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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 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 multi-national perspective to understand the important governance dimensions of success and failure of salmonid stocking and transfer policies.
3. The present study analyses the historic development and contemporary governance of 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. It is based on analyses of published and unpublished literature, and a survey of experts.
4. Current salmonid stocking policies and practices varied significantly among the 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 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 negative ecological impacts of transfer and stocking of salmonids. This has led to small, incremental stocking policy changes *de facto*, that are reflective of the *advocacy coalition policy framework*.

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

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1 Introduction

1.1 Background

A range of anthropogenic 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 (Dudgeon, Arthington, Gessner, & Kawabata, 2006; Arthington, Dulvy, Gladstone &Winfield, 2016). 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). Man-mediated changes are similarly threatening river biodiversity in the developing world (Winemiller et al., 2016; Zarfl, Lumsdon, Berlekamp, Tydecks, & Tockner, 2015).

Humans have for many centuries transferred organisms, including fishes, across biogeographic barriers to benefit food security, recreation or for ornamental purposes. Hoffmann (1994) reconstructed the human-mediated spread of 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 530 and 1100 A.D. 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 were also actively transferred by humans since at least medieval times (Pister, 2001). Recent global analyses suggest 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, loss of yield and other ecosystem services (e.g., water clarity), and 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 those of the genera *Salmo*, *Salvelinus* and *Oncorhynchus.* They are of considerable importance to humans for their contributions to food and culture. However, such

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introductions and transfers also regularly generate political and social conflicts, especially in the context of biodiversity conservation associated with the interaction between native and introduced non-native populations (Crawford & Muir, 2007; Halverson, 2010; Buoro, Olden, & Cucherousset, 2016). This has made them objects of active management efforts 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 where management objectives generally promoted 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 due to human-assisted transfer (Pister, 2001; Crawford & Muir, 2007). The same is the case for brown trout (*Salmo trutta*), originally native to Europe (MacCrimmon & Marshall, 1968).

New scientific knowledge emerged during the 1970s – 1980s that provided empirical evidence that stocking and transfer of salmonids could threaten native aquatic biodiversity at all levels – genes, populations, species and ecosystems (e.g., Billingsley, 1981; Ryman, 1981; Townsend, 1996; Simon & Townsend, 2003). Salmonids have genetically distinct populations, due to their homing behaviour and adaptation to specific rivers and catchments (Ryman & Utter, 1987; Garcia de Leaniz et al., 2007; Fraser, Weir, Bernatchez, Hansen, & Taylor, 2011). Accordingly, this leads to the genetic integrity of local salmonid stocks being generally threatened not only by non-native species, but also by introgression of genetic material from conspecifics of non-native (e.g. from another region or catchment) and cultured origins (that might be a result of crossbreeding of different populations, see Hansen & Mensberg, 2009; Perrier, Guyomard, Bagliniere, Nikolic, & Evanno, 2013; Karlsson, Diserud, Fiske, & Hindar, 2016). Whereas scientists agree that mixing of stocks of salmonids should be avoided, they also point out 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 (e.g. Johnsen & Jensen, 1991), and international agreements, conventions and guidelines now emphasize the obligation to conserve native biodiversity and recommend reduction of transfers and introductions of salmonids (see Sandström, 2010 for an overview of international policies and guidelines). 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, stocking and transfer of salmonids in natural freshwater basins continues to varying degrees and for differing 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 (Sandström, 2010; Lorenzen, Beveridge, & Mangel, 2012). Furthermore, stakeholders often hold differing views on stocking principles and objectives (Aas, Haider, & Hunt, 2000; Arlinghaus, 2006; Arlinghaus, Beardmore, Riepe, Meyerhoff, & Pagel, 2014; Arlinghaus et al., 2015; Cowx, 1994; Cowx, Arlinghaus, & Cook, 2010; von Lindern & Mosler, 2014). At the policy level, Sandström (2010) found that limited policy change and adaption 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 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 rationalise 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 & Carleton-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, e.g., 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 of the effects of socio-political factors on stocking and transfer policy either on 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 (Orach & Schlüter, 2016; Bennett et al., 2017). Studies anchored in political sciences have analysed processes of policy change in environmental governance, including management of freshwater catchments (Pedersen, 2010), fishery policy (Sandström, 2010), wildlife conservation (Clark, Lee, Freeman, & Clark 2008, Matti & Sandström, 2011), and climate change policy (e.g. Carter & Jacobs, 2014). An overarching issue in many of these studies has been to identify frameworks to explain observed policy change processes along dimensions of degree of change (small or large), time (rapid or slow) and scale (local to international). Policy change might stem from new knowledge (learning), changing organisational 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 (Orach & Schlüter, 2016; Bennett et al., 2017). To identify and discuss drivers and barriers to policy change in salmonid management and conservation, we assess these in light of established frameworks of policy change and governance of social-ecological systems (Paavola, Gouldson, & Kluvankova-Oravska, 2009; Orach & Schlüter, 2016).

The specific objective of this paper is to analyse policy change in salmonid fish stocking and transfer governance and 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, 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 eco-region (North Atlantic), with relatively similar sets of societal values (e.g., western countries (Schwartz, 2007)), possessing well-developed governance structures, and partly sharing and exploiting the same mixed stocks (e.g., Atlantic salmon) have different policies despite being guided by the same international environmental policies and guidelines (e.g., Convention on Biological Diversity, (1992)).

2 Cases and 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 most relevant for comparison with the 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* were introduced in all jurisdictions and all jurisdictions were considered to share similar fisheries management histories, level of economic well-being and 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 (two to five in each country) conducted document analysis of national-level grey 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, key national statistical figures if available)
- Key objectives for introductions and transfers
- Sources of funding for stocking/transfer
- Key national policy statements (primary laws, secondary regulations, bye-laws or guidelines)
- Property rights in relation to fisheries
- Governance organizations
- References/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 to finding information (Colette, 1990), and the team's in-depth knowledge of the salmonid fisheries sector in each region and their language skills exploited, 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 dialogue with stakeholders from all countries at a workshop in Gothenburg, Sweden, in 2016.

In the analysis, we specifically use the two contrasting frameworks of Advocacy Coalition (AC) and Punctuated Equilibrium (PE) to assess policy change processes 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 actors 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 in terms of transfer and stocking of salmonids (Table 1). 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 lead 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 seminal transfers of non-native salmonids in the study area took place within little more than a decade at the end of 19th century: brook trout eggs 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/associations and develop laws and guidelines for facilitating salmonid transfer. Management was influenced by the 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 developed during the second half of the 1800s, motivated by the goal to distribute the new knowledge and to stimulate enhancement and artificial cultivation. The educational nature of these early efforts is deducible 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 prime actor 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 study jurisdictions prioritised yield objectives and anthropocentric perspectives on salmonid management, i.e. imported species should serve the needs of people for food security, jobs and recreation. For instance, this was clearly expressed 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 common also in North America (Bottom, 1997).

3.2 Current policy and governance

All five study jurisdictions now have national policy statements for stocking of salmonids in nature that are different and partly contrary to the historic objectives described above. Currently, to varying degrees, they reflect 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 stocking of non-native or harmful species, or populations, in natural, open freshwater basins. However, there are large differences in terms of 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 the fish species that can cause such "imbalance". Non-native salmonids already present in national French territories are not listed as causing "imbalance" and hence no general limitations on transfer apply. Thus, 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 EU Water Framework Directive, and ii) the species is not listed as being present in the French watercourses. France has established several Natura2000 areas (cfr. Council Directive 92/43, 1992), specifically targeting the protection of diadromous fishes, including Atlantic salmon and brown trout. How these affect stocking policies, however, it varies and is unclear whether it has led to stricter practices.

In Germany, stocking of non-native fishes in principle *de jure* demands permission from relevant fisheries authorities. In practice, stocking of native and of some economically important non-native salmonids that are already present within Germany territory (i.e., "naturalized") generally is done without authority involvement or consent. This is because all

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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 earlier, Nehring et al., 2010) as an invasive (i.e., damage-inducing) species in Germany is neither legally binding nor has changed policies thus far. Some exceptions to the above practice in Germany exist at state levels that effectively prohibit 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 Natura2000 areas (Council Directive 92/43, 1992) are assigned for Atlantic salmon in Germany.

Overall, this *de facto* treatment of salmonid stocking means that 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 actively enforced by authorities. Stocking concessions depend on relatively strict demands on the use of local stocks 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 one side and the strict rules of Atlantic Canada and Norway on the other side. This is well illustrated by the classification of salmon and sea trout rivers in Sweden into four categories, where some rivers have liberal stocking regulations while in others, it is prohibited (table 2). Several catchments with salmon and brown trout in Sweden are assigned as Natura 2000 areas. However, the obligatory conservation plans generally do not address stocking issues in detail, and focus on habitat conservation and restoration (Naturvårdsverket 2011).

3.3 Organisation

The countries have organized their responsibility for salmonid stocking differently (Figure 2). Despite differences between all countries regarding how relevant governmental ministries are organized (i.e., 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

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Norway, where the Ministry of Environment (biodiversity and climate) is responsible for wild salmonid management, while 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. Those in central Europe generally have communally held private fishing rights for freshwater fisheries via authorised angling clubs and associations (also commercial fishers in Germany). In Scandinavia, the private fishing rights are normally held by individual or cooperative right-holders, while in Canada, fishing rights are most often public and managed by agencies (federal and provincial). When assessing what administrative levels are making decisions and what stakeholders are considered the *de-facto* decision-maker, this differs. Regional authorities are the most important and influential actor in Atlantic Canada, Norway and Sweden, while 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 stocking of fish in response to angler expectations (Arlinghaus & Mehner, 2005). However, there are differences by species, with greater regional and federal involvement commonly for Atlantic salmon management in France and Germany, as opposed to, for example, rainbow and brown trout.

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

3.4 Current rainbow trout, Atlantic salmon and brown trout stocking practice across jurisdictions

Governance of stocking and transfer of the three most commonly stocked salmonid species in the countries studied can be summarized as follows (see tables in appendixes AT1-AT3 for details).

The governance practice for rainbow trout (Table AT1), 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 currently allowed 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. However, in Germany it recently became classified as invasive, causing damage to brown trout (Nehring, Rabitsch, Kowarik, & Essl, 2015). In Sweden and in a few locations in Atlantic Canada, stocking of rainbow trout takes place in confined freshwater systems, such as ponds, reservoirs and smaller lakes with no runoff (offering “put-and-take” fisheries). In France, despite the continued stocking of rainbow trout, the volume has shrunk somewhat while in Germany, the annual stocking volume (~2200 tonnes) has remained constant, with much of it being for aquaculture (Brämick, 2014). The amount stocked in open water bodies is much smaller (Table AT1). Overall, the abundance and distribution of rainbow trout in freshwater 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 are now 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 only limited, strictly regulated fisheries takes place 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 latter countries populations in some regions are also under severe threat from a range of mostly anthropogenic factors (WWF, 2001; Thorstad, Whoriskey, Rikardsen, & Aarestrup, 2011). It is the most thoroughly and extensively monitored species, with all countries having 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 a nearby stock). However, all countries, in principle, 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, though 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/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 as little impacted as possible or to avoid spreading 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 to trout, however, stocking volumes of salmon 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 species has a least concern (LC) red list status. 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 (e.g., 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. Awareness and use of local broodstock for hatchery production and stocking has 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 of non-local brown trout is still ongoing and widespread, at least in Germany and likely as well in France, 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 to 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 reflected new international guidelines that emphasized conservation of native biodiversity, as well as advances in the understanding of potential harmful impacts of previous policies favouring stocking and transfer. The new policy guidelines also reflected changing social values and attitudes that place more emphasis on environmental conservation. However, the jurisdictions have accomplished strikingly different degrees of policy change. Canada and Norway have seen radical, rapid changes in policies, both *de jure* and *de facto*, while changes in France and Germany have so far been more limited, and mostly *de jure*. Sweden can be characterised 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 northern jurisdictions in regards to salmonid stocking and transfer are (Figure 2): the cultural and political importance of salmonids; experiences with severe negative impacts of the activity on native salmonids; and the scale and institutional settings and power (foremost local versus national/international governance). These differences collectively give rise to three important general observations.

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 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 elevation 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).

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

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North Atlantic. The negative impacts of non-native salmonids can be more severe in species poor fish communities that characterize 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 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), to which all the countries in this study are members. The differences in on-the-ground experiences adds nuances 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.

Policy reflects differences in ownership and level of decision-making

The organisation of salmonid stocking governance, scale and ownership arrangements also differ between jurisdictions. All countries have complex sectorial 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 local level, and to varying degrees involves private and public stakeholders and institutions. In terms of vertical distribution of responsibilities and decision-making, there are substantial differences among the jurisdictions. The clearest difference exists between France and Germany on the one side, where local, primarily private stakeholders (angling clubs) are 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 licencing local actors and right holders to stock (See Figure S1). Especially in Norway and Canada, regional (provincial) authorities operate on the premises of detailed regulations from national authorities that are also linked directly to international guidelines for salmonid (salmon) stocking and transfer (NASCO 2006, and see supplementary material). Obviously, the transaction cost of policy change is smaller when there are fewer, higher level actors 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

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that two countries (Sweden and Finland) operating mainly under regional-level decision authority might still opt to pursue somewhat different trajectories depending on contextual factors and culture. Differing empowerment of private actors adds to the difference. 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 typical of the punctuated equilibrium framework (True, Jones & Baumgartner, 2007). The interplay between the high cultural and political importance of migratory Atlantic salmon and concrete on-the-ground negative impacts on native salmonids was crucial in generating enough political attention for change.

Additionally, 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 Canada and Norway on one hand and France and Germany on the other. The freshwater fish fauna of Sweden is in a middle position being 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 emphasising 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 programs (IBSFC, 1997). With many salmon stocks severely depleted due to damming and pollution, Sweden has categorised 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 be a useful policy approach to reduce transfers of non-native salmonids in Central Europe as well.

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 main driver of the observed differences. Rather, the current case study shows that the political and cultural importance of salmonids combined with manifested negative impacts of transfers and stocking have led to rapid policy change in Norway and Atlantic Canada. In contrast, a lower importance held for 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 stocking of salmonids in the studied jurisdictions are the continuing releases of the non-native species rainbow trout in open catchments, especially in France and Germany, and stocking of brown trout of non-native origin (to the catchment) or of unknown origin. Policy change to curtail negative 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 (since 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 existing zoning approaches based on European Habitat (Council Directive 92/43) and Water Directives (Directive 2000/60), which aim to cull unsustainable stocking in regions and catchments where salmonids form type-specific fish communities (as opposed to the other dominating type – 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 organisations, and practitioners, including actors operating at different scales, should be prioritised. More detailed research is also needed to better understand the different policies between the Atlantic and Baltic sub-regions (Canada and Norway versus Sweden), as well as between countries with simple and more complex freshwater fish fauna.

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

	Canada (Atlantic Provinces)	**France**	**Germany**	**Norway**	**Sweden**
Area (km²)	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 mill (2015)	64 mill (2014)	80.7 mill (2014)	5.1 mill (2014)	9.7 mill (2014)
Native salmonids*	*S. salar* *S. alpinus* *S. fontinalis* *S. namaycush*	*S. salar* *S. trutta* *S. alpinus (umbla)*	*S. salar* *S. trutta* *S. alpinus*	*S. salar* *S. trutta* *S. alpinus*	*S. salar* *S. trutta* *S. alpinus*
Confirmed non-native salmonids*	*S. trutta* *O. mykiss* *O. gorbusha* *O. tschawytscha* *O. kisutch*	*S. fontinalis* *S. namaycush* *O. mykiss*	*S. fontinalis* *O. mykiss* *S. namaycush*	*S. fontinalis* *S. namaycush* *O. mykiss* *O. gorbusha*	*S. fontinalis* *S. namaycush* *O. mykiss* *O. clarkii* *O. nerka*
First known salmonid* hatchery (year, place)	1868 (*S. salar*), Miramichi River, New Brunswick	1853 (*S. trutta* and *S. salar*), Huningue, Haut-Rhin, Northeast France	1869 (*S. salar, 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

** Salmo salar, S. salar; Salmo trutta, S. trutta; Salvelinus alpinus, S. alpinus; Salvelinus fontinalis, S. Fontinalis; Salvelinus namaycush, S. namaycush; Oncorhynchus mykiss, O. mykiss; Oncorhynchus clarkii, O. clarkii; Oncorhynchus nerka; O. nerka; Oncorhynchus tschawytscha, O. tschawytscha; Oncorhynchus gorbusha, O. gorbusha.*

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Table 2. Key national governance objectives/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 a 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 programs based on foreign genotypes.
Norway	Law on salmonids and freshwater fish and fisheries (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/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 no risk of spreading diseases exists. Permits for salmon in freshwater or estuaries may only refer to strains derived from the catchment within which the permit is valid.	*S. salar*: Rivers in 4 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.

Appendix tables 1, 2 and 3:

Appendix table 1. 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 the last 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: 3 938 (tonnes) 1997: 2 213 (tonnes) 2007: 1 998 (tonnes)	No systematic stat, Estimate 2010: 283 (tonnes)	Not stocked last decades, no updated figures except for aquaculture	1990: 1040 (tonnes) 2012: 640 (tonnes)

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Know 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)

Appendix table 2. 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)	Redlisted Vulnerable (VU)	Extinct, reintroduction programs	Redlisted Least Concern (LC)	LC
Current practice	Stocked	Stocked	Stocked	Stocked	Stocked
Purpose	Compensation, restoration	Restoration Compensation	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 (tonnes)	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, monitoring by the Swedish electrofishing register.

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Trend	Reduction and refocus from enhancement to conservation from around 1995	Unknown	Stocking only as part of reintroduction programs. Native stocks extinct.	Stocking reduced, but lacks good statistics.	Stable, but more smolt, less parr. Stocking is not allowed in certain rivers.

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Appendix table 3. 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 (tonnes) 2000: 91 (tonnes) 2010: 53 (tonnes)	2010: 391 (tonnes)	Good figures not readily available	For anadromous Baltic trout only. 1990: 8 000 (no. parr) 78 000 (no. smolts) 2000: 7000 (no. parr) 100 000 (no. smolts) 2012: 138 000 (no. parr) 20 000 (no. smolts)

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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.

Figure Legends:

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

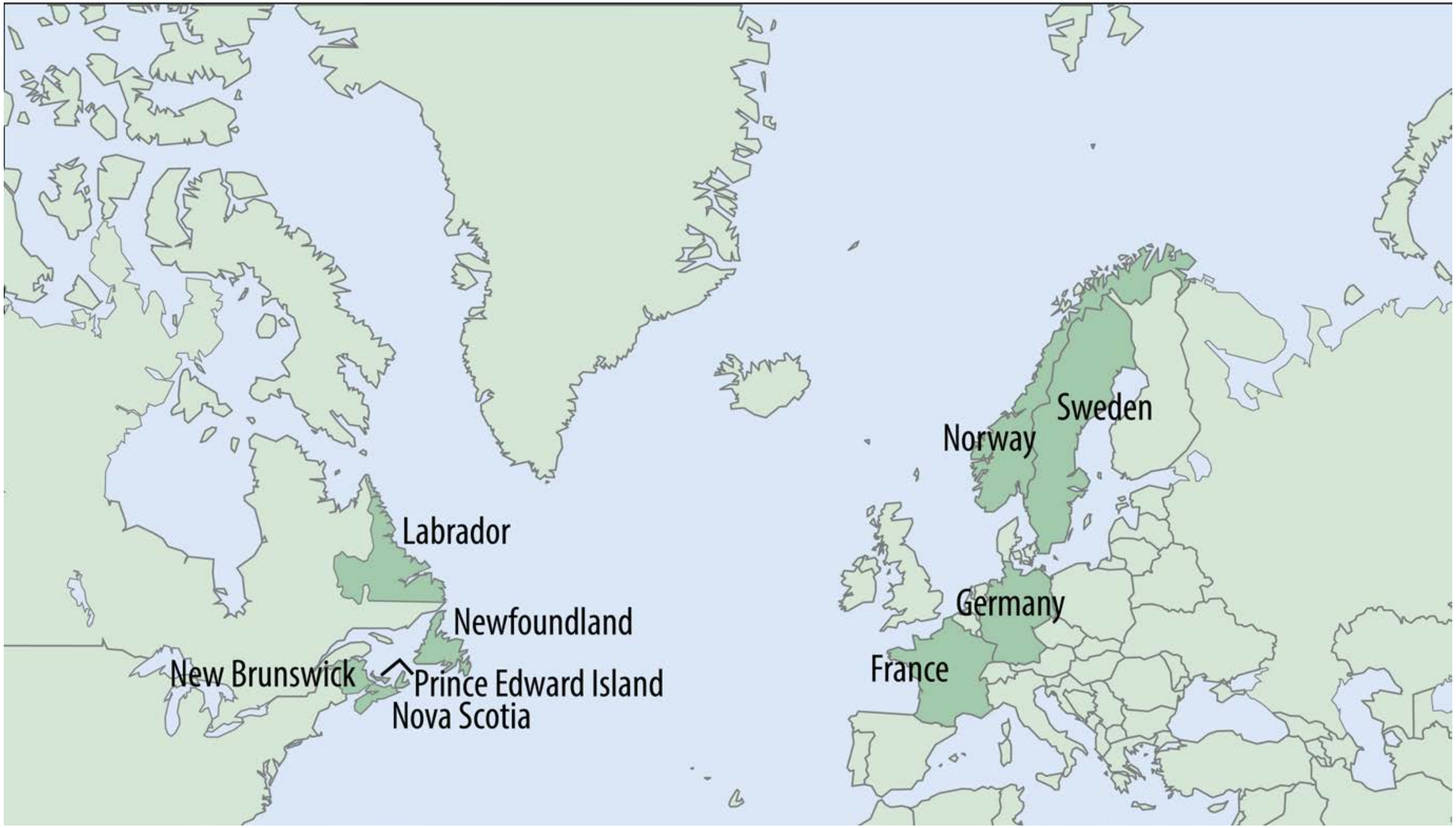

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Figure 2. Summary of stocking governance in the five legislative units highlighting similarities and differences in key factors.

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

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Supplementary material:

Figure: Sectorial organization and decision-making in salmonid stocking in the five jurisdictions.

Stocking policy

Stability ⟷ **Change**

Governance 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 ''naturalised''. 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 actors/scale	Local level. Practitioners organised in authorised angling clubs	National and international scientists. National and regional agency personnel. EU/Baltic fisheries commissions	National and international scientists. National and regional agency personnel, NASCO
Negative impacts from stocking	Unclear, limited	Local, regional	Significant, national, regional

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