 2024. 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 functionality and effects of prescribed measures (*e.g.*, County Administrative Boards, 2022; Lenvin, 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 legally binding requirements for remedial measures. We summarize the listed measures and monitoring obligations, with particular attention to the European eel, *Anguilla anguilla*, given the high importance of up- and downstream connectivity for this species, and since it is critically endangered (Pike *et al.*, 2020). Gaps in the

requirements are identified, and we provide recommendations for measures and monitoring to be included in future retrials.

## 2 Review of court decisions

### 2.1 Data extraction

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 relicensing 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 had been completed until the end of 2024 (*i.e.*, before the onset of the pause, only counting 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 Portable Document Format (.pdf). From Strömmen, the following information was extracted: 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, the following information was extracted: capacity of the hydropower plant (Q), hydropower plant effect/power (in kilowatt, 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 inclined [alfa rack] or angled [beta rack]; Harbicht *et al.*, 2022), maximum gap width of rack (in cases where the type of guidance was an inclined or angled rack), discharge through downstream bypass, eel ramps (yes/no), type of fishway, required slope of fishway, flow in fishway, hydropeaking restrictions, e-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. In what context eel was mentioned was noted, and other relevant comments in relation to context were also noted. Information on measures and monitoring 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 the verdict were not taken into account.

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

### 2.2 Downstream passage measures in the court decisions

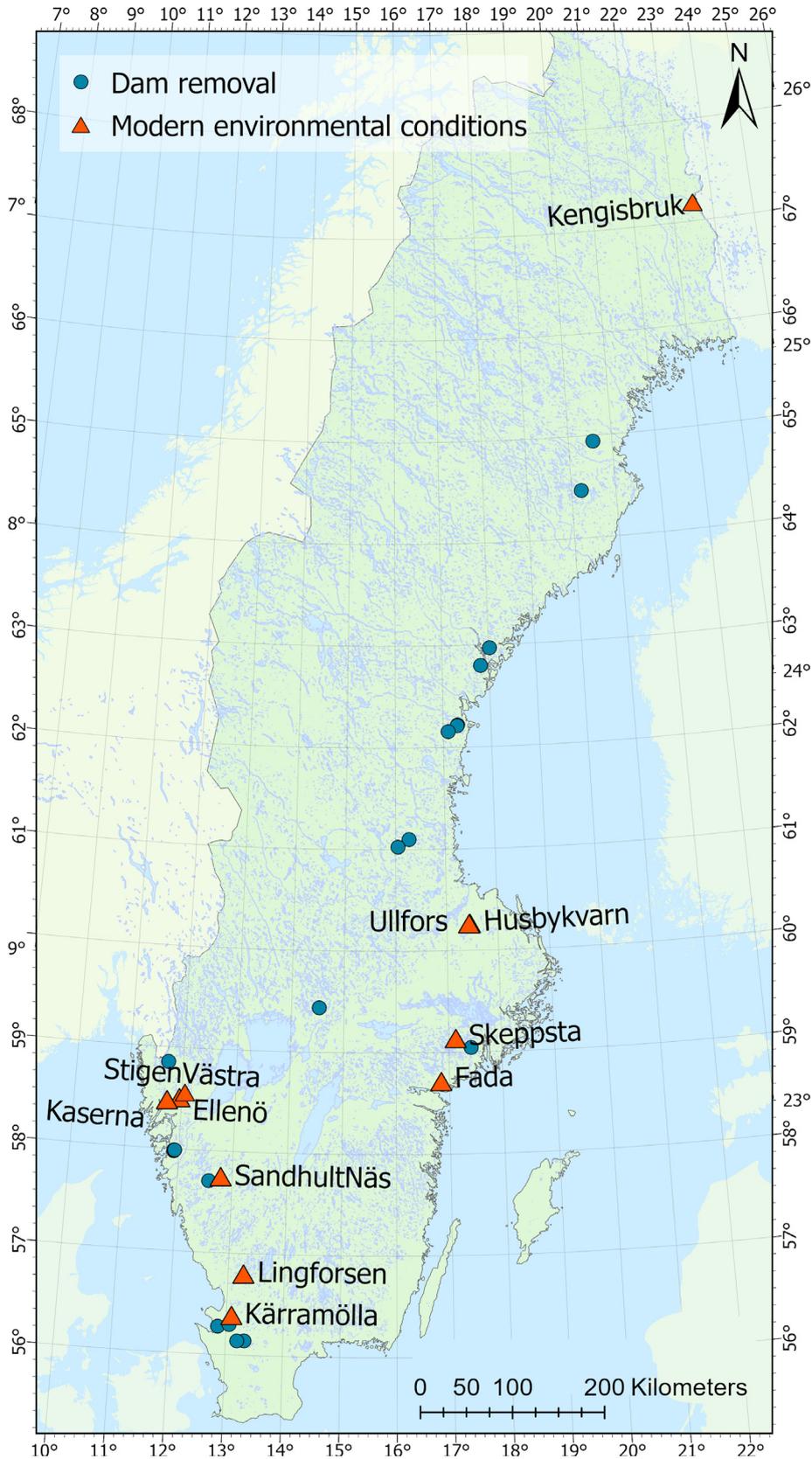
Guidance screens and associated bypasses are required at nine of the 11 facilities (Tab. 2). Among the required guidance screens, four are inclined (*i.e.*, guiding the fish vertically towards the water’s surface: alfa rack), one is angled (*i.e.*, guiding the fish laterally towards one side of the river/channel: beta rack), and four are undefined (Tab. 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 ( $n=6$ ) (Tab. 2). Bypass pipes leading fish downstream are required together with the rack at all facilities 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, ranging 30–220 L s<sup>-1</sup>. 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* 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).

### 2.3 Upstream passage measures in the court decisions

At all facilities except *Kengis bruk* (where the dam does not span the full river width), some type of upstream passage solution is required (Tab. 2). This includes fishways that allow the entire fish community to pass, or at least a large part of it ( $n=6$ ), or eel ramps for juvenile eels ( $n=6$ ) (Tab. 2). Two verdicts require both an eel ramp and a technical fishway (Tab. 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 are vertical slot fishways, (Tab. 2). Slopes for nature-like fishways range from 1.2% to 4% (Tab. 2), while the vertical slot fishway has a maximum drop of 15 cm and a slope of 5–7%. Where specified ( $n=3$ ), water discharge to the fishways range from 50 to 330 L s<sup>-1</sup> (Tab. 2), or 5% to 17% of the river’s mean annual flow (MQ). 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 for one



**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): name of the facility, river catchment, court, court case number, water flow of the hydropower plant (Q), effect of the hydropower plant (in kilowatt, 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).

Facility	Catchment	Court	Court case	Hydropower plant		River	
				Q (m <sup>3</sup> /s)	Effect (kW)	MQ (m <sup>3</sup> /s)	MLQ (m <sup>3</sup> /s)
Husbykvarn	Tämnaån	Nacka	M 593-22	6.00	340	6.12	1.03
Ullfors	Tämnaån	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	Vänernsborg	M 332-22	1.10	16	1.04	0.18
Lingforsen	Fylleån	Vänernsborg	M 3419-22	1.10	NP	1.58	0.13
Sandhult Näs	Rolfsån	Vänernsborg	M 3466-22	0.15	15	0.07	0.01
Ellenö	Örekilsälven	Vänernsborg	M 351-22	9.80	360	7.30	NP
Stigen Västra	Örekilsälven	Vänernsborg	M 395-22	2.50	120	0.66	0.10
Kaserna	Örekilsälven	Vänernsborg	M 415-22	NA	NA	10.00	1.70

\*\* Provided by the County Administrative Board.

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).

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.

#### 2.4 Flow and habitat measures in the court decisions

Hydropeaking (*i.e.*, short term shifts in turbinized 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 turbinized flow without specifying thresholds. 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<sup>-1</sup> (Tab. 2) or the 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%) 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*, and *Ellenö*). No other habitat measures are mentioned in any verdicts.

#### 2.5 Monitoring in the court decisions

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*, and *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 3 yr post-implementation. This verdict also allows adjustment if conservation status targets (in Swedish: *bevarandestatus*) or environmental quality standards (in Swedish: *miljö kvalitetsnorm*) are not met in accordance with relevant legislation (*i.e.*, the implementation of the EU Habitats directive (92/43/EEC) and Water Framework directive (2000/60/EC) in the Swedish Environmental Code). 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*)

**Table 2.** Descriptive data for the 11 facilities granted continued hydropower production (conditional on meeting modern environmental standards): name of the facility, requirements concerning type of guidance, maximum angle of rack (in cases where the type of guidance was an alpha 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 (yes/no), type of fishway, required slope of fishway, flow in fishway, minimum flow, restriction against hydropeaking (No peaking), and requirements to change turbine discharge at a slow rate (Reduced rate). 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 are not applicable (NA) at this site).

Facility	Downstream passage			Upstream passage			Fishway	Slope	Flow (L/s)	Flow		Reduced rate
	Guidance	Angle	Gap width (mm)	Bypass (L)	Eel ramp	Min. flow (L)				No peaking		
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	180			
Kärrmölle	Rack (undefined)	35	13	80	No	Nature-like	4%*	NP	170	X	X	
Långforsen	Rack (undefined)	35	15	70	Yes	Nature-like	3%	NA	5			
Sandhult Näis	Rack (undefined)	35	15	30	Yes	No	NA	NA	220	x		
Ellenö	Inclined rack	35	18	NP	Yes	No	NA	NA	100	X	X	
Stigen Västra	Angled rack	30	18	100	Yes	Vertical slot**	5%	NP	1000			
Kaserna	Spill (no turbine)	NA	NA	NA	Yes							

\*Provided in comment to the court decision (in Swedish: *domskäl*).

\*\* Provided by the County Administrative Board.

where the eel ladder should be checked weekly, no additional information is given in the verdict.

### 2.6 Withdrawal of permit and dam removals in the court decisions

Of the 33 retrials completed so far, 22 led to dam removal (Tab. 3). These cases fall outside of the main scope of this study. Monitoring post-removal-effects is however 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), which is within the same range as those that were granted permission for continued hydropower production (Tab. 1), and the remaining 15 were listed as having “unknown” effect (some of which were dams, not hydropower plants) (Tab. 3). One dam could not be found in the field, not even remains of it, (*Damm vid Småvatten* M 580-22, Tab. 3). All verdicts list some form of restorative and/or habitat enhancing measures.

## 3 Discussion

Since the start of the retrials within the National Plan for Modern Environmental Conditions for Hydropower in 2022 to the first pause in 2023, a total of 33 cases have been completed (until the end of 2024, counting decisions that cannot be overruled). 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. 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 of remedial measures.

### 3.1 Downstream passage and 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 characteristics to 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  $\leq 30^\circ$ , but the authors do not exclude good performance at slightly larger gap-widths and greater angles. 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). Guidance performance also depends on features like overlay plates and bypass entrance design (Albayrak *et al.*, 2020), which at times can result in low

**Table 3.** Descriptive data for 22 facilities where the retrial led to dam removal: 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
Torrings*	Ljungan	Östersund	1523-23	Unknown
Ovansjö Kraftverk	Ljungan/Stångån	Östersund	M 107-23	Unknown
Skärsätts Kraftverk	Ljungan/Stångån	Östersund	M 1521-23	Unknown
Torrjö kraftverk	Ljungan/Stångån/Torrjöån	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	Vänernborg	M 580-22	Unknown
Damm vid Älevatten	Örekilsälven	Vänernborg	M 578-22	Unknown
Stora Holmevatten	Örekilsälven	Vänernborg	M 582-22	Unknown
Jordals kraftverk	Örekilsälven	Vänernborg	M 368-22	Unknown
Hulta kraftstation	Rolfsån	Vänernborg	M 3476-22	Small scale
Loviseholms kraftverk	Enningdalsälven	Vänernborg	M 16-22	Small scale
Stockforsens kraftverk	Gullspångsälven	Vänernborg	M 2093-23	Small scale
Ebbarps kraftverk	Rönne å	Vänernborg	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

guidance performance (de Bie *et al.*, 2018). Also, fish sizes up to 20-times the gap-width can pass through these racks (Knott *et al.*, 2023), however, this likely varies between species due to differences in body shape. Therefore, given the technical specifications defined in the verdicts, good guidance performance is possible but should not be assumed for all species of fish.

### 3.2 Upstream passage vs. guidelines

Upstream passage solutions adapted for the entire fish community are only required at sites that allowed natural passage historically. Described slopes in the verdicts align 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 turbinated, and low attraction

when much water is spilled, or vice versa, depending on where the fishway is positioned in relation to the hydropower plant (Hagelin *et al.*, 2019). Interestingly, one verdict mandates a chain guidance barrier to guide fish towards the fishway. While potentially useful, the scientific knowledge on physical guidance for upstream migrating fish remains poor (Benitez *et al.*, 2025). Overall, 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).

Due to natural barriers such as waterfalls, some locations are considered naturally passable only by juvenile eels, and hence only requiring an eel ramp. Importantly, eel ramps – as most upstream passage solutions – are only designed to aid upstream migration, not downstream migration, and hence constitute a one-way migration solution that needs to be accompanied by downstream passage solutions. Placement is important for the performance of the eel ramp, as well as the design, including longitudinal and lateral slope, climbing substrate, conveyance flow, flow direction, and crest shape (Fjeldstad *et al.*, 2018). 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). Monitoring of the eel ramp functionality is generally lacking. It is also worrying that the operation period varies (when defined, specified to start in May or June, and last until end of September or mid-October), 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 the nearby 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 the river Göta älv (ICES WGEEL, 2024; unfortunately, the data collection was discontinued in 2018). Only one verdict requires regular checks of the eel ramp (*Lingforsen*), but no information is given on what the checks imply, or if data on eel counts should be collected. To ensure the function of eel ramps and data collection on recruitment, guidelines, monitoring, and an adaptive approach regarding operation period, placement, and design, will be needed in future verdicts.

### 3.3 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 rates of change of turbine discharge. 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 (Poff *et al.*, 2010; Kiernan *et al.*, 2012). Despite this, environmental flows are only a consequence of flow through the fishway (*i.e.*, there's no additional environmental flow requirements), 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 fish passage 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; Widén *et al.*, 2022a, c; 2023).

The narrow 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 (Poff *et al.*, 2010; Zaidel *et al.*, 2021; Li *et al.*, 2022). 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, at national scale this oversight may have significant 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 approximately 1030 micro-powerplants with effects under 125 kW, Lindblom and Holmgren, 2016). Only 208 power plants

have an effect over 10 MW, contributing approximately 94% of the Swedish hydroelectricity (Lindblom and Holmgren, 2016).

### 3.4 Lack of monitoring requirements

Ensuring proper function of passage solutions is important given the inherent compromise between energy production and function, which means that there are many different passage solution designs (Noonan *et al.*, 2012; Bunt *et al.*, 2012). Even if fish are able to pass through the fishway it may 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 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 some 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 relies on monitoring. When monitoring is required, it is 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, well-formulated specific and relevant 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; Nyqvist *et al.*, 2025). 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. Similarly, technical validation could also be coordinated, ensuring that the implemented measures follow standards and guidelines. Validation documents could be shared, and the joint level of ambition could thereby increase. Requiring functionality, maintenance of installations, and monitoring appears fundamental for a successful re-licensing process, and its omission a lost opportunity to the detriment of our rivers.

### 3.5 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 ecosystems (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.

## 4 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, or vice versa, 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), the operation period should cover the entire migration period (Westerberg and Wickström, 2016; Sjöholm and Käll, 2024; Jaktén Langert *et al.*, 2025), and a downstream passage solution needs to be combined with the eel ramp. Beyond passage, other parameters should be covered, including but not limited to habitat restoration, ensuring flow and avoiding dry stretches, avoidance of temperature effects 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 resulting dam removals represent an unprecedented chance to further improve ecological integrity in our waters, as well as contributing to the mandated goals within the recently implemented EU Nature Restoration Regulation (EU, 2024/1991). At the current retrieval speed however, there is a risk that the goal of processing all hydropower facilities within 20 yr will not be reached, implying prolonged ecological risk to the riverine ecosystems (Nyqvist *et al.*, 2025). The nation-wide Swedish retrieval process does nonetheless provide a unique opportunity to implement measures and monitoring to improve not only connectivity, but the whole riverine ecosystem, and early cases can serve as case studies for implementation of mitigation measures in other hydropower-regulated rivers.

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## Conflicts of interest

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

## Data availability statement

The raw data extracted from court verdicts can be found in Tables 1–3 in the paper. All court verdicts can be accessed via each respective court, in line with the principle of public access to information (SFS 2009:400; Riksdag of Sweden 2009). A list of completed court verdicts can be found via the web application “Strömmen”, provided by the Swedish Agency for Marine and Water Management (SwAM, 2024).

## Author contribution statement

Author contribution roles are listed 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.

## Ethics approval

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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