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CASE STUDIES AND REVIEWS

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Salmonid stocking in five North Atlantic jurisdictions: Identifying drivers and barriers to policy change

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Abstract

1. New knowledge challenges long-established practices of fish stocking and transfer because of increasing scientific consensus that the release of cultivated fish can pose risks to biodiversity; however, stocking can also improve fisheries, creating difficult decision trade-offs regarding its use.
2. Accordingly, controversy persists about fish stocking and transfer. No studies, however, have embraced a multinational perspective to understand the important governance dimensions of the success and failure of salmonid stocking and transfer policies.
3. The present study has analysed the historical development and contemporary governance of the stocking and transfer of native and non-native salmonids of the genera *Salmo*, *Salvelinus*, and *Oncorhynchus* in five legislative units around the North Atlantic Ocean: the Atlantic Provinces of Canada, France, Germany, Norway, and Sweden. The study is based on the analyses of published and unpublished literature, and a survey of experts.
4. Current salmonid stocking policies and practices varied significantly among jurisdictions; the degree of policy change varied, from radical and rapid changes *de jure* and *de facto* in Atlantic Canada and Norway to incremental mostly *de jure* changes in France and Germany.
5. Rapid policy change in Atlantic Canada, Norway, and partly in Sweden can be explained by the socio-political importance of salmonid fisheries, stocking regulations based on policy objectives to conserve wild Atlantic salmon (*Salmo salar*), well-documented examples of the harmful consequences of transfers of non-native species, and well-developed vertical governance linkages. The policy changes resemble that of the 'punctuated equilibrium policy framework'.
6. By contrast, France and Germany place less socio-political emphasis on salmonids, have stocking regulations less directed at wild salmonids, more local-level decision making, more species-rich fish communities, and little evidence of adverse ecological impacts of the transfer and stocking of salmonids. This has led to small, incremental changes in stocking policy *de facto* that are reflective of the 'advocacy coalition policy framework'.

KEYWORDS

advocacy coalition, alien species, conservation, environmental policy, governance, institutions, invasive species, *Oncorhynchus*, punctuated equilibrium, *Salmo*, *Salvelinus*

1 | INTRODUCTION

1.1 | Background

A range of human impacts (e.g. water use, pollution, eutrophication, habitat simplification, dams, climate change, and invasive species) have substantially reduced the ecological status of freshwater catchments over the last centuries in many regions (Arthington, Dulvy, Gladstone, & Winfield, 2016; Dudgeon, Arthington, Gessner, & Kawabata, 2006). Today, in industrialized countries, riverine biodiversity has become one of the most threatened components of global biodiversity (Dudgeon et al., 2006; Vörösmarty et al., 2010). Notably, European freshwater fishes rank particularly high on the threat list relative to other vertebrates (Freyhof & Brooks, 2011). Human-mediated changes are similarly threatening river biodiversity in the developing world (Winemiller et al., 2016; Zarfl, Lumsdon, Berlekamp, Tydecks, & Tockner, 2015).

For many centuries humans have transferred organisms, including fishes, across biogeographic barriers to improve food security, and for recreation or ornamental purposes. Hoffmann (1994) reconstructed the human-mediated spread of the common carp (*Cyprinus carpio*) from its origin in the lower Danube River (Black Sea) to the rivers Elbe (North Sea) and Oder (Baltic Sea) in Germany between AD 530 and 1100. Similarly, an old runic inscription dated to the 1100s stated that a man 'Ellifr carried trout to the Red Lake' in Oppland, Norway (Eknæs, 1979), indicating that salmonids have also been actively transferred by humans since at least mediaeval times (Pister, 2001). Recent global analyses suggest that there is no saturation in the appearance of exotic species across a range of taxa, including the transfer of fish outside their native range (Seebens et al., 2017). Doubtless, fish introductions have produced important socio-economic benefits for fisheries. At the same time, introductions and transfers of non-native species have had many unintended effects, such as the spread of diseases, the loss of yield and other ecosystem services (e.g. water clarity), and the reduction or even extinction of native species or populations (Cucherousset & Olden, 2011; Hutchings, 2014). The cost-efficiency of introductions of fishes has also been questioned: i.e. whether stocking is economically profitable, or if other measures such as harvest regulations or habitat restoration are more profitable (Welcomme, 2001).

Salmonid fishes are widely affected by, or involved in, species introductions and transfers, especially fishes of the genera *Salmo*, *Salvelinus*, and *Oncorhynchus*. They are of considerable importance to humans for their contributions to food and culture. Such introductions and transfers also regularly generate political and social conflicts, however, especially in the context of biodiversity conservation associated with the interaction between native and introduced non-native populations (Buoro, Olden, & Cucherousset, 2016; Crawford & Muir, 2007; Halverson, 2010). This has led to these fishes being subject to active management effort, for both fisheries and conservation, for more than a century (Halverson, 2010; Stankovic, Crivelli, & Snoj, 2015). During the 1800s, knowledge about artificial fertilization and breeding became widespread, which accelerated the global transfer of salmonids within and outside their native range (Goode, 1881; Kerr, 2006). This was the start of a long period in which management objectives generally promoted stock transfers and introductions (Bottom, 1997). Rainbow trout (*Oncorhynchus mykiss*), originally native to catchments of western North America, can now be found in temperate climates almost everywhere around the world through human-assisted transfer (Crawford & Muir, 2007; Pister, 2001). The same is the case for brown trout (*Salmo trutta*), originally native to Europe (MacCrimmon & Marshall, 1968).

New scientific knowledge emerged during the 1970s and 1980s that provided empirical evidence that the stocking and transfer of salmonids could threaten native aquatic biodiversity at all levels: genes, populations, species, and ecosystems (Billingsley, 1981; Ryman, 1981; Simon & Townsend, 2003; Townsend, 1996). Salmonids have genetically distinct populations, owing to their homing behaviour and adaptation to specific rivers and catchments (Fraser, Weir, Bernatchez, Hansen, & Taylor, 2011; Garcia de Leaniz et al., 2007; Ryman & Utter, 1987). Accordingly, this leads to the genetic integrity of local salmonid stocks being generally threatened not only by non-native species, but also by the introgression of genetic material from conspecifics of non-native (e.g. from another region or catchment) and cultured origins that might result from the crossbreeding of different populations (Hansen & Mensberg, 2009; Karlsson, Diserud, Fiske, & Hindar, 2016; Perrier, Guyomard, Bagliniere, Nikolic, & Evanno, 2013). Although scientists agree that the mixing of stocks of salmonids should be avoided, they also note that too little effort is devoted to monitoring the genetic risks (Laikre, Schwartz, Waples, Ryman,, & The GeM Working Group, 2010). Transfers (of non-native species as well as non-native populations) have also caused the spread of diseases and parasites (Johnsen & Jensen, 1991), and international agreements, conventions, and guidelines now emphasize the obligation to conserve native biodiversity, and recommend the reduction of transfers and introductions of salmonids (for an overview of international policies and guidelines, see Sandström, 2010). Accordingly, the term 'native' has relevance at several scales, and is used later in this article to distinguish between native and non-native species, as well as populations. The term 'native' is used for populations from the local catchment.

Despite international policy developments and changes in national regulations, the stocking and transfer of salmonids in natural freshwater basins continues to varying degrees, and for different reasons, ranging from maintaining culture-based fisheries (i.e. fisheries where the target salmonid does not naturally recruit) to efforts at re-establishing previously extinct native populations (Lorenzen, Beveridge, & Mangel, 2012; Sandström, 2010). Furthermore, stakeholders often hold differing views on stocking principles and objectives (Aas, Haider, & Hunt, 2000; Arlinghaus, 2006; Arlinghaus et al., 2015; Arlinghaus, Beardmore, Riepe, Meyerhoff, & Pagel, 2014; Cowx, 1994; Cowx, Arlinghaus, & Cook, 2010; von Lindern & Mosler, 2014). At the policy level, Sandström (2010) found that limited policy change and adaptation to more enlightened salmonid stocking practices in Sweden (e.g. discontinuation of the mixing of different salmonid populations through cultivation practices) may lie in the lack of consensus on the implications of the stocking of non-native populations on native biodiversity conservation, coupled with scientific disagreement on the topic as perceived by decision makers. Given a lack of scientific consensus, decision makers might rationalize away the concerns that negative impacts of stocking raise, and continue the practice because of other societal objectives (Sandström, 2010). This is one example of why the interface between science and policy is seen as contentious (Ormerod & Ray, 2016).

Sandström's hypothesis has yet to be assessed in other jurisdictions, and there is a general lack of knowledge about the direction and degree of policy change for stocking and transfer governance across jurisdictions that share some widely distributed species, such as the Atlantic salmon (*Salmo salar*) in the North Atlantic. The only study comparing stocking decisions across national jurisdictions (Sweden and Finland) revealed substantial among- and within-country variation in how decision makers deal with the stocking of salmonids (Sevä, 2013). Moreover, we are unaware of studies on the effects of socio-political factors on the stocking and transfer policy, either at broad geographical scales or across aquatic species more generally (Copp et al., 2005).

Policy change is the expected outcome of the perpetual process of adaptive management (Bennett et al., 2017; Orach & Schlüter, 2016). Studies anchored in political sciences have analysed processes of policy change in environmental governance, including the management of freshwater catchments (Pedersen, 2010), fishery policy (Sandström, 2010), wildlife conservation (Clark, Lee, Freeman, & Clark, 2008; Matti & Sandström, 2011), and climate change policy (Carter & Jacobs, 2014). An overarching issue in many of these studies has been to identify frameworks to explain the observed processes of policy change along dimensions of the degree of change (small or large), time (rapid or slow), and scale (from local to international). Policy change might stem from new knowledge (learning), changing organizational responsibilities, new networks or coalitions, and 'windows of opportunity' (Orach & Schlüter, 2016). Studies of biodiversity conservation governance highlight the difficulty in predicting policy change, as it is sometimes surprising and often highly context specific (Bennett et al., 2017; Orach & Schlüter, 2016). To identify and discuss drivers and barriers to policy change in salmonid management and conservation, we have assessed these in light of established frameworks of policy change and governance of social–ecological systems (Orach & Schlüter, 2016; Paavola, Gouldson, & Kluvankova-Oravska, 2009).

The specific objective of this article is to analyse policy change in salmonid fish stocking and transfer governance, and to identify key drivers and barriers to change in five jurisdictions around the North Atlantic Ocean. Salmonids serve as a good model to study how societies 'perform' (Kenward et al., 2011) in governing aquatic biodiversity, particularly where general governance structures (e.g. agencies or regional management organizations) and associated formal institutions (e.g. fisheries legislation) are well established, and the knowledge base and resource situation is well developed. The overarching question asked is whether and why countries bordering the same ecoregion (North Atlantic), with relatively similar sets of societal values (western countries; Schwartz, 2007), possessing well-developed governance structures, and partly sharing and exploiting the same mixed stocks (Atlantic salmon), have different policies despite being guided by the same international environmental policies and guidelines (e.g. the Convention on Biological Diversity 1992).

2 | METHODS

Five jurisdictions around the North Atlantic Ocean were studied (Figure 1): the Atlantic Provinces of Canada [limited to New Brunswick (NB), Prince Edwards Island (PEI); Nova Scotia (NS), and Newfoundland and Labrador (NL)], France, Germany, Norway, and Sweden. The Canadian region was the most relevant for comparison with the

FIGURE 1 Map of the countries included in the study and their locations around the North Atlantic Ocean

European countries because of its similar size and biogeography. All jurisdictions are important native biogeographical areas for salmonids of the genera *Salmo* and *Salvelinus*. Non-native salmonids of the genus *Oncorhynchus* have been introduced in all jurisdictions, and all jurisdictions are considered to share similar fisheries management histories, level of economic well-being, social values, and general governance structures, at least when considered in a global context. Three species, which are or have been present in all five jurisdictions, and which have been or still are cultivated and stocked, were subject to specific consideration: Atlantic salmon, brown trout, and rainbow trout.

The analysis uses secondary qualitative data (Ember, 2009), which is common in comparisons of policies across several jurisdictions. The compilation was guided by a detailed structured questionnaire. Key expert informants (between two and five from each country) conducted document analysis of national-level unpublished literature in the autumn of 2014 and approached other experts for information, as needed, to complete the questionnaire. The following information was compiled:

- current distribution of salmonids (juridical status, history of transfers, reasons for transfer, stock status, and outlook);
- statistics on the magnitude of introductions and transfers (availability, period, and key national statistical figures if available);
- key objectives for introductions and transfers;
- sources of funding for stocking or transfer;
- key national policy statements (primary laws, secondary regulations, by-laws, or guidelines);
- property rights in relation to fisheries;
- governance organizations;
- references and sources (including laws and regulations, scientific articles, unpublished literature, and government documents).

Responses were written answers (narratives), and quantified figures constructed on comparable rating scales or in absolute quantities. Access to relevant unpublished literature was crucial for finding information (Collette, 1990), exploiting the team's in-depth knowledge of the salmonid fisheries sector in each region and their language skills, as information sources were normally in the native languages of each country. Based on the completed questionnaires, a first comparative analysis of differences and similarities was completed at the end of 2015. Information gathered was presented, discussed, and updated in discussion with stakeholders from all countries at a workshop in Gothenburg, Sweden, in 2016.

In the analysis, the two contrasting frameworks of advocacy coalition (AC) and punctuated equilibrium (PE) were used to assess the processes of policy change in the five jurisdictions. The AC framework is typically used to assess specific policies or issues over longer periods of time, and how stable, similar beliefs among those forming coalitions tend to lead to slow, incremental processes of change (Sabatier, 1987). PE aims to identify how and why, often after a period of stable policy, one large or several smaller 'disturbances' break a 'policy monopoly', causing a rapid process of policy change (Baumgartner et al., 2009).

3 | RESULTS

The five jurisdictions show a strikingly similar history of the transfer and stocking of salmonids (Table 1). The artificial propagation of salmonids in hatcheries and subsequent stocking was in operation already by the mid-1800s in all countries. Soon after, methods were developed to transport fertilized eggs over long distances, including to tropical areas, and this led to the transfer of salmonids across the North Atlantic Ocean, from the Pacific to the Atlantic drainages of North America, as well as to other locations around the world. A number of primary transfers of non-native salmonids in the study area took place within little more than a decade at the end of the 19th century: eggs from *Salvelinus fontinalis* (brook trout) were transferred to Norway and Germany in 1877, brown trout arrived in eastern Canada in the 1880s, and rainbow trout was introduced to most countries and regions outside its range during the 1880s.

Following these introductions, attempts were made to put in place trained staff in fishery agencies and associations, and to develop laws and guidelines for facilitating salmonid transfer. Management was influenced by new discoveries and the practical application of artificial propagation in hatcheries. For example, in both Norway and Sweden, federal employees were hired and new fisheries laws were developed during the second half of the 1800s, motivated by the goal to distribute new knowledge and to stimulate the enhancement and artificial cultivation of salmonids. The educational nature of these early efforts may be deduced from the fact that Sweden's first official in-fisheries management was entitled 'educator' (Sörensen, 1919). In Germany, the German Fisheries Association was founded in 1870 and was also the main organization involved in exchanging fishes between Germany and North America. Its main objective was to enhance declining river fisheries at that time by initially stocking primarily Atlantic salmon and then other salmonids (and other species) in subsequent years.

From 1870 to 1980, all the jurisdictions studied gave priority to yield objectives and human perspectives on salmonid management, i.e. imported species should serve the needs of people for food security, jobs, and recreation. This was clearly expressed, for instance, in the Norwegian Law of Salmon and Freshwater Fisheries of 1964, which stated that the overall goal of the law was to 'arrange for the largest possible benefit for society and right holders from salmon and freshwater fisheries'. Similar objectives were also common in North America (Bottom, 1997).

3.1 | Current policy and governance

All five study jurisdictions now have national policy statements for the stocking of salmonids in the wild that differ from, and are partly contrary to, the historic objectives described above. At present, they reflect to varying degrees recent international conventions and guidelines on biodiversity conservation, and now focus on preserving native species and aquatic biodiversity while balancing these objectives with fisheries objectives (Table 2). All contemporary legislations acknowledge the desire to avoid or limit the stocking of non-native or harmful species, or populations, in natural, open freshwater basins; however,

TABLE 1 The five selected case areas, their historic salmonid distributions, stocking, and cultivation history. History, status and important milestones

	Canada (Atlantic Provinces)	France	Germany	Norway	Sweden
Area (km^2)	502 927 (6.5% water)	551 695 (1.35% water)	357 021 (2.2% water)	324 260 (5.2% water)	450 295 (8.7% water)
Population (no. people)	2.37 million (2015)	64 million (2014)	80.7 million (2014)	5.1 million (2014)	9.7 million (2014)
Native salmonids*	*S. alpinus* *S. fontinalis* *S. namaycush* *S. salar*	*S. alpinus* (*umbla*) *S. salar* *S. trutta*	*S. alpinus* *S. salar* *S. trutta*	*S. alpinus* *S. salar* *S. trutta*	*S. alpinus* *S. salar* *S. trutta*
Confirmed non-native salmonids*	*O. gorbusha* *O. kisutch* *O. mykiss O. tschawytscha* *S. trutta*	*O. mykiss* *S. fontinalis* *S. namaycush*	*O. mykiss* *S. fontinalis* *S. namaycush*	*O. gorbusha* *O. mykiss* *S. fontinalis* *S. namaycush*	*O. clarkia* *O. mykiss* *O. nerka* *S. fontinalis* *S. namaycush*
Firs known salmonid* hatchery (year, place)	1868 (*S. salar*), Miramichi River, New Brunswick	1853 (*S. salar* and *S. trutta*), Huningue, Haut-Rhin, North-east France	1869 (*S. salar* and *S. trutta*), Frauenberg, River Elbe catchment	1855 (*S. salar*), River Drammen catchment, Eastern Norway	1864 (*S. salar*), River Ångermanälven, Västernorrland County, Mid-Sweden
First documented transfers of non-native salmonids* (year, species, regions of origin and transfer)	1882: *S. trutta* from Germany and Scotland to USA. 1883 to Newfoundland. 1887: *O. mykiss* from California via Au Sable river, USA to Newfoundland	1877: *O. tschawytscha* 1878: *S. fontinalis* 1881: *O. mykiss*	1877: *O. tshawytscha* from Sacramento River (California) to Hüningen and Freiburg. 1879: *S. fontinalis* fertile eggs from USA to Berneuchen (Max von dem Borne). 1882: *O. mykiss* fertile eggs from North America to Hüningen, Freiburg, and Starnberg.	1877: *S. fontinalis* eggs from North America to Oslo region. Appr. 1900: *O. mykiss* from Denmark to Oslo region and to south and west coastal locations.	1892: *O. mykiss* and *S. fontinalis* from a hatchery in Germany (Max vonn dem Borne) to Jämtland. 1894: *O. mykiss* from Germany to Västmanland

*Full species names: *Oncorhynchus clarkii*; *Oncorhynchus gorbusha*; *Oncorhynchus mykiss*; *Oncorhynchus nerka*; *Oncorhynchus tschawytscha*; *Salvelinus alpinus*; *Salvelinus fontinalis*;*Salvelinus namaycush*; *Salmo salar*; *Salmo trutta*.

TABLE 2 Key national governance objectives and goals for salmonid introductions and transfers as stated in law, regulations, or statutory white papers (*de jure*), and current operative stocking practice (*de facto*)

Legislation	Source	Policy substance (*de jure*)	Stocking management practice (*de facto*)
Atlantic Canada	Fisheries Act, Fisheries (General) Regulations. Department of Fisheries and Oceans (DFO) (2013)	Stocking needs permission and should be in line with the national code on introductions and transfers, aiming to protect aquatic ecosystems and genetic integrity of aquatic biodiversity as well as maintaining human benefits from these resources.	Federal and/or provincial authorization is required and enforced for salmonid stocking and transfer (native and non-native).
France	Environmental code from 29 June 1984, Art. L.432.10. EU Water Framework Directive, see Guevel (1997).	Forbidden to introduce fish that: (1) can cause biological imbalance (e.g. pumpkinseed); (2) are not listed as present in France (*O. mykiss* and *S. fontinalis* are); and (3) in 'cat. 1' catchments, stocking of pike, perch, and pikeperch is not allowed. Demand of basin plan. Stocking should in principle not occur in basins with good ecological status.	Generally no authorization is needed in practice for most salmonid stocking and transfer (native and non-native) by registered angling clubs if the species is listed as present in the country. Fish should originate from a certified farm. Stocking is forbidden in basins with 'good ecological status'.
Germany	National Nature Conservation Act Clause 5, paragraph (4) clause 40 paragraph (4) White paper on protection of Agrobiodiversity, see Arlinghaus et al. (2015); Nehring et al. (2015).	Stocking of waters with non-native animals shall principally not take place and needs specific permission. Economically important species are often exempt from the general rules, such as rainbow trout and brook trout. These species do not legally feature as 'non-native' in the Nature Conservation Act if they have been naturalized for at least 100 years and have self-sustaining populations. Fisheries legislation and associated policy documents express a strong recommendation to stock with local strains of native salmonids, but enforcement is lacking.	No agency approval needed in practice for stocking native salmonids (including rainbow and brook trout). All native as well as feral introduced salmonids are defined as 'naturally occurring' (naturalized) and therefore legally native. State-specific regulations might limit some types of stocking of specific salmonids, in particular rainbow trout and brook trout. No native stocks of Atlantic salmon present, all release programmes based on foreign genotypes.
Norway	Law on salmonids and freshwater fish and fisheries (Norwegian Ministry of Environment, 1992). Norwegian Environment Agency (2014).	Stocking is illegal unless permission is given. Stocking must be based on a water-basin plan and local, native stocks only. Exception from this is commercial fish farming given concession after the aquaculture law.	Formal concession required and enforced, issued by regional authorities. All stocking based on regional or water-basin cultivation plans. Broodstock must be local, first generation. Exceptions: stocking can be allowed downstream in the same basin. Stocking of salmon can be allowed above the anadromous section when impacts are considered reversible. Restoration of extinct stocks must be based on native stocks from nearby basins.
Sweden	Prescriptions provided by the Agency for Marine and Water Management (SwAM), previously (until June 2011) National Board of Fisheries (FIFS 2011:13)	Permission to stock fish can only be issued if the species is suitable for the characteristics of the catchment and if there is no risk of spreading diseases. Permits for salmon in fresh water or estuaries may only refer to strains derived from the catchment within which the permit is valid.	*S. salar*: Rivers in four categories: wild, mixed, reared, and potential. Practice varies between categories. Generally, stocking needs approval from authorities and should be based on broodstock from the same basin.

there are large differences in the definitions of 'non-native' or 'harmful' species and practices (Table 2).

In France, a key criterion for harmfulness is the term 'biological imbalance'. In this context, only pumpkinseed (*Lepomis gibbosus*) and black bullhead (*Ameiurus melas*) are listed as fish species that can cause such 'imbalance'. Non-native salmonids that are already present in national French territories are not listed as causing 'imbalance', and hence no general limitations on transfer apply. Thus, the stocking of native as well as non-native salmonids in France by angling clubs registered as fishing right holders does not require permission unless: (i) the catchment is classified as being in 'good ecological status' according to the European Water Framework Directive (Council of the European Communities, 2000); and (ii) the species is not listed as being present in French watercourses. France has established several Natura 2000 areas (Special Areas of Conservation under the European Habitats Directive; Council of the European Communities, 1992) specifically targeting the protection of diadromous fishes, including Atlantic salmon and brown trout. How these affect stocking policies varies, however, and it is unclear whether it has led to stricter practices.

In Germany, the stocking of non-native fishes in principle (*de jure*) requires permission from the relevant fisheries authorities. In practice, the stocking of both native and some economically important non-native salmonids that are already present within German territory (i.e. 'naturalized') is generally done without the consent or involvement of any authority. This is because all salmonid species are considered naturalized and therefore legally speaking are considered native in Germany. A recent relisting of rainbow trout (which was not on a 'black list' previously; Nehring et al., 2010) as an invasive (i.e. damage-inducing) species in Germany is not legally binding, and has not changed any policies thus far. There are some exceptions to the above practice in Germany at state levels that effectively prohibit the stocking of rainbow trout, for instance in basins with naturally occurring brown trout or in rivers in general (Arlinghaus et al., 2015). Moreover, fisheries legislation recommends the use of local genetic strains of native salmonids whenever possible, but enforcement is limited and *de facto* mixing of stocks of brown trout is commonplace in Germany (Arlinghaus et al., 2015). No Natura 2000 areas (Council of the European Communities, 1992) are assigned for Atlantic salmon in Germany.

Overall, this *de facto* treatment of salmonid stocking means that the stocking of salmonids in Germany, and to an extent in France, is relatively uncontrolled, and the non-native species already present are legally considered naturalized and established, despite (for example) rainbow trout rarely reproducing naturally in Europe (Stankovic et al., 2015).

In Atlantic Canada and Norway the general stocking regulations are much stricter and stocking is illegal unless a permit is issued, and this is actively enforced by the authorities. Stocking concessions depend on the relatively strict demands for the use of local stock, and in Norway must follow detailed protocols, securing as far as possible the use of wild broodstock for native salmonids. In contrast, Sweden has general objectives and operational policies that operate between the *de facto* liberal practice of Germany and France on the one side and the strict rules of Atlantic Canada and Norway on the other. This is clearly illustrated by the classification of salmon and sea trout rivers in Sweden into four categories, where some rivers have liberal stocking regulations, whereas others are prohibitive (Table 2). Several catchments with salmon and brown trout in Sweden are assigned as Natura 2000 areas; however, the obligatory conservation plans do not generally address stocking issues in detail, and focus on habitat conservation and restoration (Naturvårdsverket, 2011).

3.2 | Organization

The countries have organized their responsibility for salmonid stocking differently (Figure 2, for details, see Figure S1). Despite differences between all countries in how the relevant government ministries are organized (i.e. the number of ministries and their responsibilities), all have ministries responsible for fisheries, conservation, and water management. In four, the fisheries or agriculture sector has jurisdiction over salmonid management, including stocking and transfer. The exception is Norway, where the Ministry of Environment (biodiversity and climate) is responsible for wild salmonid management, and the Ministry of Fisheries oversees marine fisheries and salmonid aquaculture. In addition to variation in public roles and responsibilities, there are further differences between the regions. Generally, regions in central Europe have communally held private fishing rights for freshwater fisheries via authorized angling clubs and associations (also commercial fishers in Germany). In Scandinavia, private fishing rights are normally held by individual or cooperative right-holders, whereas in Canada fishing rights are most often public and managed by agencies (federal and provincial). When assessing which administrative levels are making decisions and which stakeholders are considered the *de facto* decision makers, this differs. Regional authorities are the most important and influential actor in Atlantic Canada, Norway, and Sweden, whereas in France and Germany angling clubs operating at the local level are the key decision makers. Fisheries laws in France and Germany combine the right to catch fish with the duty to manage the resource, which traditionally was and still is put into practice via the stocking of fish in response to angler expectations (Arlinghaus & Mehner, 2005). There are differences by species, however: commonly there is greater regional and federal involvement in the management of Atlantic salmon in France and Germany, as opposed to rainbow trout and brown trout, for example.

Overall, the greatest difference in stocking governance can be found between Norway and Germany. Both have private ownership of freshwater fisheries, but the stocking is organized and practised very differently. In Germany, stocking occurs largely by authorized local angling clubs as the decision maker, without much interference from state authorities, whereas in Norway it is conducted under near-complete state authority and control.

3.3 | Current stocking practice for rainbow trout, Atlantic salmon, and brown trout across jurisdictions

The governance of the stocking and transfer of the three most commonly stocked salmonid species in the countries studied can be summarized as follows (for details, see Tables A1–A3).

Stocking policy

Stability ⟷ **Change**

Legislative unit	France, Germany	Sweden	Atlantic Canada, Norway
Responsible national authority	France: National Angling Agency Germany: Ministry of Agriculture and Consumer Protection	Marine and Water Management Agency	AC: Department of Fisheries and Oceans N: Ministry of Environment
Key salmonid resource	Brown trout, rainbow trout	Atlantic (Baltic) salmon	Atlantic salmon
Policy substance	Non-native salmonids legally classified 'naturalized'. Stocking of salmonids widespread and common	Stocking policy based on category of water. Stocking widespread in highly modified waters	Stocking prohibited. Concession to stock contingent use of local strains
Key level for decision making. Actors	Local level. Practitioners organized in authorized angling clubs	Regional level. National and international scientists. National and regional agency personnel. EU/Baltic fisheries commissions	Regional level. National and international scientists. National and regional agency personnel, NASCO
Perceived negative impacts from stocking	Unclear, limited, especially in cyprinid-type catchments	Local, regional. Salmonid and cyprinid-type catchments	Significant, national, regional. Salmonid-type catchments

FIGURE 2 Summary of stocking governance in the five legislative units, highlighting similarities and differences in key factors

The governance practice for rainbow trout (Table A1), a non-native species in all legislations, differs most across the countries. In Norway, it is black-listed as a high-risk species (HI), most likely because it has been a vector in the spread of the lethal salmon parasite *Gyrodactylus salaris*. No legal stocking of rainbow trout is allowed at present and the species plays an insignificant role in recreational fisheries. By contrast, in Germany and France it is the most stocked species and has legal status as 'naturalized' or 'present'. Moreover, it forms the basis for recreational fisheries, mostly in smaller lakes and reservoirs. In Germany, however, it has recently been classified as invasive, causing damage to brown trout (Nehring, Rabitsch, Kowarik, & Essl, 2015). In Sweden and in a few locations in Atlantic Canada, the stocking of rainbow trout takes place in confined freshwater systems, such as ponds, reservoirs, and smaller lakes with no run-off (offering 'put-and-take' fisheries). In France, despite the continued stocking of rainbow trout, the volume has shrunk somewhat, whereas in Germany the annual stocking volume (~2200 tonnes) has remained constant, with much of it being used for aquaculture (Brämick, 2014). The amount stocked in open water bodies is much smaller (Table A1). Overall, the abundance and distribution of rainbow trout in fresh water is decreasing in all five jurisdictions, as reported by Stankovic et al. (2015). The main source of rainbow trout in natural freshwater basins in Atlantic Canada, Norway, and Sweden is now from aquaculture escapees (Veinott & Porter, 2013).

Atlantic salmon (AT2) was originally native in all jurisdictions; however, in Germany it has been declared extinct (EX) and no fishing occurs, but is subject to reintroduction efforts, for instance in the Rhine and Elbe river systems, using non-native stocks (Granek et al., 2008). In France, the species is red-listed (Vulnerable, VU) and there are only limited, strictly regulated fisheries in a few basins. The species has Least Concern (LC) status in Atlantic Canada, Norway, and Sweden, and is subject to significant fisheries interests; however, in these countries populations in some regions are also under severe threat from a range of mostly anthropogenic factors (Thorstad, Whoriskey, Rikardsen, & Aarestrup, 2011; WWF, 2001). It is the most thoroughly and extensively monitored species, with all countries running stocking programmes for enhancement or conservation (e.g. to reintroduce the species after severe pollution or disease events, such as acidification, either from gene bank material or from nearby stock). In principle, however, all countries now aim to use native populations for stocking, unless native stocks are extinct, as in the case of Germany. In Canada, Norway, and Sweden, it is the most stocked of the three species considered, although in Canada and Norway stocking is clearly reduced. In Sweden, the salmon rivers are categorized with different stocking regulations and in some – typically heavily modified rivers – enhancement and ranching operations based on large numbers of smolts are still common. In other Swedish catchments, stocking is illegal or limited, primarily to leave native stocks with as little impact as possible or to avoid the spread of diseases or parasites. In contrast, in France and to a more limited extent in Germany, new hatcheries have been established as part of restoration and reintroduction programmes, often put in place by self-organized local networks and in cooperation with federal agencies and research institutes (Schneider, 2011). Compared with trout, however, the quantities of salmon stocked in these two countries are small (Granek et al., 2008; Martin et al., 2012).

Brown trout (AT3) is native in all European countries, but not in Atlantic Canada. All countries have significant fisheries, mostly recreational, for brown trout. As for Atlantic salmon and rainbow trout, the species has a long history of transfer and stocking within and outside its native range to enhance fisheries. In Europe, the red-list status of the species is of Least Concern (LC). In Atlantic Canada, it is considered naturalized and reproduces in the wild, gradually having colonized new catchments in several provinces since its introduction (e.g. Westley & Fleming, 2011). It is only quite recently that in its native range concern has been expressed about the stocking of non-native populations of brown trout (Ryman, 1981; Vera, Martinez, & Bouza, 2018). All European countries have a long history of brown trout hatcheries based on a few preferred populations (often expressing large body size and fast growth) for transfer to other basins and across biogeographical zones. Evidence indicates that this may lead to the loss of local gene pools through genetic swamping (Lerceteau-Köhler, Schliewen, Kopun, & Weiss, 2013). Stocking has decreased in Atlantic Canada, France, and Norway, but is stable in Germany and in most of Sweden. An awareness and the use of local broodstock for hatchery production and stocking have increased in all European countries, except where local broodstock is unavailable or hatcheries still operate based on foreign stocks. The latter is the situation in large parts of Germany, where local angling clubs buy stocking material from commercial hatcheries without any legal control of source populations (Arlinghaus et al., 2015). Thus, the practice of stocking non-local brown trout is still continuing and widespread, at least in Germany, and probably in France as well, but less so in Sweden and Norway. However, all European countries generally lack good statistics on the stocking of brown trout, including the origins, volumes, and life stages stocked, especially compared with Atlantic salmon.

4 | DISCUSSION

Following stable and near identical policies for salmonid stocking and transfer from the mid-1800s to the 1980s, with a strong emphasis on yield, the five study jurisdictions changed their policies and governance in favour of biodiversity conservation. These changes reflect new international guidelines that have emphasized the conservation of native biodiversity, as well as advances in the understanding of the potential harmful impacts of previous policies favouring stocking and transfer. The new policy guidelines also reflect changing social values and attitudes that place more emphasis on environmental conservation. The jurisdictions have accomplished strikingly different degrees of policy change, however. Canada and Norway have seen radical, rapid changes in policies, both *de jure* and *de facto*, whereas changes in France and Germany have so far been more limited, and mostly *de jure*. Sweden can be characterized as intermediate. Consequently, the jurisdictions now manage salmonid introductions differently, especially in the southernmost jurisdictions of France and Germany. There, the continued release of biologically non-native fishes, and transfer and mixing of salmonid populations, still prevails at a high level.

Factors demarcating the southernmost from more northerly jurisdictions with regards to salmonid stocking and transfer (Figure 2) are: the cultural and political importance of salmonids; experiences with severe adverse impacts of the activity on native salmonids; and the scale and institutional settings and power (foremost being local versus national or international governance). These differences collectively give rise to three important general observations.

4.1 | Policy reflects the relative importance of native salmonids

The Scandinavian countries and Canada have a history and culture that is strongly tied to the presence of native salmonids across much of their territory. Atlantic salmon is the most culturally, economically, and politically valued freshwater fish, at least in Norway and Atlantic Canada, and as such it is important to their regional and national identities. Salmon is also the most stocked species of the three assessed in detail, and general salmonid stocking policies take their point of departure from guidelines derived for Atlantic salmon. This is not the case in France and Germany, where salmonids are currently less widespread and often confined to restricted areas at high altitude and along coasts. Brown trout and rainbow trout are the most important and valued salmonid species in these countries. Fisheries here exploit a much wider range of freshwater species, and salmonid conservation has been one of many concerns addressed in their more diverse aquatic conservation strategies. Moreover, unlike the northern legislations, most of the existing economic interests related to salmonids rely on stocked fish (Arlinghaus et al., 2015).

4.2 | Policy reflects history of impacts on native salmonids

Different experiences among the countries with the severity of impacts of non-native salmonids and non-local genotypes has fostered variation in policy development across the North Atlantic. The adverse impacts of non-native salmonids can be more severe in the species-poor fish communities that are found in parts of Scandinavia and Canada than in species-richer communities, such as those in Germany and France (Fitzgerald, Tobler, & Winemiller, 2016). In Norway, rainbow trout stocking is prohibited and the species is black-listed as high risk. Control of the transfer of salmonids across regional and national borders is also strict. The fatal transfer and spread of the *G. salaris* parasite in Norway (Johnsen & Jensen, 1991) has probably played a major role in imposing this strict regime. At about the same time, salmonid stocking and transfer also became recognized as a threat high on the agenda of the intergovernmental North Atlantic Salmon Conservation Organisation (NASCO), of which all the countries in this study are members. The differences in practical experiences adds nuance to the scientific knowledge about the pros and cons of salmonid stocking and transfer strategies, and as such aligns with Sandström's (2010) hypothesis that knowledge (un)certainty contributes to different salmonid stocking policies between regions and countries.

4.3 | Policy reflects differences in ownership and level of decision making

The organization of salmonid stocking governance, scale, and ownership arrangements also differ between jurisdictions. All countries have complex sectoral settings. Thus ‘complexity’ in itself, as discussed by Sandström (2010), cannot be the key reason for the identified variation. Salmonid governance is a policy system that operates both at the (inter)national and at the local level, and to varying degrees involves private and public stakeholders and institutions. There are substantial differences in the vertical distribution of responsibilities and decision making among the jurisdictions. The clearest difference exists between France and Germany on the one side, where local, primarily private stakeholders (angling clubs) are the key decision makers, and Atlantic Canada, Norway, and Sweden on the other side, where national and regional (county, provincial) authorities are the key decision makers, eventually licensing local actors and right holders to stock. Especially in Norway and Canada, regional (provincial) authorities operate on the premise of detailed regulations from national authorities that are also linked directly to international guidelines for salmonid (salmon) stocking and transfer (NASCO, 2006). The transaction cost of policy change is, of course, smaller when there are fewer, higher level participants and organizations involved. We thus suggest that the vertical distribution of responsibility common to France and Germany, which empowers local angling clubs, is a major contributor to the identified differences in adaptive changes to stocking policies. Even so, Sevä (2013) showed that two countries (Sweden and Finland) mainly operating under regional-level decision making might still opt to pursue somewhat different trajectories depending on contextual factors and culture. The differing empowerment of private organizations adds to these differences. Interestingly, the two jurisdictions with the largest policy change and strictest approach to stocking and transfer – Atlantic Canada and Norway – have placed responsibility in different sectors horizontally: fishery and environment, respectively.

The fact that a stocking-friendly policy continues *de facto* in France and Germany shows that new scientific knowledge and new international guidelines are not sufficient to change policy and practice on the ground. Our analysis suggests that the rapid policy change in Atlantic Canada and Norway happened because enough ‘disturbance’ emerged, a pattern that is typical of the punctuated equilibrium framework (True, Jones, & Baumgartner, 2007). The interplay between the high cultural and political importance of migratory Atlantic salmon and the demonstrable adverse impacts on native salmonids was crucial in generating enough political attention for change.

In addition, in Norway and Atlantic Canada, the acceptance of stocking and transfers was gradually challenged by scientists and representatives of national and international authorities. The linkages between state authorities and local practitioners were simple and well developed, and regional state or provincial authorities have been able to enforce the policy change actively. In central Europe, strong coalitions between mostly local, legally empowered stakeholders with significant economic interest in upholding stocking for angling purposes has so far led to little *de facto* policy change. Also, more diverse freshwater fisheries interests involving many non-salmonid species appears to make the policy setting more complex and therefore also more complicated and difficult to change.

The situation in Sweden operates somewhere between that found in Canada and Norway on one hand and France and Germany on the other. The freshwater fish fauna of Sweden is more complex than in Norway, and less so than that in Central Europe. International guidelines for salmonid stocking in Atlantic Canada and Norway are issued by NASCO, which has little tradition for emphasizing stocking or sea-ranching based fisheries (NASCO, 2006). In most parts of Sweden (eastern and southern), the International Baltic Sea Fisheries Commission is responsible for salmon conservation, and multiple fisheries (commercial, subsistence, and recreational) are upheld by large-scale stocking programmes (IBSFC, 1997). With many salmon stocks severely depleted by damming and pollution, Sweden has categorized its salmon rivers into groups and zones with different policies. This strategy addresses the more varied and diverse ecological and social contexts by applying differing *de facto* practices, and could also be a useful policy approach to reduce the transfers of non-native salmonids in Central Europe.

5 | CONCLUSION

A major objective of studies of biodiversity policy and governance is to identify factors that can lead towards more sustainable practices (Bennett et al., 2017). Policy studies have carefully focused on understanding the social, political, and ecological contexts that influence outcomes in specific cases, but dissecting policies and factors related to divergent outcomes (Clark, 2011; Orach & Schlüter, 2016). The countries in this study are quite similar in their socio-political profiles, both within Europe and between Europe and North America, making it unlikely that socio-political differences are the sole or even the main driver of the observed differences. Rather, this current case study shows that the political and cultural importance of salmonids, combined with the observed adverse impacts of transfers and stocking have led to rapid policy change in Norway and Atlantic Canada. In contrast, a lower importance given to salmonids and a more complex fish fauna, combined with empowered local decision makers, have so far held back change in France and Germany.

From this analysis, the most severe and least addressed problems related to the stocking of salmonids in the jurisdictions studied are the continuing releases of non-native rainbow trout in open catchments, especially in France and Germany, and the stocking of brown trout non-native to the catchment or of unknown origin. Policy change to curtail the adverse impacts on biodiversity should highlight the following measures. First, the jurisdictions should ensure sufficient monitoring of the volume, location, stage, and origin of all salmonid stockings and transfers, especially for brown trout and rainbow trout (as Atlantic salmon is reasonably well documented). Second, the gap between *de jure* and *de facto* policy should be reduced, especially in countries with a complex fish fauna. Here, strengthening and elaborating the present zoning approaches based on the European Habitats Directive (Council of the European Communities, 1992) and the Water Framework Directive (Council of the European Communities, 2000), which aim to cull unsustainable stocking in regions and catchments where salmonids form type-specific fish communities (as opposed to the other dominating type – i.e. cyprinid-dominated fish communities), could be a viable approach. In addition, stronger engagement from national authorities as well as improved dialogue between local, regional, and national authorities is recommended in France and Germany.

Further studies of policy change are imperative to address the rapid loss of aquatic biodiversity. How policy change is influenced by the interaction between stakeholders from science, public and private management organizations, and practitioners, including those operating at different scales, should be given priority. More detailed research is also needed to understand better the different policies of the Atlantic and Baltic subregions (Canada and Norway versus Sweden), as well as between countries with simple and more complex freshwater fish fauna.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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APPENDIX

TABLE A1 Status for rainbow trout (*Oncorhynchus mykiss*) in Atlantic Canada, France, Germany, Norway, and Sweden (stocking focus, not aquaculture)

	Atlantic Canada	France	Germany	Norway	Sweden
O. mykiss	Non-native	Non-native	Non-native	Non-native	Non-native
Legal status	NA	'Naturalized'	'Naturalized'	Black-listed, high risk (HI), illegal for stocking	NA
Current practice	No stocking after 1965 in NB. Put-and-take (P&T) in selected lakes in NS. Occasionally in PEI. No stocking in NL	Enhancement	Enhancement	Not actively stocked in recent decades, but common along the coast as farm escapees	Used for enhancement in closed systems (dams, ponds++)
Self-recruitment status	Self-sustaining populations established in several basins	Very few, three locations in Pyrenees	Seldom/little. See Stankovic et al., 2015	Seldom/little. See Stankovic et al., 2015	Seldom/little. See Stankovic et al., 2015
Stocking statistics	NA	1991: 3938 t 1997: 2213 t 2007: 1998 t	No systematic stat, Estimate 2010: 283 t	Not stocked in recent decades, no updated figures except for aquaculture	1990: 1040 t 2012: 640 t
Known distribution?	Partly	Yes, well mapped (Keith, Persat, Feunteun, & Allardi, 2011)	Yes, well mapped over time (Wiesner, Wolter, Rabitsch, & Nehring, 2010)	Common along coast from farm escapees, inland: limited, see Stankovic et al., 2015	Common along coast from farm escapees, inland: limited, see Stankovic et al., 2015
Trends	Reduced stocking and mostly limited to put-and-take (P&T) fisheries	Stocking reduced (based on stats above)	Reduced stocking, illegal in some states in basins with *S. trutta*	Common on the coast (aquaculture escapees), reduced in inland waters	Stocking still common in closed systems (P&T)

Atlantic Provinces of Canada: NB, New Brunswick; NL, Newfoundland and Labrador; NS, Nova Scotia; PEI, Prince Edwards Island.

TABLE A2 Status for Atlantic salmon (*Salmo salar*) in Atlantic Canada, France, Germany, Norway, and Sweden (stocking focus, not aquaculture)

	Atlantic Canada	France	Germany	Norway	Sweden
S. salar	Native	Native	Native (extinct)	Native	Native
Legal status	Endangered in some localities (Inner Bay of Fundy)	Red-listed Vulnerable (VU)	Extinct, reintroduction programmes	Red-listed Least Concern (LC)	LC
Current practice	Stocked	Stocked	Stocked	Stocked	Stocked
Purpose	Compensation, restoration	Compensation, restoration	Restoration/ reintroduction	Compensation, restoration, enhancement	Compensation, restoration, enhancement
Stocking stats	1990: 4 780 000 (no juv.) 2000: 3 411 000 (no juv.) 2005: 2 606 000 (no juv.)	2007: 4 000 000 (no eggs) 2 755 000 (no fry, parr) 330 000 (no smolts)	2010: 11 t	2010: 5 200 000 (no eggs) 2 400 000 (no parr) 400 000 (no smolts)	1990: 361 000 (no. parr) 401 000 (no. smolts) 2000: 1 284 000 (no. parr) 891 000 (no. smolts) 2012: 185 000 (no. parr) 1 971 000 (no. smolts)
Known distribution?	Yes	Yes	Yes	Yes	Yes, monitored by the Swedish electrofishing register
Trend	Reduction and refocus from enhancement to conservation from around 1995	Unknown	Stocking only as part of reintroduction programmes. Native stocks extinct	Stocking reduced, but lacks good statistics	Stable, but more smolt, less parr. Stocking is not allowed in certain rivers

TABLE A3 Status for brown trout (*Salmo trutta*) in Atlantic Canada, France, Germany, Norway, and Sweden (stocking focus, not aquaculture)

	Atlantic Canada	France	Germany	Norway	Sweden
S. trutta	Non-native	Native	Native	Native	Native
Legal status	'Naturalized'	LC		LC	LC
Current practice	Limited stocking in NS	Stocked	Stocked	Stocked	Stocked
Purpose	Recreational fishery	Enhancement Compensation	Enhancement Compensation Stock rebuilding (sea trout) Restoration (sea trout)	Compensation Enhancement	Compensation Enhancement
Self-reproducing status	Yes	Yes	Yes	Yes	Yes
Stocking stats	Not available	1990: 131 t 2000: 91 t 2010: 53 t	2010: 391 t	Good figures not readily available	For anadromous Baltic trout only. 1990: 8000 (no. parr) 78 000 (no. smolts) 2000: 7000 (no. parr) 100 000 (no. smolts) 2012: 138 000 (no. parr) 20 000 (no. smolts)
Known distribution?	For some provinces. Self-sustaining stocks established in most provinces	Yes, mostly all over the country	Yes	Yes, mostly all over the country	Abundant all over the country, both migratory and landlocked Scattered monitoring by the Swedish electrofishing register
Trend	Stocking reduced; non-existent in most provinces	Stocking reduced	Continuous stocking, with concern for conservation of local gene pools	Stocking is reduced, and use of non-native populations also reduced	Increasing self-reproducing populations on the west coast, stocking stable on the east coast/Baltic region