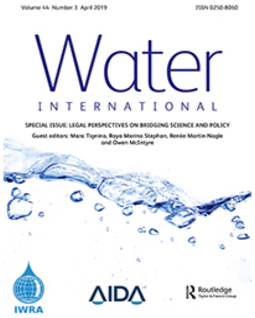

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RESEARCH ARTICLE

Bringing back ecological flows: migratory fish, hydropower and legal maladaptivity in the governance of Finnish rivers

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ABSTRACT

Historically, Finnish rivers supported vital populations of migratory salmonids. Presently, these species are more or less endangered due to extensive damming and hydropower production. In this article, we study the main legal and scientific drivers for re-evaluating some of the existing hydropower operations in Finland. We argue that there is a need for re-evaluation on the basis of legal obligations stemming largely from EU law and new scientific knowledge. Theoretically, our setting opens up a classical adaptive governance problem in how to address laws and past decisions that are based on outdated assumptions about the functioning of social-ecological systems.

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Water governance; adaptive law; migratory fish; hydropower; Finland

Introduction

Prior to the industrial revolution, Finland boasted 25 Atlantic salmon (*Salmo salar*, hereafter salmon) and some 72 anadromous brown trout (*Salmo trutta*, hereafter trout) rivers running to the Baltic Sea, four rivers supporting both species (Teno, Näätämö, Paatsjoki, Tuulomajoki) with outlets to the Barents Sea (HELCOM, 2011a), and two inland rivers with reproducing landlocked Atlantic salmon populations. Currently, the number of Finnish rivers sustaining natural reproduction of salmon has been reduced to four, and only small and rare populations of wild anadromous brown trout, migratory whitefish and migratory grayling have survived in rivers with a connection to the Baltic Sea (HELCOM, 2011a). In Finland, the anadromous brown trout and landlocked Atlantic salmon are classified as critically endangered, the freshwater brown trout as endangered, and the anadromous Atlantic salmon as vulnerable (Rassi, Hyvärinen, Juslén, & Mannerkoski, 2010).

The near-complete loss of spawning habitats for migratory salmonids resulted primarily from the large-scale damming of rivers for hydropower production (HELCOM, 2011a).[1] The damming of Finnish rivers started in southern Finland at the turn of the twentieth century and proceeded to the rural northern provinces from the 1940s onward (Autti & Karjalainen, 2012). Currently, almost all the major Finnish rivers discharging into the Baltic Sea are dammed. Fishways allowing Atlantic salmon to reach significant breeding habitats have been constructed only in the River Kymijoki,

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which now supports a wild – although non-native – Atlantic salmon population of River Neva origin (HELCOM, 2011a; Mäki-Petäys, Louhi, Orell, & Karjalainen, 2014). With these developments, Finland followed the lead of most industrialized countries globally (Vörösmarty et al., 2004).

Given the grim history of Finnish salmonid stocks, it is no surprise that the past decades have witnessed major political and legal efforts in several forums to restore ecological flows to the Finnish rivers. To reflect this, in 2012 the Finnish government issued a National Fishway Strategy aiming at restoring the natural reproductive cycle of migratory fish populations and prioritizing restorative actions in watersheds with the highest potential (Government of Finland, 2012). The uneasy relationship between migratory fish and hydropower has also attracted attention in the European Union and in international arenas. At present, the EU Water Framework Directive (WFD, 2000/60/EC) requires that EU member states reach good ecological status or good ecological potential in all inland waters by 2015 (or if postponed, by 2021, or 2027 at the latest). The vitality of migratory fish populations is among the 'biological quality elements' that contribute to the assessment of ecological status. Also, the Helsinki Commission, established by the 1992 Helsinki Convention,[2] has on several occasions expressed its concern for the state of Finnish rivers, and recommended that some of the old hydropower operations be re-evaluated (HELCOM, 2007).

In this article, we study the main legal and policy drivers that led to the large-scale damming of Finnish rivers and discuss why damming continues to be a problem for reviving migratory fish stocks today. Second, we study the legal, scientific and policy drivers for re-evaluating the fisheries obligations of the existing hydropower permits. We argue that there is a need for re-evaluation not only on the basis of international and EU legal obligations, but also because the science underlying the foundations on which permits were originally issued has developed significantly. Recent developments in law, science and policy constitute grounds for adjusting some of the existing hydropower permits in Finland. Theoretically speaking, this setting opens up a classical problem discussed in the adaptive law and governance literature: how to address law and past management decisions that are based on outdated and false assumptions about the functioning and development of social-ecological systems (e.g., Arnold & Gunderson, 2013; Cosens et al., 2017; Ruhl, 1997).

Overall, the uneasy relationship between biodiversity and hydropower has been well documented across the globe (Vörösmarty et al., 2004).[3] In a global context, the defects of Finnish hydropower governance offer a cautionary example of failure to manage the resilience of freshwater systems and adapt to global environmental change and the development of science. The current challenges in restoring and maintaining migratory salmonid stocks, and balancing them with the production of hydropower, trace back to three peculiarities of Finnish water law and policy. First, most of the present hydropower operations have their background in ad hoc legislation that permitted the large-scale damming of Finnish rivers in the 1930s and 1940s, a time of pressing societal and energy needs. Second, the laws under which the existing hydropower permits were issued (mostly between the 1930s and 1970s) were ambivalent as to the methods with which the impacts of hydropower on aquatic ecosystems and fisheries could be compensated (Hepola, 2007). Third, hydropower permits were granted permanence once issued (Belinskij & Soininen, 2017). These three characteristics have prevented new knowledge on the societal need for and the negative environmental consequences of hydropower from penetrating into water management practices.

Although this article concentrates on reconciling hydropower and fisheries biodiversity, research has shown that the reservoirs needed to store water for the production of hydropower have environmental impacts on a wider scale. Reservoirs not only destroy the natural landscape and reduce the flow of freshwater and organic material to the ocean, but also cause significant habitat fragmentation and act as an important source of greenhouse gas emissions due to the breakdown of organic material that accumulates in the reservoirs (Barros et al., 2011; Gagnon & van de Vate, 1997; Rosa, dos Santos, Matvienko, dos Santos, & Sikar, 2004; Rosenberg, Bodaly, & Usher, 1995; Vörösmarty et al., 2004). Reservoir construction also tends to lead to the leaching of mercury from immersed terrestrial soils and subsequent bacterial methylation in the reservoirs (Rosenberg et al., 1995). In addition to direct biogeochemical impacts, dams have reduced nutrient inputs from the sea to the rivers by blocking the spawning migration of fish (Jonsson & Jonsson, 2003). Absence of migratory fish has further caused local extinctions of species, such as freshwater pearl mussel (*Margaritifera margaritifera*), that are directly dependent on the presence of salmonid hosts (Karlsson, Larsen, & Hindar, 2014). The matter of regulating hydropower is further complicated by hydropower being a significant source of low-carbon energy. Against this background, the conflict between free-flowing rivers is not only between environment and development, but also between local environment (biodiversity) and global environment (climate mitigation).

Overall, the harms and the benefits of hydropower raise wide-ranging questions of law and policy, from both anthropocentric and ecocentric perspectives.[4] The present article concentrates, however, on studying Finland as a case of maladaptive water governance. Hopefully, this cautionary example can illuminate some characteristics that should be avoided in designing adaptive and effective water governance.

A history of losing the natural reproductive cycles of migratory fish in Finland

Ad hoc laws and insufficient fisheries compensation

Natural rivers provide many ecosystem services, including provisional services such as fish and flow to run turbines, regulation services such as flood mitigation and water purification, and cultural services such as recreation and aesthetic landscapes (Dyson, Bergkamp, & Scanlon, 2003). Typically, rivers host a variety of actors utilizing these services. As many of these uses are competing or conflicting, there is a need to manage the flows allocated for each use (Davis & Hirji, 2015; Dyson et al., 2003). ‘Environmental flow’ is a concept designed to strike a balance between the allocation of flows for different ecological and human uses (Gillespie, 2014). Within the EU context, the commission uses a narrower concept of ‘ecological flow’, which refers to the flows required to meet the WFD’s ecological objectives (European Commission, 2015). This requires, among other things, that aquatic organisms can navigate rivers upstream and downstream.

The management of environmental flows in Finland has been largely dominated by the allocation of water for hydropower production. For most of the twentieth century, Finnish water policy and law leaned heavily towards allocating all the available water to the production of electricity (Belinskij & Soininen, 2017; Haataja, 1959). This was mostly due to hydropower being sorely needed to drive a growing – and after the Second World War crippled – economy (Pokka, 1991). A prevailing view within the industry in the 1930s and 1940s was that the allocation of water for any other purpose than the production of hydropower was frivolous and vain (Myllyntaus, 2002). This view came to dominate Finnish water policy and law for a long time.

Before the 1930s, the Water Rights Act (31/1902) had favoured fisheries over power. But as the demand for electricity increased over the years, interpretations of the 1902 act, and political pressure to pass legislation deviating from its strict rules, increased accordingly (Myllyntaus, 2002). The 1930s saw the dawning of a great recession, and by the end of the decade Finland entered World War II as a response to violent Soviet invasion (Pokka, 1991). These circumstances led to the introduction of ad hoc legislation that established far-reaching exemptions to the 1902 Water Rights Act (Pokka, 1991). In 1934–41, the Finnish Parliament passed four acts (62/1934; 134/1939; 383/1940; 196/1941) that permitted certain damming and regulation projects and lowered the criteria and procedural safeguards for permits to hydropower operations. The earlier ban on blocking a river's navigable fairway was replaced by a weighing norm requiring merely that the benefits of a project must outweigh the harms (Löyttyjärvi, 2013). If the economic value of a hydropower operation was great, the fisheries interests were sacrificed, with compensation (Legislative proposal 99/1938; Löyttyjärvi, 2013). All together, these legislative changes resulted in roughly half of Finnish hydropower capacity (61 operations with a combined output of 5400 GWh) being constructed before the enactment of the 1961 Water Act (Hinkka, 1969).

Despite the urgent need for electricity to fuel economic growth and the consequent prioritization of hydropower over environmental and societal impacts (Erkinaro et al., 2011), the laws at the time did contain provisions limiting construction on Finnish rivers. First of all, the operations were still subject to permitting, and the law required that hydropower-related harms to fisheries must be mitigated, minimized and compensated. Although the strict obligation of the 1902 Water Rights Act to compensate for hydropower harm to fisheries by building fishways was removed by the 1939 ad hoc legislation, fishways remained the main fisheries compensation mechanism in the Water Act (264/1961) well into the 1980s (Chapter 2, Section 22; Hepola, 2007).

Nevertheless, from the 1950s compensation practices started moving towards stocking rivers with farmed fish. This process was initiated because fishways and fish transfers were considered dysfunctional and expensive (Government of Finland, 2012; Hepola, 2007; Löyttyjärvi, 2013). A good illustration of this is that in the River Kemijoki – probably the most productive salmon river in Europe, until its damming soon after World War II – attempts were initially made to transfer ascending salmon over the dams, but the transfers turned out unsuccessful, and were later replaced by stocking of hatchery-reared fish (Alaniska, 2013). Compensatory stocking was legalized in 1987, when the 1961 Water Act was amended (amendment 467/1987). The amended act – read in light of the preparatory materials – prioritized stocking of farmed fish as the main method for compensating harm to fisheries (Legislative proposal 266/1984). At present, stocking still remains the main fisheries compensation method, despite the current Water Act (587/2011) giving the three compensation mechanisms of fishways, fish transfers and stocking equal weight (Chapter 3, Section 14; Legislative proposal 277/2009).

Taken together, the societal need to develop hydropower for energy security in the first half of the twentieth century was reflected closely in the four pieces of ad hoc legislation that were passed as exemptions to the 1902 Water Rights Act, which originally prohibited the blocking of river fairways. The laws that facilitated the large-scale development of hydropower required compensation for harm to fisheries, and these compensations evolved from the building of fishways towards stocking rivers or river mouths with farmed fish. While the societal significance of hydropower development in the shadow of recession and war was evident, the significance of shifting the compensatory mechanisms towards the stocking of farmed fish can only be understood in the historical light of biological understanding of fish and their genetic characteristics (see the section on ‘Changes in Science’).

Doctrine of permanence in hydropower permits

In addition to the large-scale river construction on the basis of dubious ad hoc legislation, the issued hydropower permits were granted permanence by Finnish water legislation. The 2011 Water Act and its predecessors (1961 Water Act; 1902 Water Rights Act 31/1902) are based on a strict *ex ante* ideology: once a hydropower operation is considered in a public process and granted a permit to operate, the permit cannot be revoked or greatly adjusted without the consent of the hydropower operator (Belinskij & Soininen, 2017). The permits granted to hydropower operations are considered to reflect the private ownership of the rivers, and the public evaluation of harm conducted in an original permit cannot be revisited after its assessment (Belinskij & Soininen, 2017; Hepola, 2005, 2007). This is not so much a procedural rule but a substantive one: permits cannot be considerably changed after the initial *ex ante* assessment.

On the basis of the permanence doctrine, the 2011 Water Act does not allow for entirely new permit conditions to be added to hydropower permits, if they were not present at the origin (Belinskij & Soininen, 2017). In particular, the permits for small (under 5 MW) hydropower operations quite often (38 operations out of 153 in total) lack conditions for compensating harm to fisheries (Kosunen & Mikkola, 2017). Furthermore, even the alteration of existing hydropower permit obligations is contingent on several rather strict legal criteria (Belinskij & Soininen, 2017). These criteria include the existence of a public interest in reviving migratory fish stocks (2011 Water Act, Chapter 19, Section 10), a change in the social-ecological circumstances (Chapter 3, Section 22), and a finding that the changes in permit obligations do not constitute disproportionate costs to the hydropower operator (Chapter 3, Section 21; Chapter 2, Section 7).

Overall, the 2011 Water Act and its predecessors have always had a dualistic approach to the development of policy and science. The law has been, and still is, remarkably adaptive to social-ecological knowledge in permitting *new* hydropower operations and deciding on their compensatory measures (Belinskij & Soininen, 2017; Haataja, 1951; Soininen, 2016). This close linkage between science, policy and law is, however, in stark contrast with the strict permanence of *existing* hydropower permits (Belinskij & Soininen, 2017; Hepola, 2005, 2007). The doctrine of permanence creates an atmosphere of maladaptivity that presents obstacles to adjusting past water management decisions to new developments in policy and law, as well as to new scientific knowledge.

The previous sections have sought to describe and evaluate some of the key historical reasons for the large-scale damming of Finnish rivers and explain how these historical developments continue to hold importance today. We next review the legal, scientific and policy arguments for a change in hydropower operations.

Flows of change: towards adjusting maladaptive regulation and permits?

Changes in law and context

In the first half of the twentieth century, hydropower was such a valuable commodity that it dominated over fisheries and other interests in the development and interpretation of water law in Finland. Hydropower accounted for roughly 90% of Finland's electricity production in the 1950s and 1960s (Finnish Energy, 2017), but since then, its contribution has decreased to the present 10–20% (Aslani, Naaranoja, Helo, Antila, & Hiltunen, 2013; Finnish Energy, 2017). But at the same time, the importance of hydropower's combined storage capacity has increased due to climate mitigation efforts and the development of fluctuating power sources, such as renewable wind, solar, and wave power (KEMA Consulting, 2015). Despite the diversification of hydropower's roles for climate change mitigation, energy security and some predicted growth in its electricity generation due to climate-change-induced increase in precipitation (Venäläinen et al., 2004), it is reasonable to assert that the societal importance and political sway of hydropower in Finland are substantially weaker now compared to its heyday in the 1950s and 1960s.

In the wake of hydropower's declining role in the Finnish energy mix, the last three decades have witnessed several political and legal attempts to balance hydropower and fisheries interests. The key political attempt in this regard is the National Fishway Strategy issued by the government of Finland in 2012. The strategy seeks to reconcile hydropower and fisheries interests, and recognizes that in the long term, healthy migratory fish populations can only be maintained by reviving their natural reproductive cycles (Government of Finland, 2012). To reach this overarching goal, the strategy proposes several measures, such as building fishways, watering dried-up channels, restoring dredged rivers, transferring fish over the existing dams, improving river flow regulation, and improving the regulation of fishing. It also recognizes that the permanence of hydropower permits (outlined in the previous section) stands in the way of these goals and measures.

Indeed, many legal attempts to balance hydropower and fisheries interests have not had significant success. While the two amendments of the 1961 Water Act (467/1987; 553/1994) introduced the possibility of adjusting ineffective fisheries compensation obligations in hydropower permits, the core of the permanence doctrine remained intact: no new conditions could be added to the existing permits. The current 2011 Water Act maintains the doctrine.

But, while the balancing of environmental flow allocation between hydropower and fisheries has been at an impasse for decades in Finland, this might be about to change due to EU law. The WFD requires all EU member states to reach good ecological status in all inland waters by 2015, or, if postponed, by 2021, or 2027 at the latest (Article 4(1); Squintani & van Rijswick, 2016). In the WFD system, the classification of ecological status in rivers is based on composition, abundance and age structure of fish fauna, among other biological quality elements (Annex V). Good ecological status of a river (or part of a river) requires, with regard to fish fauna, that there are only slight changes in species composition and abundance attributable to anthropogenic impacts. Hydro-morphological quality elements, such as the quantity and dynamics of water flow and river continuity, must also be considered.

These biological and hydro-morphological quality elements are somewhat different if a stretch of river is 'artificial and heavily modified' due to damming and the production of hydropower (Articles 2(9), 4(1)). In such case, the member state has an obligation to seek good ecological potential, which is established by comparing it to the maximum ecological potential of the water body. In practice, the latter refers to an ecological quality achievable 'once all mitigation measures, that do not have significant adverse effects on its specified use [here: hydropower] or on the wider environment, have been applied' (WFD CIS Guidance Document No. 4, 2003). Good ecological potential requires that there are only slight changes in quality elements as compared to the maximum ecological potential.

The WFD requires that member states re-evaluate all the existing impoundment and other water management permits to bridge the gap between the existing status and good ecological status/potential of all waters in their territory (Articles 11(3), 11(5)). In the *Weser* ruling, the Court of Justice of the EU declared that the environmental goals of the WFD are legally binding in relation to the authorization of an individual project (Case 461/13, *Bund für Umwelt und Naturschutz Deutschland eV v Bundesrepublik Deutschland* [2015] ECLI:EU:C:2015). While the legally binding nature of good ecological status may introduce far-reaching legal consequences for the re-evaluation of existing permits, good ecological potential sets more modest standards for heavily modified rivers. Attaining good ecological potential does not require cancelling hydropower permits or removing dams, but it might well require a wide array of ecological compensation mechanisms to allow the natural reproductive cycle for salmon and trout as far as technically possible, and economically feasible. These measures may include building fishways, watering original drained channels, restoring dredged rivers, transferring fish over the dams, and improving river flow regulation, as listed in the National Fishway Strategy (Government of Finland, 2012).

Most of the Finnish rivers dammed for hydropower have been classified as artificial and heavily modified. But, notwithstanding their less demanding ecological quality criteria, 66% of the artificial and heavily modified rivers (or parts of rivers) in Finland were not in compliance with good ecological potential in the first WFD planning period, between 2004 and 2009 (Finnish Environment Institute, 2013). Against this background, the directive's obligations cast a long shadow, especially on those hydropower permits that do not presently contain any fisheries compensation obligations. Stocking of farmed fish may not be enough to produce good ecological potential.

The dire situation of salmon and trout in Finland has also attracted some attention in the context of international law, mainly under the 1992 Helsinki Convention. In the 2007 Baltic Sea Action Plan, the Baltic Sea states agreed to develop restoration plans for migratory routes and spawning sites to reach favourable conservation status in Baltic Sea biodiversity (HELCOM, 2007). HELCOM has also recommended that the states take urgent measures for the recovery of the original salmon and sea trout populations (HELCOM, 2011b). In this regard, Finland should assess anthropogenic hindrances to fish migration in its territory and commit to re-establishing wild salmon populations in certain rivers where justified (HELCOM, 2011b).

Overall, the legal and policy developments at all levels (national, EU, international) have sought to establish a balance between the social and ecological uses of environmental flows. The WFD especially is applying significant pressure toward changing Finnish water and fisheries management regulation and practices. This pressure is felt especially in the requirement to use a full array of fisheries compensation mechanisms (fishways, fish transfers, restocking) in aspiration toward good ecological status/potential. In light of this, the above analysis contests the doctrine of permanence of hydropower permits, especially if the permit does not contain any fisheries compensation obligations.

In the next section, we show how – in addition to law and policy – science has changed considerably since the time most of the Finnish hydropower permits were issued (between the 1930s and 1970s). Our argument here is that all the existing permits are, to a certain extent, based on an overoptimistic (and thus dismissive) evaluation of hydropower's harm to the environment in general, and fisheries in particular.

Changes in science: (re-)evaluating hydropower impacts and fisheries compensation

While it is evident that the environmental impacts of hydropower and the smolt production capacity of the impacted rivers (Romakkaniemi, 2008) were originally underestimated, research has also cast serious doubt on whether hydropower's harm to fisheries can be sustainably compensated by releasing farmed fish. At the time of early dam building (before the 1970s), there was little understanding of the importance of genetic diversity, microevolution or local adaptations in fish. Evolution was considered something that takes millions of years, though the current view is that ecologically significant genetic changes can occur in 10 or fewer generations (Hard et al., 2008; Rice & Emery, 2003; Schoener, 2011). Understanding of the importance of genetic factors was further hindered by the strict view that an evolutionary change cannot be inferred from a phenotypic change without direct genetic evidence (Merilä & Hendry, 2014).

The management implications of population genetic differences among brown trout populations were generally realized in the early 1980s (Taggart, Ferguson, & Mason, 1981). Ferguson and Mason (1981) were among the first to demonstrate that brown trout morphotypes formed reproductively isolated sub-populations, even in the same waterbody. From the late 1980s, awareness of the population-genetic structures of fish in general and salmonids in particular started to grow (Hallerman & Beckmann, 1988). Taylor (1991) concluded that the ample genetic variation among stocks and strays was potentially largely adaptive, with apparent concern for the increasing rates of fish releases and escapees from fish farms. Bourke, Coughlan, Jansson, Galvin, and Cross (1997) pointed out that hatchery releases of Atlantic salmon could compromise the original Europe-wide genetic variation in Atlantic salmon populations. In addition, there was increasing concern that hatchery-rearing could favour traits such as fast growth or early maturation, affecting the productivity of the sea-ranched stocks (Kallio-Nyberg & Koljonen, 1997). However, it has taken until very recently for the full-scale genomic diversity among populations (Lemopoulos et al., 2018) and the genetic basis for traits such as migration timing to be revealed in salmonids (Cauwelier, Gilbey, Sampayo, Stradmeyer, & Middlemas, 2018).

Despite the lack of modern genetic methods in the 1970s, biologists were concerned that hatchery-rearing might change the heritable traits of fish. For example, it was reported in 1977 that hatchery-reared steelhead trout (*Oncorhynchus mykiss*) had differences in growth and survival compared to wild trout and wild × hatchery hybrids (Reisenbichler & McIntyre, 1977). The first papers that reported that hatchery-rearing might have caused loss of genetic diversity due to genetic drift and the small number of founders used in establishing hatchery broodstocks appeared in the 1980s (Cross & King, 1983; Ryman & Ståhl, 1980; Vuorinen, 1984).

While the positive association between the genetic diversity and the vitality of various animal populations has been long known (Hutchings & Fraser, 2008), there were no studies on the fitness consequences of hatchery-rearing until the 2000s. Tiira, Piironen, and Primmer (2006) observed that a lack of genetic diversity was associated with malformations in landlocked Lake Saimaa salmon juveniles, and Araki, Cooper, and Blouin (2007) showed that the genetic effects of domestication reduced the subsequent reproductive capabilities of steelhead trout by ca. 40% per captive-reared generation when fish were moved to their natural environments. In the 2010s, the modern functional genomics approaches have developed quickly: Vasemägi, Kahar, and Ozerov (2016) demonstrated directly that different genes contributed to the fast growth of salmon in the wild, compared to a hatchery environment. Christie, Marine, Fox, French, and Blouin (2016) showed that just a single generation of hatchery breeding altered the expression of hundreds of genes in steelhead trout.

Currently, it is not a scientific question whether hatchery-rearing has negative genetic impacts on fish (Araki, Berejikian, Ford, & Blouin, 2008; Araki et al., 2007; Christie et al., 2016; Hansen, Meier, & Mensberg, 2010; Kallio-Nyberg, Jutila, Jokikokko, & Saloniemi, 2006). Rather, the question is how long hatchery breeding and the current restocking practices can support fisheries at feasible economic costs (Hutchings & Fraser, 2008).

While the scientific evidence for negative hatchery-induced genetic effects is solid, one is left wondering what the practical implications are. For example, the final power plant that destroyed all the remaining breeding grounds of landlocked Lake Saimaa salmon was constructed in 1971 (Pursiainen, Makkonen, & Piironen, 1998). This was roughly a decade before the genetic diversity of salmonid populations in general – and the significant losses of genetic diversity already during the first years of hatchery rearing in Lake Saimaa brown trout and landlocked Atlantic salmon – were revealed (Vuorinen, 1982, 1984). Thus, the apparent future-looking answer is that the current large-scale stocking severely threatens the small remaining wild populations.

Stocking induces homogenization of genetic structures and loss of local adaptations as well as phenotypic changes in a multitude of traits (Hansen et al., 2010; Palmé, Wennerström, Guban, & Laikre, 2012; Vainikka, Kallio-Nyberg, Heino, & Koljonen, 2010). Genetic changes in captive-bred fish can significantly lower restocking success and limit the possibility of restoring the salmon and trout populations in rivers that have lost their original fish. Virtually no examples of self-sustaining migratory salmonid populations with stocking origin exist in Finland, with the exception of the River Kymijoki salmon, which breed in low numbers.

The present knowledge of genetic harm caused by hatchery rearing is fully in line with the success of stocking over the past decades. Early stocking in both the Baltic Sea and inland waters produced good catches with generally high recapture rates (International Council for the Exploration of the Sea, 2011). As recently as in the 1990s, compensatory stocking supported intensive commercial salmon and anadromous brown trout fisheries in the Baltic Sea. More than 5 million salmon smolts were released annually, and the sea ranching produced peak salmon catches of ca. 5.5 million kg in the early 1990s. In the 1980s, the post-smolt survival of hatchery-reared salmon was 20–30% (HELCOM, 2011a). Commercial fisheries based on sea-ranching of hatchery-released salmon smolts started to decline from the 1990s onward. Much of the decline in catches was explained by the decreasing survival rates of stocked Baltic salmon (HELCOM, 2011a). Although several environmental changes – including climate change, the increase of seal and cormorant populations, and overfishing of Baltic cod, with effects on salmon diet – have also had ecological impacts on the survival of wild salmon and sea trout post-smolts, these alone cannot account for the extremely low survival rates of the stocked smolts (Kallio-Nyberg et al., 2006; Salminen, 2002).

While there is no direct genetic evidence that unintended domestication explains the decreased recapture rates of stocked fish, there is no solid evidence to reject the hypothesis either. Overall, the very low recapture rate and the inadvertent genetic impacts of stocked smolts have challenged the prevailing stocking practices (Erkinaro et al., 2011; Ozerov et al., 2016). Many Finnish salmon and trout broodstocks have now been maintained in hatcheries for 6 to 10 generations. In theory, this is the time after which the negative genetic effects would start to become significant (Hutchings & Fraser, 2008). Genetic evidence from the Estonian River Selja, which was recolonized by salmon from neighbouring rivers in 1990s and by stocking since 1997, after prior heavy pollution and extinction of the original salmon population, suggests that wild fish are more important in rebuilding a new population than stocked fish, even if the stocked fish outnumber the wild fish by an order of magnitude (Vasemägi et al., 2001).

In a broader context, populations of wild migratory salmonids are affected by numerous anthropogenic factors. For example, the major global threats to wild Atlantic salmon include (in addition to dam construction and stocking of hatchery-reared smolts) over-fishing, river engineering, pollution and salmon aquaculture. Forseth et al. (2017) identified escaped farmed salmon and salmon lice (*Lepeophtheirus salmonis*) from fish farms as *emerging* population threats in Norway, and *Gyrodactylus salaris* parasite, freshwater acidification, hydropower regulation and other habitat alterations as *stabilized* threats. The threats vary regionally, and in the Baltic Sea basin, the management of stocking and sea ranching has been classified as the most urgent concern (Palmé et al., 2012).

In conclusion, although it would be anachronistic and vain to criticize the historical hydropower and fisheries management decisions that led to the damming of Finnish rivers, the loss of natural fish populations and the triumph of hatchery-reared fish, a strong argument can be made that those decisions should be reconsidered in today's social-ecological context and under current scientific knowledge. If one is serious about restoring the natural reproductive cycles of salmon and trout, as one must be based on the present analysis, the harmful impacts of using hatchery-reared fish in compensating for hydropower harm must be considered.

Discussion and a way forward

After the hydropower boom in Finland, two interrelated challenges remain in reviving the reproductive cycles of migratory fish – one biological, and the other related to law and policy. From a biological perspective, the original migratory salmonid populations in dammed rivers have become extinct, and their original genetic characteristics may not be recoverable, even if some subset of the original genetic variation has been maintained in the fish hatcheries. This means that, instead of simple population recovery, the challenge is to re-introduce and establish new populations in rivers that are open to fish migration. Such a task is not trivial and will need evolutionary thinking and consideration of the adaptive potential of the fish strain used for re-introductory stocking (Rice & Emery, 2003). While the conservation status of a species can be regionally improved by creating new populations, nothing will bring back the unique population-genetic units, with their original river-specific characteristics, once they are lost.

The legal and policy challenges include questions as to whether and to what extent hatchery-impacted stocks can recover in rivers that are potentially subjected to the re-evaluation of the hydropower permits and compensation measures. Thus, the apparent question is whether compensation measures should be taken nationally, in rivers where the opportunities for the recovery of native populations are better. Damming's local harm to the landscape cannot be compensated for anywhere else, but aquatic ecosystem diversity at the national scale could be maximized by taking action where the cost–benefit ratio is the best. This would require a new national-level compensation mechanism and fisheries fees collected from all hydropower companies.

At present, most of the Finnish rivers do not support natural salmonid life-cycles, and movement towards the goals of the WFD and the Baltic Sea Action Plan has been slow. Overall, the pressure from the EU and international arenas has not yet been strong enough to produce significant changes in the Finnish legal system. Despite this, the last two decades have witnessed several modest attempts to reallocate environmental flows. The legal framework of the EU does require the utilization of a broader array of fisheries compensation mechanisms than those in use in Finland at the moment.

Under the WFD, there is an obligation to evaluate whether the compensation mechanisms set in the permit conditions are adequate in relation to the environmental objectives of the directive. To this end, some administrative processes grounded in the 2011 Water Act may change existing hydropower permits by introducing new fishways and fish transfers and restoring breeding habitats (Lapin ELY-keskus, 2017). With these grass-roots developments, it remains to be seen whether the Finnish legal framework is flexible enough to allow changes in implementing obligations stemming from the EU, international law and conservation science. The slow progress towards balancing hydropower interests and aquatic biodiversity is a testament to the uneasy relationship between permanent water permits on the one hand, and adaptive management of rivers on the other. Laws once passed and management decisions once made cast a long shadow into the future. For this reason, balancing permanence and adaptivity becomes a key question in designing effective and legitimate water governance. The Finnish example leaves a lot to be desired in this regard.

Notes

1. In addition, intensive forestry operations – including the transformation of 6 million hectares of wetlands into ditched forests, and the dredging of rivers for timber floating – have altered the chemical and structural composition of the rivers over the last century or so and eliminated a significant number of breeding habitats for salmon and trout (HELCOM, 2011a). Restoration of river habitats has helped mitigate harm caused by the dredging of rivers, but the conflict between hydropower operations and restoring the natural reproductive cycle of migratory fish remains at a standstill (HELCOM, 2011a).
2. Convention on the Protection of the Marine Environment of the Baltic Sea Area, entered into force 17 January 2000.
3. The Columbia River in the western United States in one of the best-known examples (Dietrich, 2003; National Research Council, 1996; Williams, 2006).
4. New Zealand and Ecuador are among the first countries to grant rivers legal personhood (Scientific American, 2017).

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