



Arctic Charr
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4.7. Fish

4.7.1. Introduction

Fishes are often the top consumer in freshwater habitats, feeding on an array of prey including zooplankton, macroinvertebrates, and other fish. Over 100 species of fish, from 18 families, are reported from freshwaters throughout the circum-Arctic region (Wrona et al. 2013). Five families account for most of the freshwater taxonomic diversity and include Salmonidae (salmon, trout, and whitefish), Cottidae (sculpins), Cyprinidae (carps and minnows), Percidae (perch), and Petromyzontidae (lamprey) (Wrona et al. 2013). Much of the diversity in Arctic fish species occurs within one family, the Salmonidae. Within the Salmonidae family, there is a high degree of phenotypic and ecological diversity throughout the circumpolar Arctic (Klemetsen 2010), and those species that are closely related are often considered as a species complex that includes phenotypic, systematic, and taxonomic variation. Furthermore, fish of the same species may occur sympatrically (e.g., in the same lake), but occupy different niches -- and the use of different resources is often accompanied by differentiation of physical or morphometric characteristics (Knudsen et al. 2007, Siwertsson et al. 2010). For example, the Arctic charr (*Salvelinus alpinus*) species complex, including the North American Dolly Varden (*S. malma*) and at least 10 other Siberian charrs (Wrona et al. 2013), is widely spread across the Arctic and exhibits a broad range of behavioral and morphological variation (Reist et al. 2013). Within a species, charr exhibit a range of biodiversity characteristics including variation in life history (see Box 4-1), trophic status, and size structure, resulting in a highly adaptable taxonomic group (Snorrason et al. 1994, Wrona et al. 2013). In fact, diadromous Arctic charr is the only fish species present through much of the extreme high Arctic (~75° N latitude; Wrona et al. 2013).

At large spatial scales (e.g., continents or regions), historical and modern features of climate, geology, and hydrology influence species distributions. Dispersal barriers, landscape

differences, and climate events such as glaciations, sea level rise and fall, and flooding regimes have influenced present day patterns of species richness and distribution (Tonn 1990, Matthews 1998, Hugueny et al. 2010). For example, the North Atlantic region is species-poor as it was colonized only by anadromous species, whereas Beringia and northwest Canada are relatively speciose because of high variation in space and time of glaciation events that allowed for multiple refugia from glaciation and recolonization pathways (Mims et al. 2010, Wrona et al. 2013). Within northern regions, high variability in environmental conditions across the landscape can support equally high variation in the richness of species at smaller spatial scales (Tonn 1990). Climate change will likely alter the geographic range of species -- affecting both local and regional biodiversity -- through the northward expansion of southern "non-native" species and the contraction or loss of "native" Arctic species (Wrona et al. 2006b, Culp et al. 2012b, Hayden et al. 2017).

At local scales, a number of environmental drivers affect fish diversity through direct impacts on distribution, growth, and phenology (Culp et al. 2012a, Culp et al. 2012b). Water temperature can have significant impacts on the timing of ontogeny and incubation, on growth and energy requirements of all life stages, and may affect the timing of migrations in diadromous fishes. Connectivity is a strong driver of fish distributions and community composition and is affected by water availability and human development (Schindler and Smol 2006, Dias et al. 2014, Laske et al. 2016). Nutrient concentrations can also affect body size and production of fish (Hayden et al. 2017). While these examples illustrate local-scale influences of environmental shifts on fish diversity, interacting effects across local and regional spatial scales complicate the prediction of species shifts with changing environmental drivers (Box 4-2).

Box 4-1. Fish Life History

At high latitudes, fish life history strategies predominantly promote survival and reproduction in environments that are suboptimal or resource-limited (North America, Mims et al. 2010). Many Arctic fish species are large-bodied, long-lived, late-maturing, highly fecund, and often migratory (e.g., Atlantic salmon; Niemelä et al. 2006, Erkinaro et al. 2018). Migration is common among many species of Arctic fishes. Migrations can either be fully within freshwater habitats (e.g., Arctic Grayling; West et al. 1992, Heim et al. 2016), or between fresh- and saltwater habitats (i.e., diadromy; Gross et al. 1988). Strictly, anadromous fish migrate from sea to freshwater to reproduce, while catadromous fish migrate from freshwater to reproduce in the sea (Mecklenburg et al. 2002). Among the Arctic fishes that migrate between fresh- and saltwater, 39 species (families: Acipenseridae [sturgeons], Gasterosteidae [sticklebacks], Osmeridae [smelts], Petromyzontidae [lampreys], and Salmonidae [salmon, trout, and whitefish]) are anadromous, and two are catadromous (family Anguillidae [eels]; Wrona et al. 2013).

In northern climates, anadromy is the dominant migratory strategy because it allows fishes to exploit the highly productive marine environment, thereby increasing growth rates and reproductive advantages (Gross et al. 1988, Wrona et al. 2013). Anadromous migratory behavior may be reduced at the lower latitudes where feeding and rearing resources are more available to fish in freshwater (Reist et al. 2006). At higher latitudes, anadromy and its benefits to Arctic charr (the only fish species in the extreme high Arctic) decrease because of limited access to marine habitats (Svenning and Gullestad 2002).

4.7.2. Objectives and Approach

The circumpolar fish assessment provides a summary of broad spatial patterns of species diversity in Arctic rivers/streams and lakes, including those in sub, low, and high Arctic regions. Fish diversity was evaluated across continental (104 – 107 km²) and regional scales (103 - 105 km²). Specifically, we assessed fish diversity by examining spatial distribution patterns of species composition, alpha diversity, and beta diversity and its component parts (turnover and nestedness). Data were assessed for the circumpolar region by evaluating alpha diversity (species richness) at the ecoregion scale. Beta diversity and its components were calculated within ecoregions for this circumpolar assessment. Regional-scale assessments were completed for highly-sampled ecoregions in Alaska, Iceland, and Fennoscandia, where data were aggregated at the hydrobasin scale to compare diversity patterns at more standardized spatial scales. Diversity measures for this regional assessment included ecoregion-scale gamma diversity (species richness), basin-scale alpha diversity (species richness), and basin-scale beta diversity (species compositional differences). At the regional scale, hydrobasins were divided across ecoregions of similar geography and climate (Olson et al. 2001). Only stations with data for the entire fish assemblage were included in analyses of biodiversity (Figure 4-36a). We identified gaps in the current distribution of fish monitoring, providing a baseline of information for comparison with future monitoring.

4.7.3. Overall Patterns and Trends

Freshwater fish biodiversity was assessed using fish presence data from 3148 stations spanning c. 240° longitude and 23° latitude and 25 ecoregions (Figure 4-36a). Two-thirds (n = 2116) of the stations occurred in lotic systems, with the

remainder in lentic systems (n = 1058). In several ecoregions and countries the provided data were robust - having high numbers of both lotic and lentic sample stations. For example, in Fennoscandia (Norway, Sweden, and Finland) 1807 stations were available for analysis, including 1585 lotic stations and 237 lentic stations. Overall, only six ecoregions (24 %) were represented by more than 100 stations, and 12 ecoregions (48 %) were represented by more than 10 stations. The remaining 13 ecoregions were represented by fewer than 10 stations, and often stations of only one type - lentic or lotic. Poor data coverage among the circumpolar ecoregions results from lack of sampling, sampling focused only on particular species, or lack of data contribution to the CBMP freshwater database. Within the 25 ecoregions included in this assessment, 100 fish species of 52 genera and 15 families are known to occur (Figure 4-36b). Sixty-five of the species are in the two most speciose families: the Salmonidae, with 34 species from 8 genera, and the Cyprinidae, with 31 species from 21 different genera (Appendix A). The remaining 35 species are from 13 families of 23 genera.

4.7.3.1. Circumpolar Diversity

Large-scale alpha diversity (i.e., species richness within ecoregions) varied among 25 ecoregions, ranging from a single fish species in the Arctic Desert (Arctic charr) to as many as 47 species in the Scandinavian and Russian taiga (Figure 4-36b). Fish alpha diversity varied across continents; northern ecoregions or mountainous ecoregions had lower numbers of fish species. As expected, Islands (e.g., Iceland - 9 species, Greenland - 5 species) also had fewer fish species (Figure 4-36b), representing only one-fourth of all freshwater families when compared to continental ecoregions. Based on a standard sample size (n = 10 stations), alpha diversity of fish varied across ecoregions, ranging from a single species

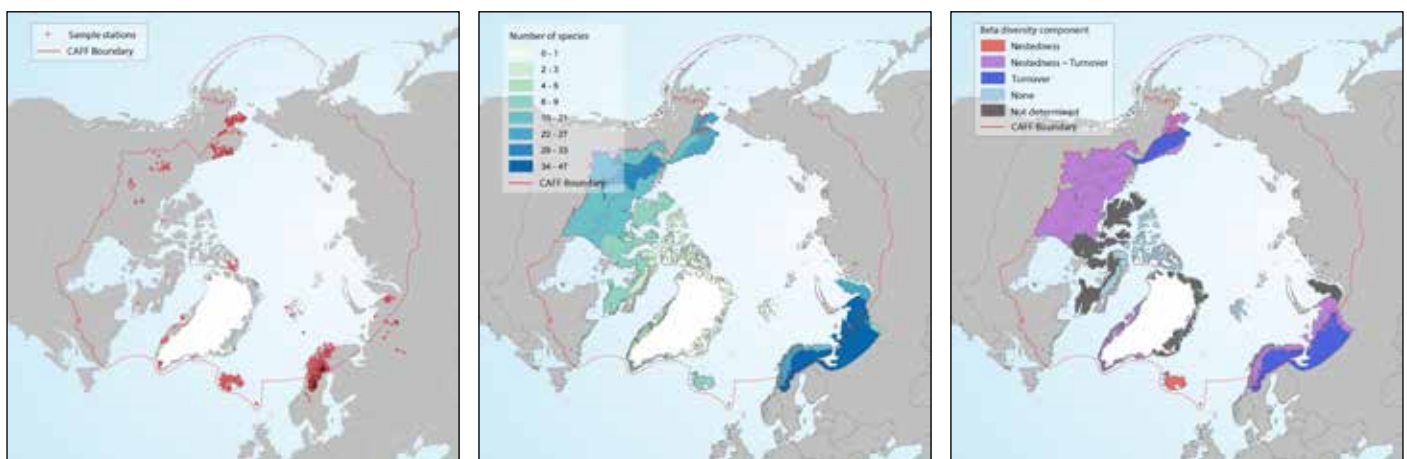


Figure 4-36 Freshwater fish sampling stations (A), ecoregion alpha diversity in each of the sampled ecoregions, as quantified by estimates of species richness from reference texts (Muus and Dahlström 1971, Scott and Crossman 1973, Mecklenburg et al. 2002) and expert knowledge (academic and government scientists and traditional knowledge) (B), and ecoregion beta diversity (C) characterized according to components of beta diversity as either nestedness, turnover, no diversity (none, beta = 0), or similar nestedness and turnover (nestedness ~ turnover) in the circumpolar Arctic. Ecoregions are shown only where sampling stations occur. Fish sampling stations included in this study assessed complete fish assemblages at each location. Regions in Alaska, United States, are BU – Beringia upland tundra, BL – Beringia lowland tundra, IY – interior Yukon-Alaska alpine tundra, IA – interior Alaska-Yukon lowland tundra, AF – Arctic foothills tundra, AC – Arctic coastal tundra, and BB – Brooks-British Range tundra; in Canada, regions are NT – Northwest Territories taiga, OM – Ogilvie-MacKenzie alpine tundra, LA – low Arctic tundra, MS – Muskwa-Slave Lake forests, MA – middle Arctic tundra, HA – high Arctic tundra, and NC – northern Canadian Shield taiga; in Greenland, regions are KH – Kalaallit Nunaat high Arctic tundra and KL – Kalaallit Nunaat low Arctic tundra; I – Iceland birch forests and alpine tundra; FI – Faroe Islands boreal grasslands; Svalbard and other northern islands are AD – Arctic desert, in Fennoscandia and Russia, regions are SM – Scandinavian montane birch forest, SR – Scandinavian and Russian taiga, and KP – Kola Peninsula tundra, RT – northwest Russian-Novaya Zemlya tundra, UM – Ural montane forests and tundra, and YG – Yamal-Gydan tundra.

in the high Arctic zones (e.g., Arctic Desert and High Arctic Tundra) to between 2 and 13 species in the low Arctic zones (e.g., Interior Yukon-Alaska Alpine Tundra) and subarctic (e.g., Northwest Territories Taiga) ecoregions of North America. In the high Arctic (above 75 °N) ecoregions with low richness are both isolated from continents by salt water (e.g., islands such as Svalbard and Ellesmere) and are extremely cold, making it difficult for freshwater species to access and persist in these areas. The relatively high alpha diversity, at 7 to 15 species, in Fennoscandia and western Russia (e.g., Scandinavian and Russian Taiga, Figure 4-36c) is likely due to the combination of history (e.g., glaciations), fish access via streams that run north, and large spatial extent (Reist et al. 2006, Wrona et al. 2013, Stein et al. 2014). Estimates of richness in all ecoregions

were generally reduced from those known from academic and government researchers, Traditional Knowledge, and literature (Figure 4-36b, Figure 4-37). For example, alpha diversity at latitudes above 72°N declined to a single species, Arctic charr, based on observations at 36 stations in 17 hydrobasins across four ecoregions. However, eight additional species are known to occur in the Middle Arctic Tundra and one additional species in the High Arctic Tundra of the Archipelago (Figure 4-36B; Scott and Crossman 1973). In addition, TK records can provide additional information about observations of fish species diversity outside of the ecoregions for which monitoring and research data were obtained, such as northern Quebec (Nunavik) and Labrador in Canada, as well as Russia (Figure 4-37).

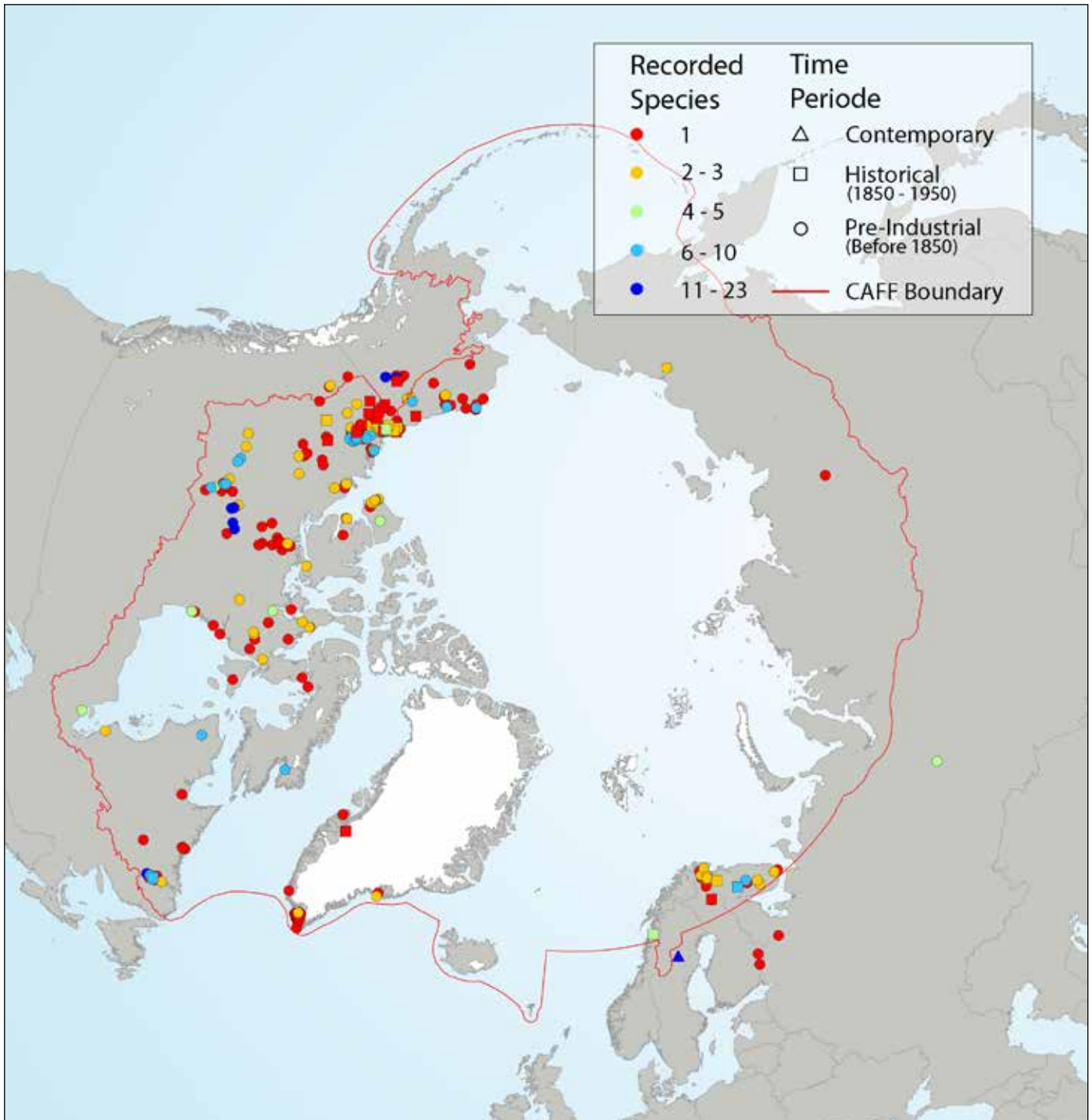


Figure 4-37 Fish species observations from Traditional Knowledge (TK) literature, plotted in the approximate geographic location of observed record, with symbol colour indicating the number of fish species recorded and shape indicating the approximate time period of observation. Results are from a systematic literature search of TK sources from Alaska, Canada, Greenland, Fennoscandia, and Russia.

Beta diversity assessment across 25 ecoregions was focused on determining the dominant component of beta diversity (i.e., nestedness or turnover) within an ecoregion. Three ecoregions had insufficient data for calculating beta diversity: Kalaallit Nunaat High Arctic Tundra, Middle Arctic Tundra, and Yamal Gydan Tundra. In the Arctic Foothills Tundra, Brooks-British Range Tundra (North America) and in the Scandinavian and Russian Taiga, the turnover component of beta diversity was greater than the nestedness component (confidence intervals did not overlap; Figure 4-36c). This indicates that the replacement of species across spatial or environmental gradients appeared to drive diversity patterns across a range of ecoregion types in North America and Fennoscandia, including alpine and taiga habitats (See Box 4-2). Generally, a heterogeneous mix of habitats or a broad range of locations (including both lakes and streams) would capture higher biodiversity in these ecoregions, because species and communities are more dissimilar over greater distances (Socolar et al. 2016). The nestedness component of beta diversity was greater only in the Iceland Boreal Birch Forests and Alpine Tundra where only three species were represented in the data, and changes in species composition across the region would result from subsetting the richest fish community. In this instance, monitoring or conserving biodiversity in high richness locations (e.g., sites, lakes, river reaches) may provide the best option of maintaining current biodiversity (Socolar et al. 2016). Beta diversity in all other ecoregions showed no significant differences in turnover and nestedness components, indicating that compositional differences within these ecoregions are due to a combination of stations containing subsets of the species found in richer communities and stations containing additional species not found elsewhere.

Beta diversity in two of the most northern ecoregions (Arctic Desert and High Arctic Tundra) equaled zero, as only a single species (Arctic charr) was captured and there was no change in freshwater fish composition among stations. These locations are species-poor and less accessible to freshwater species, presently and in the past. Reduced colonization potential in these regions prevents the addition of more species, while a hierarchy of species-specific traits may dictate distribution within those regions (Henriques-Silva et al. 2013). In these low richness regions, within-species biodiversity (e.g., polymorphisms) may be of most interest or importance for future monitoring of species.

4.7.3.2. Regional Diversity

Regional analysis was completed for five highly-sampled ecoregions, which included the Arctic Coastal Tundra and Brooks-British Range Tundra in Alaska, the Iceland Boreal Birch Forests and Alpine Tundra in Iceland, and the Scandinavian Montane Birch Forest and Grasslands and the Scandinavian and Russian Taiga in Fennoscandia. The regional species pool (based on literature and expert knowledge) in the Iceland Boreal Birch Forests and Alpine Tundra was 8 species, the lowest number among the five ecoregions. In the mountainous ecoregions, the Brooks-British Range Tundra and the Scandinavian Montane Birch Forest and Grasslands, there were 19 and 25 species, respectively. The Arctic Coastal Tundra had a species richness estimate of 26 species, and in the largest ecoregion, Scandinavian and Russian Taiga, 47 species occurred (Figure 4-36b).

When compared across a standard sample size ($n = 200$ stations), the lowest species richness was found in the Iceland Boreal Birch Forests and Alpine Tundra (3 species, significantly lower than all other ecoregions), which is isolated from other ecoregions by the North Atlantic Ocean. Rarefied alpha diversity was highest in the Scandinavian and Russian Taiga (average of 20 species; Fennoscandian stations only) and the Arctic Coastal Tundra (average of 19 species; Figure 4-38). Species richness estimates were similar for these two ecoregions and did not differ significantly even when rarefaction curves were compared at a sampling frequency of 1500 stations. Rarefied alpha diversity (at 200 stations) in the two mountainous ecoregions was reduced compared to lower elevation Taiga and Coastal Tundra, though only the Brooks-British Range Tundra (average of 9 species) had a significantly lower species richness estimate, whereas confidence intervals for the Scandinavian Montane Birch Forest and Grasslands (average of 15 species) overlapped with those of the lower-elevation ecoregions.

In a subset of 7th level hydrobasins that contained at least 10 sampling stations, the pool of available species ranged from 3 species in Iceland Birch Forest and Alpine Tundra to 21 species in Arctic Coastal Tundra (Figure 4-39a). The average species richness of hydrobasins was typically reduced from the available species pool. Mean basin richness was 9 ± 2.5 species in the Arctic Coastal Tundra, 4.5 ± 1 species in the Brooks-British Range Tundra, 9.5 ± 1.2 species in the Scandinavian and Russian Taiga, and 5.9 ± 1.2 species in the Scandinavian Montane Birch Forest and Grassland (Figure 4-39b). Only in Iceland did the basin richness of 3 ± 0 species mirror the available species pool (Figure 4-39a-b). In Alaska and Fennoscandia, the richness of mountain region basins was consistently lower than the richness of adjacent lowland (tundra or taiga) basins. Mountain regions often have fewer species due to the challenges of accessing habitats (e.g., steep stream gradients) or because of harsher climate conditions (e.g., earlier freeze-up dates).

Beta diversity differed across ecoregions, with higher values ($\beta_{\text{SOR}} > 0.70$) in the Arctic Coastal Tundra, Brooks-British Range Tundra, and Scandinavian and Russian Taiga. The Scandinavian Montane Birch Forest and Grasslands and the Iceland Boreal Birch Forests and Alpine Tundra showed moderate beta diversity (β_{SOR} values between 0.56 and 0.66). The value of β_{SOR} in Iceland Boreal Birch Forests and Alpine Tundra was likely reduced due to its low species richness and isolation. Spatial isolation may have also contributed to differences in the importance of nestedness relative to species replacement. Among the five ecoregions, only the Iceland Boreal Birch Forests and Alpine Tundra showed greater nestedness-resultant similarity compared to turnover (Figure 4-39c). Turnover, the replacement of species in space, was more important relative to nestedness in the remaining four ecoregions (Figure 4-39c), indicating that assemblages would vary across landscapes with either distance between sites or along another environmental gradient (e.g., elevation or temperature).

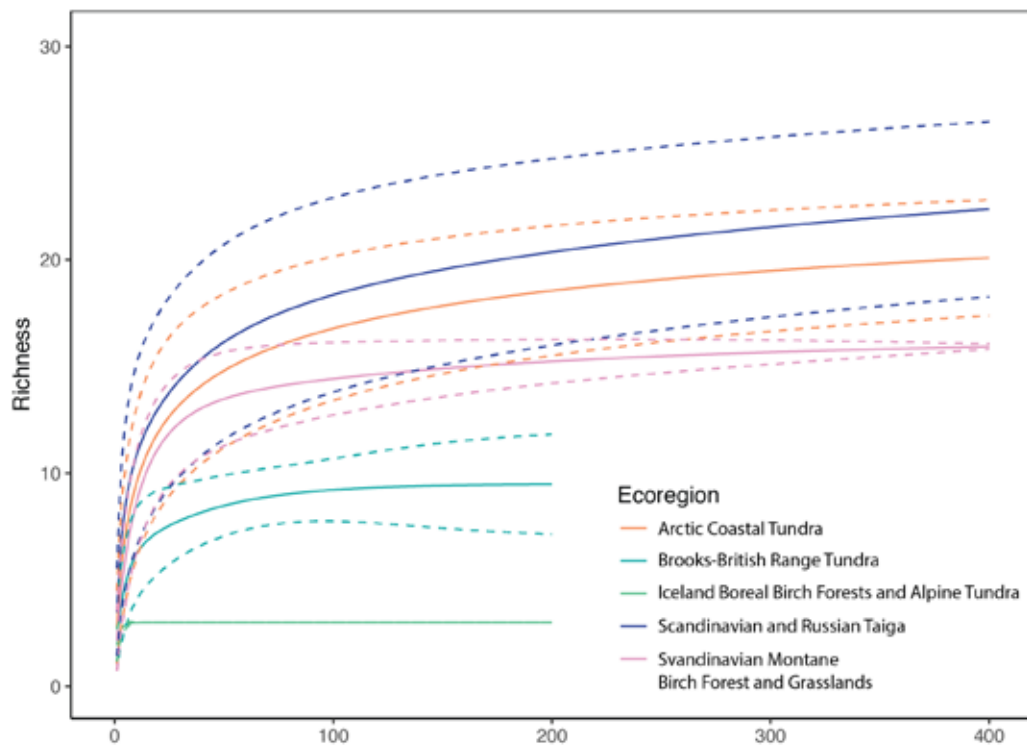


Figure 4-38 Rarefaction curves of fish species richness in the five ecoregions with robust sampling data. Dashed lines are the 95% confidence intervals. Curves for the Brooks-British Range Tundra and Iceland Boreal Birch Forests and Alpine Tundra were extrapolated to 200 stations (from 63 and 73 stations, respectively), Scandinavian Montane Birch Forest and Grasslands, Scandinavian and Russian Taiga, and Arctic Coastal Tundra were truncated at 400 stations.

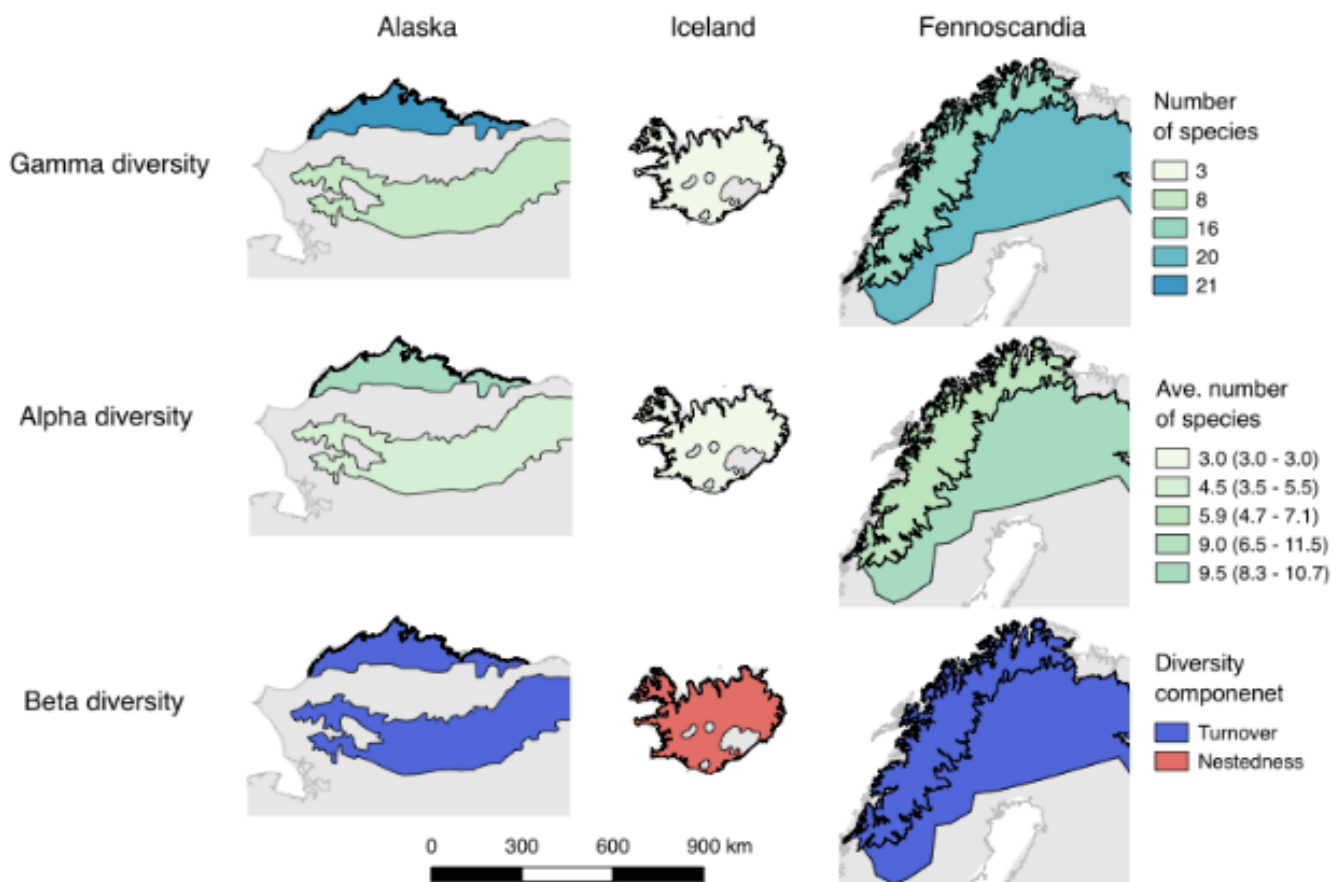


Figure 4-39 Fish diversity characteristics in three geographical regions: Alaska, Iceland, and Fennoscandia. Gamma diversity is based the total number of species sampled in hydrobasins of each ecoregion. Alpha diversity shows the mean basin species richness (95% confidence interval) and beta diversity shows the component of beta diversity, nestedness or turnover, that dominated within each of the ecoregions; gamma, alpha, and beta diversity estimates were based on a subset of basins where a minimum of 10 stations were sampled. All maps are drawn to the same scale.

4.7.3.3. Compositional Patterns

Across the total area with available fish presence data, there were discernible differences in the distribution of species (Figure 4-40), including the presence of certain families (e.g., Catostomidae in North America) or exchange in genera (e.g., *Salmo* in Fennoscandia and *Oncorhynchus* in Alaska). Fourteen species of fish had a distributional range across continents - including salmonids (7 spp.), smelts (2 spp.), sticklebacks (2 spp.), burbot (1 spp.), pike (1 spp.), and lamprey (1 spp.). Three additional species (all salmonids) have been introduced to Fennoscandia and Russia from North America. Generally, ecoregions that spanned greater spatial extents (e.g., Scandinavian and Russian Taiga) had higher numbers of species, and ecoregions that reached lower latitudes often contained minnows (Cyprinidae) and perch (Percidae). The most northern ecoregions contained few fish, sometimes only Arctic charr. Latitude limited the species richness, and therefore, the beta diversity (change in species composition) across space. Furthermore, in isolated locations like Iceland, the depauperate fish fauna and their distributional patterns - as subsets of the richest community - resulted in lower overall beta diversity, and a higher index of nestedness compared to turnover. Mountain regions may be similarly isolated, with fish species access reduced due to stream gradients or climate. In the regional analysis, species richness was reduced in the Brooks-British Range Tundra and in the Scandinavian Montane Birch Forest and Grasslands when compared to adjacent, low-elevation ecoregions (e.g., Brooks-British Range Tundra elevation range 800-2400 m, Arctic Coastal

Tundra elevation range 0-150 m; <https://www.worldwildlife.org/biome-categories/terrestrial-ecoregions>). Interestingly, the within-ecoregion beta diversity was comparable, and mountain and low elevation ecoregion beta diversity was primarily supported through species turnover.

Biodiversity analyses were influenced by the availability of data across and within ecoregions. For some areas, limitations based on sample size (the number of stations) hindered our ability to fully examine species richness from the data gathered for the CBMP database. For example, in our regional subset, which contained the most robust data, we could not discern differences in species richness between the Scandinavian Montane Birch Forest and Grasslands and the adjacent Scandinavian and Russian Taiga until nearly 300 stations were sampled. In all other ecoregions but one, we had far fewer than 300 sample stations, and therefore, an inability to compare richness at the hydrobasin level based on collected data. Fortunately, fish distributions are well known, especially compared to other aquatic organisms, and species richness of ecoregions could be determined based on literature, expert knowledge, and indigenous knowledge. While we were able to determine whether beta diversity within ecoregions was due to either replacement or loss of species, this often relied on small sample sizes, with one or two hydrobasins representing large spatial extents. Increasing spatial and temporal coverage, through additional monitoring or improved access to existing data, would improve our ability to determine the status of freshwater fishes.

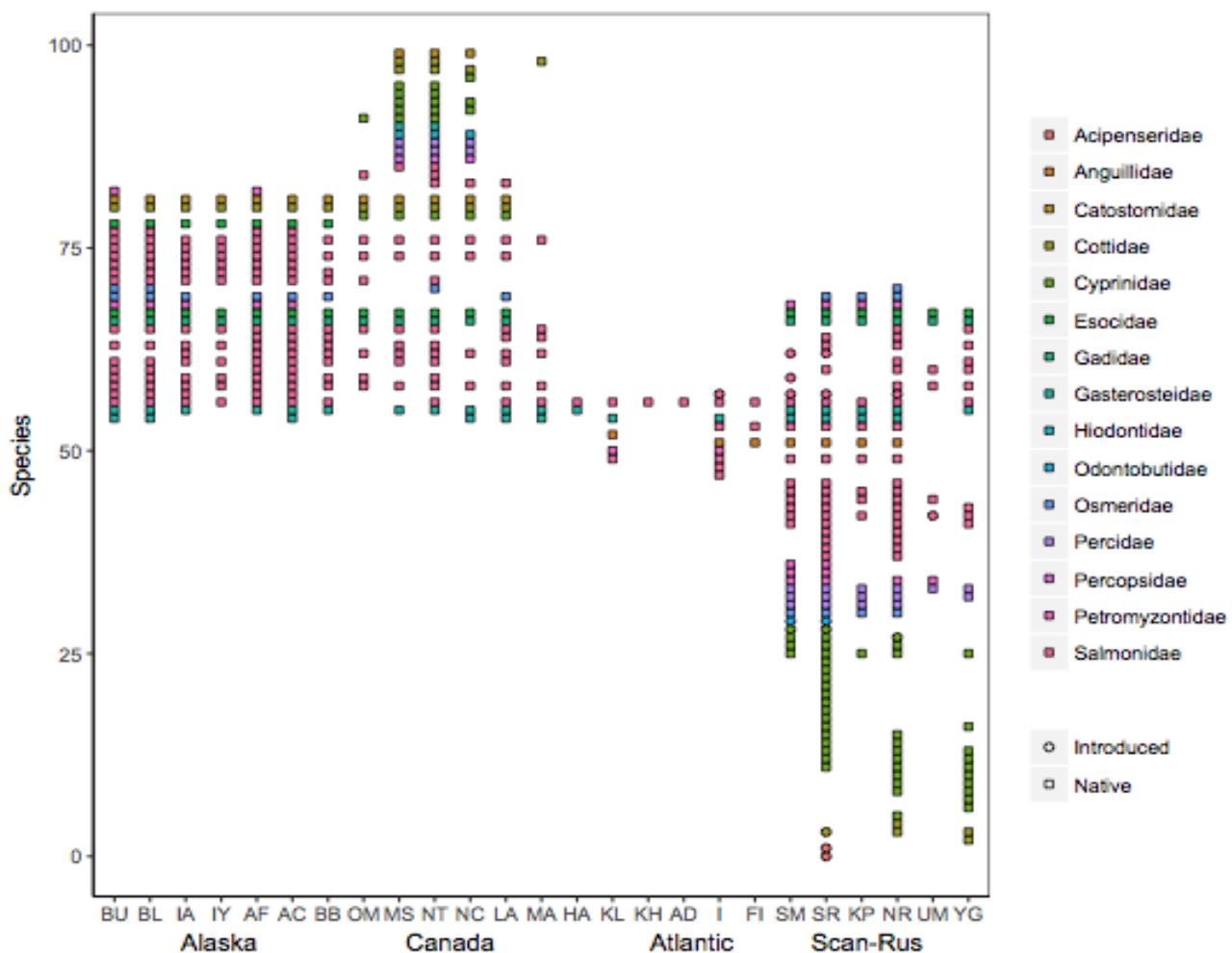


Figure 4-40 Longitudinal distribution pattern of fish species from Alaska to western Russia. Each number (y-axis) represents a single species, colored by taxonomic family. Species numbers are referenced in Appendix A. Introduced species are represented by circles. See Figure 4-36 for ecoregion abbreviations.

4.7.3.4. Temporal Trends

Changes to thermal and hydrological regimes of freshwaters due to climate change are predicted to affect the distributions and prevalence of salmonids including Atlantic salmon (*Salmo salar*), brown trout (*Salmo trutta*), and Arctic charr (*Salvelinus alpinus*) (Elliott and Elliott 2010, Finstad and Hein 2012). Northern Norway (65–71°N) and Iceland (64–66°N) are among the only regions in the world where distributions of these species overlap. Long-term catch records for these areas provide an opportunity to assess

recent changes in the abundance of these fish species and evaluate whether similar trends are evident in both countries.

A 24-year record of fish relative abundance (percent of total abundance) from Iceland shows that Atlantic salmon were most abundant in the west by a margin of about 50-70% (Figure 4-41a), while trout were most abundant in the south by about 10-30% (Figure 4-41b). Communities in the north and east exhibited the strongest changes in relative abundance over time (Figure 4-41c,d). In these regions, previously similar abundances of Atlantic salmon and

Box 4-2. Case Study. Impact of climate, land-use, and human population development on fish biodiversity

Both climate and land-use affect Arctic freshwaters and their fish communities. For example, Hayden et al. (2017) examined fish communities along a gradient of altitude, human population density, and land-use intensification in the subarctic, Tornio-Muoniojoki catchment (Figure 4-43) over the period of 2009 to 2013. Levels of nutrients (phosphorus, nitrogen, carbon) in lakes increased along the gradient leading to higher ecosystem productivity. This productivity gradient was associated with a change in fish community composition with salmonids (European whitefish, *Coregonus lavaretus*) dominant in headwater lakes. Fish composition then progressively shifted downstream towards percid (perch, *Perca fluviatilis*, and ruffe (*Gymnocephalus cernua*) and finally cyprinid (roach, *Rutilus rutilus*) dominance (Figure 4-43). This progressive change was accompanied by a near 50-fold increase in relative biomass of fish, and a 50% decrease in mean body size. This massive increase in fish abundance was correlated with a reduction in the size of invertebrate prey, a shift towards smaller invertebrate species, and decreased invertebrate diversity, particularly in the most productive lakes. They also observed distribution limits and continuous range expansions over the period of record for cool and warm water species such as percids (ruffe, perch), and cyprinids (ide [*Leuciscus idus*], roach, bleak [*Alburnus alburnus*]). In contrast, range retractions were evident for the cold water species Arctic charr (*Salvelinus alpinus*), grayling (*Thymallus thymallus*), brown trout (*Salmo trutta*), and burbot (*Lota lota*). The study concludes that effects of range expansion cannot be predicted by bioclimatic envelope models alone, but that lake-specific abiotic and biotic data must be integrated to realistically assess future fish community diversity. Hence, long-term data from Arctic systems are required to optimally assess the relative roles of different abiotic and biotic factors in determining fish diversity and ecosystem functioning. However, if such long-term data are not available, space-for-time substitution studies have the potential to provide an alternative approach to predict future change in fish diversity.

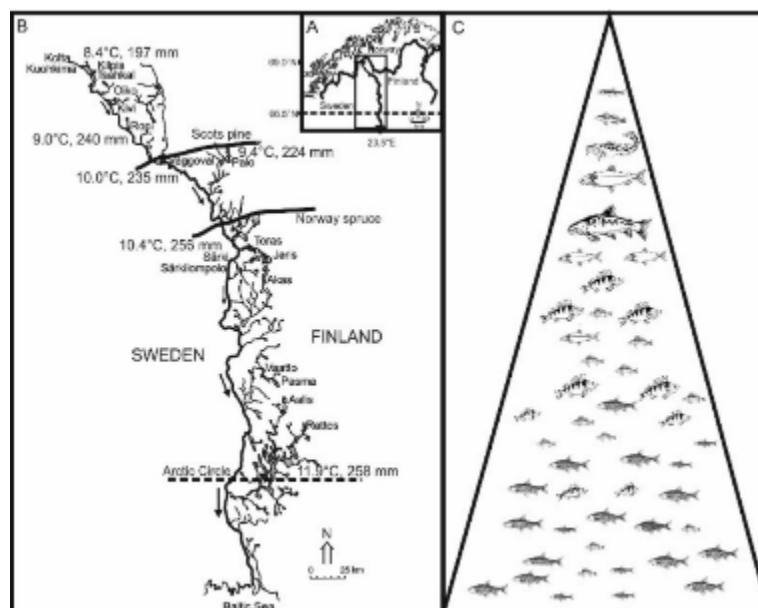


Figure 4-43 The map of northern Fennoscandia (A) and subarctic Tornio-Muoniojoki catchment showing the location of 18 tributary lakes. Open water season air temperature and precipitation (June–September 1981–2010) at six weather stations and locations of coniferous treelines are shown (B). Change in fish communities, body size, and abundance along the climate and productivity gradient are illustrated (C). (Modified from Hayden et al. 2017)

anadromous Arctic charr (~45% each) have been diverging since 2005 due to declines in the relative proportion of Arctic charr, resulting in a dominance of Atlantic salmon in these systems. At the same time, in the north and east, brown trout have steadily increased (10-15%) since 1992 (at the start of record). Potential temporal shifts in the relative abundance of fish species in Iceland's river communities will change current patterns of species diversity - lessening the evenness among species in some regions (e.g., diverging percent abundance of Arctic salmon and anadromous Arctic charr in northern rivers) while increasing the evenness of species in others (e.g., brown trout and anadromous Arctic charr in western rivers).

Long-term records from northern Norway indicate that Atlantic salmon has dominated in river-based systems for the entire period of record (1993-2016), and has been increasing in relative abundance over the last several years (Figure 4-42a). The amount of brown trout in the catches has been relatively stable throughout the period, while Arctic charr have shown a decline in relative abundance over the last 10-15 years. In lake-based systems, however, brown trout seems to be the dominant species and has shown a steady increase from 1995 until approximately 2011, while relative abundances of both Atlantic salmon and anadromous Arctic charr declined over the same period (Figure 4-42b). Thus, the relative abundance of anadromous Arctic charr has generally declined in rivers of northern Norway, both in river-based and lake-based systems (Figure 4-42a,b). However, whereas there was an early period of relative stability followed by a decline after 2002 in Norwegian river-dominated systems, similar to the patterns seen in Iceland, there was a more steady decline in anadromous Arctic charr abundance in lake-based systems in northern Norway from 1995 to 2009 (Figure 4-42b).

Coherent changes in two countries that are located on each side of the Norwegian Sea indicate that a common factor such as climate change may be causing these declines in Arctic charr. However, the mechanisms for the changes are not fully understood. In Iceland, water temperature has shown an increase in spring and autumn while the average temperature for the summer months (June – August) has not shown an increase. The effects of increased water temperatures in spring and autumn might affect and possibly cause mismatch in spawning and hatching time of Arctic charr while salmon and trout remain unaffected. The strong contrast in the dominance of brown trout and Atlantic

salmon in northern Norway between lake- and river-based systems speaks to the important influence of lakes on fish assemblage composition.

4.7.4 Gaps in Knowledge and Monitoring

While fish are key species in aquatic ecosystems and are important to communities of the North, it is evident that there are significant gaps in monitoring effort and data coverage across the circumpolar region. Although in some cases the spatial extent is limited because existing datasets were not accessible (e.g., some academic sources that were not open access or government-funded programs that are no longer in operation), there remain significant gaps in monitoring effort and coordination of routine monitoring in some areas. Across Canada, for example, a large number of historical studies focused on monitoring commercial or subsistence fisheries, and thus quantified a selection of fish species rather than assessing the diversity of the full assemblage. Furthermore, many sites across North America have only been sampled once, thus precluding temporal analyses of trends. Similarly, there are large areas that have not been sampled sufficiently to allow for analyses of spatial patterns or temporal trends.

Sparse long-term data on fish assemblages exist for the Arctic. Long-term commercial fishing data are common in North America and Europe (e.g., see section 4.7.3.4), but these records generally focus on targeted fish species rather than assessing the full assemblage. There were large spatial gaps in the distribution data that could be obtained on fish assemblages that hinder assessments of fish distribution or biodiversity patterns across large spatial or circumpolar scales. Furthermore, the number of fish species included in the database represents only 42% of all Arctic species (Wrona et al. 2013). In northeastern North America, only four of 38 species (or 10.5%) were included, and only two species (Arctic charr and threespine stickleback) that were surveyed outside of commercial fishing data were used in our analyses. In two regions, which were considered relatively data rich, Beringia (i.e., Alaska) & northwestern Canada and Russia & Scandinavia, only 50% and 57% of the species, respectively, were found in the dataset. (See Appendix A for species lists). Until broader spatial and temporal data coverage is available, the ability to assess changes in biodiversity, especially at large spatial scales, will be limited.



Arctic grayling
Photo: Rostislav Stefanek/Shutterstock.com

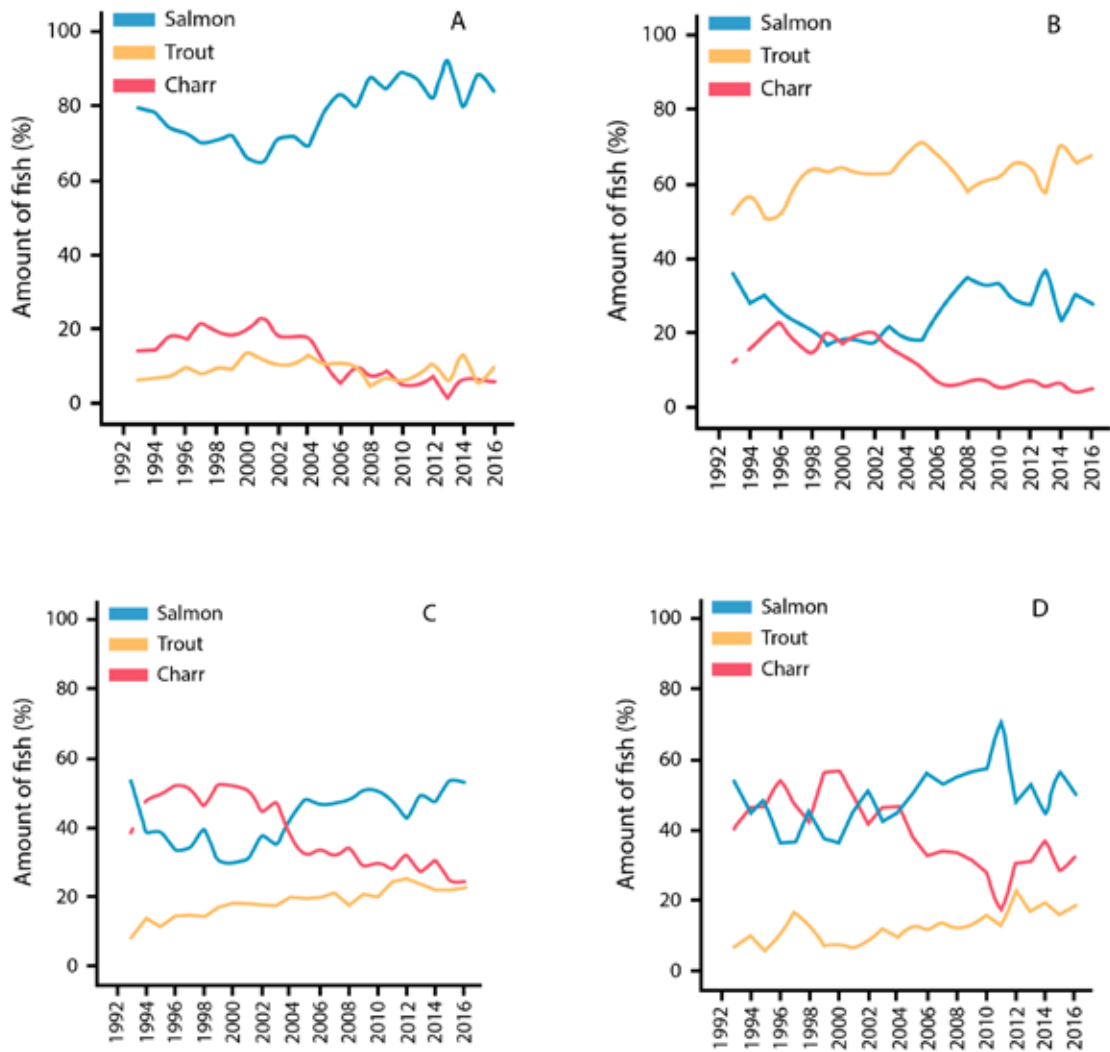


Figure 4-41 Temporal patterns in % abundance of Atlantic salmon, brown trout, and anadromous Arctic charr from catch statistics in Iceland rivers monitored from 1992 to 2016, showing results from (a) west, (b) south, (c) north, and (d) east Iceland.

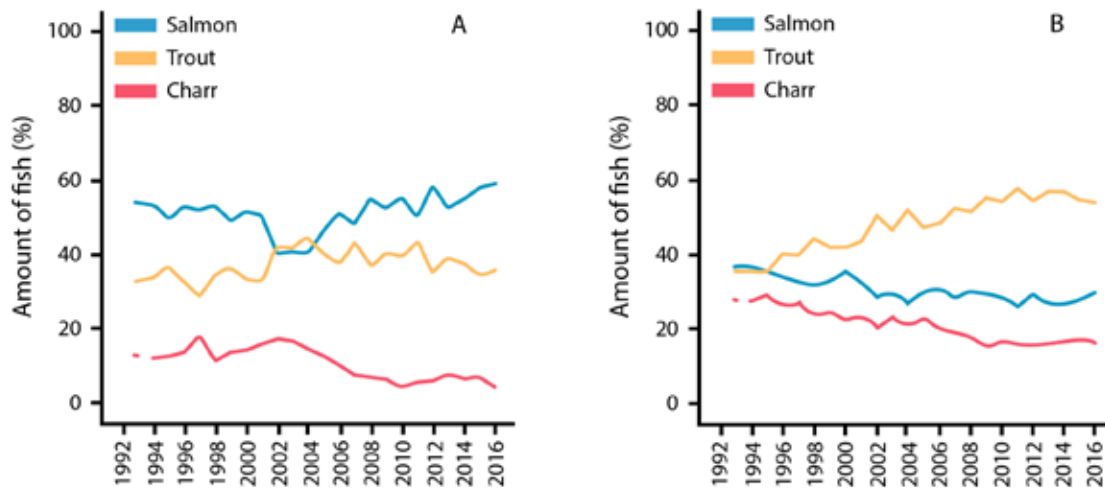


Figure 4-42 Temporal patterns in % abundance of Atlantic salmon, brown trout, and anadromous Arctic charr from catch statistics in northern Norway rivers monitored from 1993 to 2016, including basins dominated by (a) rivers and (b) lakes.