



*The larval stage of non-biting midges (Chironomidae) occurs in aquatic environments. Chironomidae are cold-tolerant and are therefore the dominant benthic macroinvertebrate group in many Arctic freshwater systems. Because they are so abundant, they are an important component of aquatic and terrestrial food webs, and provide food sources for fish and other organisms.*  
Photo: Jan Hamrsky

## 4.6. Benthic Macroinvertebrates

### 4.6.1. Introduction

Benthic macroinvertebrates are a diverse group of animals including insect larvae, crustaceans, worms, molluscs, and mites that are generally visible to the naked eye, and that are typically collected using nets with a mesh size of 0.25–0.5 mm. They live on or close to the bottom substrates of rivers and lakes, i.e., in sediments, on stony substrates and/or rocky shores. Benthic macroinvertebrate monitoring in lakes is generally either of the littoral species that inhabit the shallow waters along the shoreline or the profundal species that live in the soft sediments of the deep, dark parts of lakes. Macroinvertebrates in rivers are commonly collected in stony riffle habitats or in the sandy/clay sediments of pool habitats as well as in association with water plants. Benthic macroinvertebrates feed on water plants, algae, detritus, and other macroinvertebrates, and form the trophic link between the base of the food web (i.e., the primary producers) and predators higher up in the food chain such as invertebrate predators, fish and waterfowl. Many benthic macroinvertebrate taxa have a wide distribution and well-defined ecological niches, which make them good indicators of ecological condition.

The diversity of benthic macroinvertebrate assemblages in the Arctic has not been studied on a circumpolar scale, but regional assessments have suggested that species-specific physiological tolerance to cold temperatures may play a role in determining assemblage structure (Milner et al. 2001, Wrona et al. 2013, Culp et al. In Press). Riverine studies from higher northern latitudes (> 40° N) indicate that alpha diversity of benthic macroinvertebrates decreases with increasing latitude, shifting from high abundances of mayflies (Ephemeroptera), caddisflies (Trichoptera) and stoneflies (Plecoptera) to communities dominated by true flies (Diptera) (e.g., Oswald 1997, Castella et al. 2001, Scott et al. 2011). At lower latitudes, the benthic macroinvertebrate community in rivers typically includes the mayfly families Baetidae and Heptageniidae, stoneflies belonging to the Nemouridae and Chloroperlidae, oligochaete worms, and the water mites or Hydracarina. Further North, cold water temperatures and scarce food resources limit benthic macroinvertebrate survival and growth (Wrona et al. 2013), and adaptations such as freeze-avoidance or freeze-tolerance (Irons III et al. 1993) are necessary for survival (Danks 1992, Danks et al. 1994). The predominant taxa at the highest latitudes are the non-biting midge (family Chironomidae) subfamily Diamesinae, which dominates in glacial streams where maximum temperatures are 0–2°C, while worms (Oligochaeta), crane flies (Tipulidae), and the midge subfamily Orthocladiinae are found in streams with maximum temperatures between 2°C and 4°C (Milner et al. 2001).

Important environmental drivers of benthic macroinvertebrate assemblages in northern rivers include substrate composition, water velocity, nutrients, temperature, catchment geology and catchment vegetation (Lento et al. 2013). Arctic streams and rivers are also highly dynamic systems, with long periods of ice cover followed by peaks in flow during the spring freshet, when melt-water from snow and ice enters the system, leading to high water levels, fast-flowing water, and the potential for flooding (Prowse

and Culp 2003, Prowse et al. 2006b, Prowse et al. 2011a). These ecosystems have recurrent high turbidity due to unstable streambeds and high sediment loads. Such physical disturbances are important drivers of macroinvertebrate biodiversity and are especially pronounced during periods of high discharge, such as during ice break-up or in glacial-fed systems, or during periods of anchor ice formation (Milner and Petts 1994, Power and Power 1995). The dynamics of Arctic streams and rivers impose constraints on macroinvertebrate biodiversity and population size, as invertebrates need specific traits to grow and reproduce in these environments (e.g., life history strategies relating to the length of the life cycle and number of generations and life stages, cold tolerance, and feeding habits; Brown et al. 2018).

Arctic lakes have lower invertebrate taxon richness than temperate lakes, but still maintain functionally and taxonomically diverse benthic macroinvertebrate communities (Johnson and Goedkoop 2002, Wrona et al. 2013). Primary production in Arctic lakes is to a large extent from benthic algae, mainly diatoms and cyanobacteria. Due to the high water clarity of Arctic lakes (except glacier-fed lakes), light penetrates and supports benthic primary production even at large depths, thus supplying food for benthic invertebrates. Common taxa in the shallow, highly-productive littoral zone of Arctic lakes are midges (Chironomidae), crane flies (Tipulidae), case-building caddisflies in the family Limnephilidae, mayflies, especially in the family Ameletidae, and stoneflies belonging to the genus *Capnia* in the family Capniidae. In contrast, the profundal zone of lakes largely consists of homogeneous sediments and is characterized by relatively low diversity. Chironomids, amphipod crustaceans, and oligochaete worms are common taxa in the profundal zone. Fishless lakes frequently contain predation-sensitive macroinvertebrate fauna, such as the crustacean *Lepidurus arcticus* (Branchiopoda, Notostraca) and the beetle *Colymetes*. These organisms may be highly abundant in fishless lakes, but are very rare on larger spatial scales.



*Rhantus Suturalis*  
Photo: Jan Hamrsky

Freshwater biomonitoring of benthic invertebrates in lakes and rivers has a long tradition (Rosenberg and Resh 1993), starting with the early work by Kolkwitz and Marsson (1909) and progressively developing into multiple, pollution-specific indicator taxa that are used to construct biological metrics. These metrics quantify effects on ecosystems by both point-source pollution and large-scale diffusive pollution on macroinvertebrate communities (e.g., Wiederholm 1980, Armitage et al. 1983, Raddum and Fjellheim 1984) by summarizing knowledge of the tolerance range of multiple macroinvertebrate species along environmental stress gradients into a single value. Such metrics (e.g., EPT and tolerance metrics) have been developed for ecological integrity, acidification, and eutrophication and form the core of assessment tools in many countries, but are not adapted to Arctic water bodies. Similarly, as lakes and rivers are closely linked to landscape modifications, macroinvertebrate communities will react to climate-induced changes in landscape-level processes such as changes in temperature, ice-regimes, and vegetation. As biomonitoring using benthic macroinvertebrates is a well-established approach, standard methods exist for the sampling, processing, and analysis of samples that can facilitate large-scale assessments of their diversity.

#### 4.6.2. Objectives and Approach

Benthic macroinvertebrate assemblages were assessed for rivers and for lake littoral and profundal zones. Analysis focused on samples collected using similar approaches (e.g., kick net in lake littorals and rivers, grab samples in profundal zone of lakes). Analysis was conducted at the lowest taxonomic level that allowed maximum inclusion of stations, which was generally at family level or higher as a large number of stations did not identify chironomids to lower taxonomic units (though limited analysis was done at the genus level for chironomids in lake profundal zones). The circumpolar assessment of benthic macroinvertebrates provided a summary of broad spatial patterns of biodiversity in Arctic streams and lakes. Stations were grouped into ecoregions with similar geography and climate (Olson et al. 2001) and rarefaction curves were used to compare alpha diversity across ecoregions at a standardized number of stations (to control for differences in sampling effort). We assessed beta diversity within ecoregions (averaging beta diversity across hydrobasins in each ecoregion), as well as the proportion of beta diversity that was due to turnover or nestedness.



*Ephemeroptera (top) and Heptageniidae (bottom)*  
Photo: Jan Hamrsky

Alpha diversity within hydrobasins was compared with the average latitude of stations within each hydrobasin to evaluate latitudinal trends in diversity. Assemblage structure was also assessed to describe regional and latitudinal shifts in taxonomic composition, contrasting different areas of the circumpolar Arctic. Using this approach and contemporary data, we produce a baseline to which future monitoring results can be compared and identify gaps in the current distribution of benthic macroinvertebrate monitoring.



*Baetidae*  
Photo: Jan Hamrsky

### 4.6.3 Overall Patterns and Trends

#### 4.6.3.1 Circumpolar Diversity

##### 4.6.3.1.1. Lake Littoral Zones

Lake littoral invertebrate samples were not collected across the entire circumpolar region, but primarily came from Fennoscandia, Iceland, and USA, with a small number of stations in southern Greenland, Faroe Islands, and northern Russia (Kola Peninsula and Wrangel Island; Figure 4-29a). There were four ecoregions in the highly sampled regions with sufficient sampling to allow the assessment of littoral zone alpha diversity rarefied to 80 stations. Among these ecoregions, the lowest alpha diversity was found in the Iceland Boreal Birch Forests and Alpine Tundra, which had an average of 16 taxa in 80 stations (Figure 4-29b). This may have been due in part to the sampling method used in this country, as invertebrate samples were collected using rock scrapes rather than kick nets. Although these methods are broadly comparable, rock scrapes have been shown to collect fewer taxa than kick nets (Lento and Morin 2014). The Arctic Coastal Tundra in Alaska had significantly higher alpha diversity, with an average of 37 taxa in 80 stations (Figure 4-29b). The Fennoscandian ecoregions had the highest taxonomic richness, with an average of 56 taxa in the mountainous Scandinavian Montane Forests and Grasslands and an average of 70 taxa in the Scandinavian and Russian Taiga. Alpha diversity estimates for Fennoscandia were significantly higher than for Iceland or Alaska, suggesting strong regional differences in taxonomic richness across the sampled area.

Alpha diversity was rarefied to 10 stations to allow comparison of all ecoregions in which invertebrate samples were collected. In this analysis, low alpha diversity (9-13 taxa on average in 10 stations) was found for four ecoregions. These ecoregions were all found on remote islands, and included the Faroe Islands Boreal Grasslands, Wrangel Island Arctic Desert in Russia, Kalaallit Nunaat Low Arctic Tundra in Greenland, and the Iceland Boreal Birch Forests and Alpine Tundra (Figure 4-29c). The low diversity in these island ecoregions is indicative of a dispersal effect on taxonomic richness, with barriers to dispersal limiting the number of taxa that can colonize a region. Alpha diversity estimates were higher for the Arctic Coastal Tundra in Alaska (average

of 24 taxa), the Kola Peninsula Tundra (average of 24 taxa), the Scandinavian Montane Forests and Grasslands (average of 34 taxa) and the Scandinavian and Russian Taiga (average of 42 taxa), with the latter two ecoregions having significantly higher alpha diversity than the low diversity ecoregions (Figure 4-29c). The similarity in diversity estimates for the most taxonomically-poor ecoregions suggests that barriers to dispersal, such as proximity to mainland and presence of mountains, limits biodiversity in these northern lakes. Even in areas of high biodiversity, such as Fennoscandia and northern Alaska, there was evidence of lower diversity where the presence of mountainous ecoregions likely limited dispersal. Beta diversity within ecoregions ranged from 0.19 to 0.77, indicating a relatively large range in the level of similarity between lakes. The lowest beta diversity ( $\beta\text{SOR} = 0.19$ ) was in the Faroe Islands Boreal Grasslands, where only four lakes were sampled over a relatively small area, alpha diversity

was low, and composition among lakes was extremely similar. Other ecoregions with low to moderate beta diversity included the Kola Peninsula Tundra ( $\beta\text{SOR} = 0.43$ ) and the Iceland Boreal Birch Forests and Alpine Tundra ( $\beta\text{SOR} = 0.56$ ). In all three of these ecoregions, nestedness contributed to beta diversity, either as the predominant component (in the case of the Kola Peninsula) or approximately equally to taxonomic turnover (Figure 4-29d). Thus, among-lake differences in composition in these ecoregions were due primarily or in part to a loss of species. In the remaining ecoregions, within which  $\beta\text{SOR}$  ranged from 0.65 to 0.78, turnover was generally the dominant component of beta diversity (with the exception of the Kalaallit Nunaat Low Arctic Tundra, where there were equal contributions of turnover and nestedness), indicating that the replacement of taxa across lakes drove differences in composition.

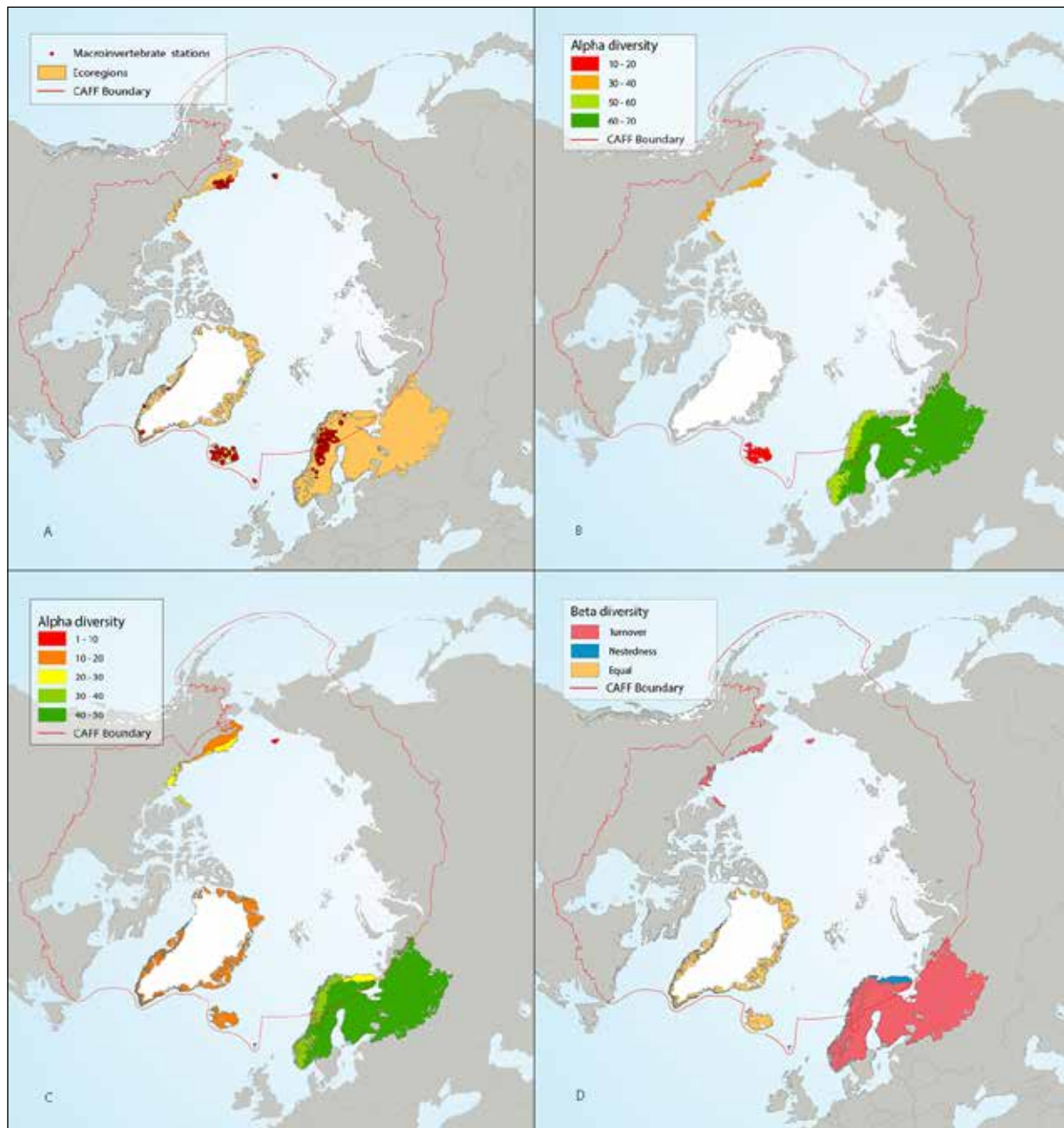


Figure 4-29 Results of circumpolar assessment of lake littoral benthic macroinvertebrates, indicating (a) the location of littoral benthic macroinvertebrate stations, underlain by circumpolar ecoregions; (b) ecoregions with many littoral benthic macroinvertebrate stations, colored on the basis of alpha diversity rarefied to 80 stations; (c) all ecoregions with littoral benthic macroinvertebrate stations, colored on the basis of alpha diversity rarefied to 10 stations; (d) ecoregions with at least two stations in a hydrobasin, colored on the basis of the dominant component of beta diversity (species turnover, nestedness, approximately equal contribution, or no diversity) when averaged across hydrobasins in each ecoregion.

#### 4.6.3.1.2. Lake Profundal Zones

Lake profundal zone samples were obtained for sub-Arctic and low Arctic regions of Canada and Fennoscandia. Profundal samples had predictably lower taxonomic richness for benthic invertebrates than littoral zone samples. Sample richness was also less variable than was found in the littoral zone samples, resulting in smaller confidence intervals around richness estimates. Alpha diversity was rarefied to 20 stations for comparison among ecoregions. The lowest diversity was found in the Low Arctic Tundra (average of 8 taxa in 20 stations) and the Northern Canadian Shield Taiga (average of 9 taxa, significantly higher than the Low Arctic Tundra estimate), both in central Canada. The remaining ecoregions had similar alpha diversity, ranging from 17 to 26 taxa on average in 20 stations. These included the Central Canadian Shield Forests and Southern Hudson Bay Taiga in Central and southern Canada, and the Scandinavian and Russian Taiga and Scandinavian Montane Birch Forest and Grasslands in Fennoscandia.



*Simuliidae*  
Photo: Jan Hamrsky

A number of stations in Canada (sub-, low, and high Arctic), Greenland, and Russia had genus-level data for Chironomidae (midges) in top surface sediments of lake profundal zones (collected using corers or grab samplers). Surface sediment samples were analyzed to compare Chironomidae diversity across ecoregions, with genus-level alpha diversity rarefied to 10 stations in each ecoregion. The lowest alpha diversity was at the highest latitudes, in the High Arctic Tundra in Canada and the Kalaallit Nunaat High Arctic Tundra in Greenland (average of 13 and 14 genera, respectively). Lower latitudes in Canada had significantly higher alpha diversity, with 20 genera in the Low Arctic Tundra, 25 genera in the Middle Arctic Tundra, and 28 genera on average in the Northern Canadian Shield Taiga. The Northwest Russian-Novaya Zemlya Tundra had significantly higher alpha diversity than all other ecoregions, at an average of 64 genera in 10 stations, but this highly elevated estimate may have reflected a different taxonomical approach, with additional splitting of genera relative to the samples from North America and Greenland.

#### 4.6.3.1.3. Rivers

River benthic macroinvertebrate stations had better spatial coverage across the circumpolar region than lake stations, and were particularly prevalent in Canada (Figure 4-30a). There were six ecoregions in Canada and Fennoscandia with a sufficient number of stations to allow for comparison of family richness rarefied to 100 stations. The lowest alpha diversity was in two mountainous ecoregions: the Ogilvie-

MacKenzie Alpine Tundra in Canada (average of 46 taxa in 100 stations) and the Scandinavian Montane Birch Forest and Grasslands (average of 56 taxa; Figure 4-30b). In contrast, the highest alpha diversity was in the low-latitude Southern Hudson Bay ecoregion in Canada (average of 76 taxa in 100 stations; Figure 4-30b) and the Scandinavian and Russian Taiga in Fennoscandia (average of 69 taxa in 100 stations; Figure 4-30b); both ecoregions had significantly higher alpha diversity than the two least diverse ecoregions. The Northwest Territories Taiga and Muskwa-Slave Lake Forests ecoregions in Canada had intermediate taxonomic richness, at 60 and 68 taxa, respectively (Figure 4-30b).

A total of 24 ecoregions had river benthic macroinvertebrate stations, and were comparable at a rarefied alpha diversity level of 10 stations. The lowest diversity was in the Arctic Desert ecoregion on Svalbard, with an average of 2 taxa in 10 stations (Figure 4-30c). Low diversity (ranging from 6 to 11 taxa in 10 stations) was also evident in other high Arctic and low Arctic island ecoregions, including the Kalaallit Nunaat High Arctic Tundra and Kalaallit Nunaat Low Arctic Tundra in Greenland, Iceland Boreal Birch Forests and Alpine Tundra, Wrangel Island Arctic Desert in Russia, and High Arctic Tundra in Canada (Figure 4-30c). The highest alpha diversity was evident in sub-Arctic mainland ecoregions, including the Scandinavian and Russian Taiga (average of 47 taxa in 10 stations), and the Muskwa-Slave Lake Forests (44 taxa), Southern Hudson Bay (53 taxa), and Central Canadian Shield Forests (56 taxa) ecoregions in Canada. Across the sampled region, alpha diversity generally was lower at the highest latitudes, on remote islands, and in mountainous ecoregions. In contrast, the highest alpha diversity was evident at the lowest latitudes on the mainland where connectivity allows for greater dispersal of taxa from southern regions. Thus, alpha diversity may reflect a combination of dispersal constraints and thermal tolerances.

Beta diversity for rivers was variable across ecoregions, with average  $\beta_{\text{SOR}}$  ranging from 0.21, implying strong similarity among stations, to 0.95, which indicated a large among-site variability in assemblage structure. Beta diversity was highest in the Southern Hudson Bay Taiga ecoregion, which indicated that the largest differences among stations were evident within one of the most diverse ecoregions. Turnover was the predominant component of beta diversity (>70%) in most ecoregions (Figure 4-30d), but there was an increased contribution of nestedness in colder ecoregions and ecoregions potentially affected by dispersal limitations. In particular, both turnover and nestedness contributed approximately equally to beta diversity in Brooks-British Range Tundra and Arctic Foothills Tundra in Alaska, the High Arctic Tundra in Canada, the Kalaallit Nunaat High Arctic Tundra and Low Arctic Tundra in Greenland, and the Wrangel Island Arctic Desert in Russia (Figure 4-30d). Furthermore, beta diversity was completely attributed to nestedness in the Arctic Desert in Svalbard, which was not surprising, as only two taxa were found in this ecoregion. For the remaining ecoregions, the dominance of the turnover component of beta shows that taxon replacement was the main driver of among-river compositional differences.

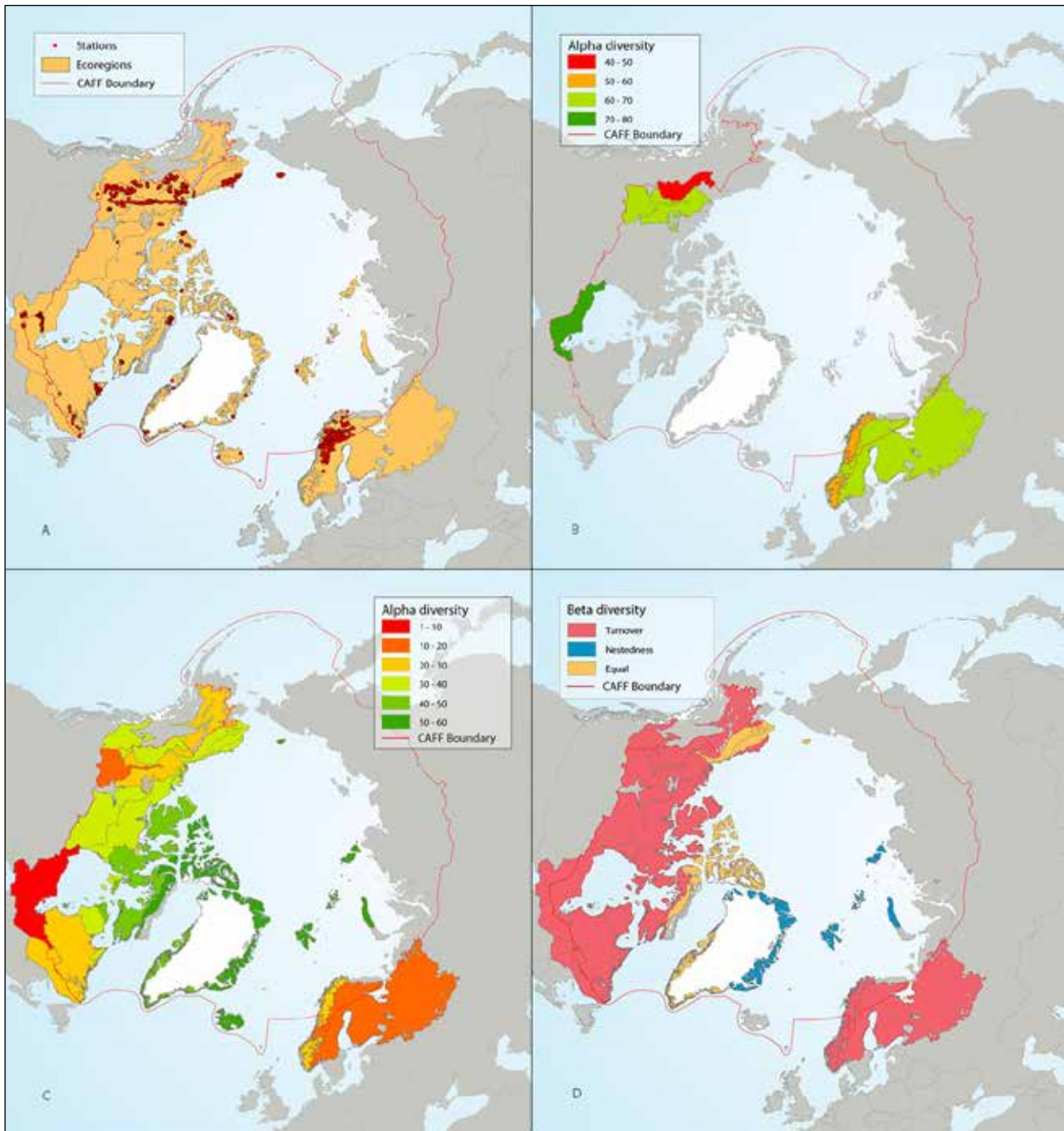


Figure 4-30 Results of circumpolar assessment of river benthic macroinvertebrates, indicating (a) the location of river benthic macroinvertebrate stations, underlain by circumpolar ecoregions; (b) ecoregions with many river benthic macroinvertebrate stations, colored on the basis of alpha diversity rarefied to 100 stations; (c) all ecoregions with river benthic macroinvertebrate stations, colored on the basis of alpha diversity rarefied to 10 stations; (d) ecoregions with at least two stations in a hydrobasin, colored on the basis of the dominant component of beta diversity (species turnover, nestedness, approximately equal contribution, or no diversity) when averaged across hydrobasins in each ecoregion.



*Lepidurus arcticus*  
Photo: Per Harald Olsen

### 4.6.3.2. Regional Diversity

The relationship between alpha diversity and latitude was explored to evaluate whether there was evidence of a decline in richness with increasing latitude, as suggested in previous studies (e.g., Scott and Crossman 1973, Castella et al. 2001). Because many ecoregions covered a wide range of latitudes, stations were grouped at a smaller spatial scale into level 5 hydrobasins, and analysis focused only on hydrobasins with at least 4 stations. To ensure comparability of richness estimates across hydrobasins with different levels of sampling, rarefied alpha diversity was compared at the level of 10 stations.



Rarefied taxonomic richness for lake littoral macroinvertebrates showed evidence of a declining trend in alpha diversity above 68°N for samples in Fennoscandia and Alaska (Figure 4-31). Other hydrobasins were located on remote islands (e.g., Iceland, Wrangel Island, Greenland, Faroe Islands) and rarefied alpha diversity in these hydrobasins was lower than those in Fennoscandia and Alaska by approximately 10 or more taxa, regardless of latitude. The low diversity of island ecoregions across all latitudes provided strong evidence for an island biogeography effect on BMI diversity in lakes. For example, Iceland has limited EPT taxa due to dispersal constraints for these taxa. In island hydrobasins,

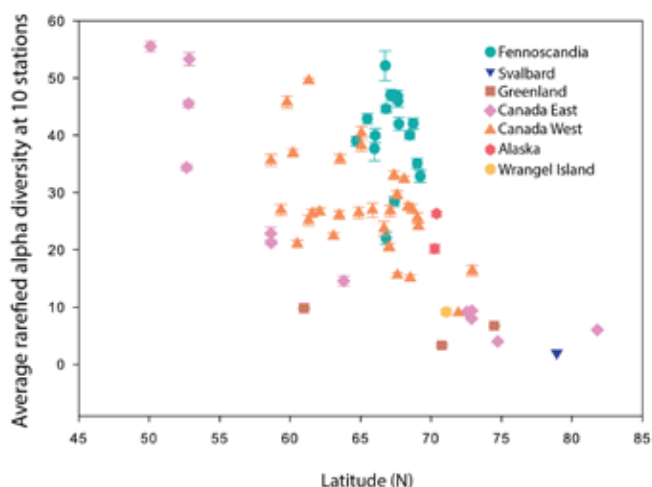


Figure 4-32 Alpha diversity (rarefied to 10 stations, with error bars indicating standard error) of river benthic macroinvertebrates plotted as a function of the average latitude of stations in each hydrobasin. Hydrobasins are coloured based on country/region

the effect of dispersal constraints on BMI diversity appeared to be stronger than latitudinal constraints, as diversity was similar across all latitudes for these hydrobasins. In contrast, in mainland (e.g., higher connectivity) hydrobasins where dispersal was less limited, a decline in diversity with increasing latitude was the predominant trend, likely related to thermal tolerances.

The river data assessment showed stronger evidence of a latitudinal decline in alpha diversity of benthic invertebrates (Figure 4-32). River data covered a wider range of latitudes (from 49°N to 83°N) and revealed clear evidence of higher taxonomic richness at the lowest latitudes and a strong decline in taxonomic richness above 68°N (Figure 43-2). However, these data also covered a wider range of longitudes, and there was evidence that the strength of the latitudinal decline in diversity differed by longitude/region, related in part to longitudinal temperature gradients across the Arctic. For example, a west-east temperature gradient exists in North America, with more historical warming in the west than along the eastern Canadian Arctic coast, and colder temperatures in the east at similar latitudes. Eastern Canadian hydrobasins clearly showed a stronger decline in diversity that began at lower latitudes than in other regions of the Arctic, and generally had lower diversity than western Canada or USA/ western Canada hydrobasins at similar latitudes (Figure 4-32). Furthermore, the eastern Canadian Arctic is colder than Fennoscandia at similar latitudes. Within the mid-latitudes, western North American stations and Fennoscandia stations had higher average alpha diversity than eastern Canadian stations, consistent with patterns expected to occur with warmer temperatures. The lowest alpha diversity values in the mid-latitudes were attributed to the Kalaallit Nunaat Low Arctic Tundra in Greenland (average richness of 12 taxa at 10 stations and average latitude 61°N) and a hydrobasin in the Middle Arctic ecoregion on southern Baffin Island in eastern Canada (average richness of 16 taxa at 10 stations and average latitude of 63.8°N). Both areas (southern Greenland and southern Baffin Island) have experienced less warming since 1990 than other areas of the Arctic (NASA GISS).

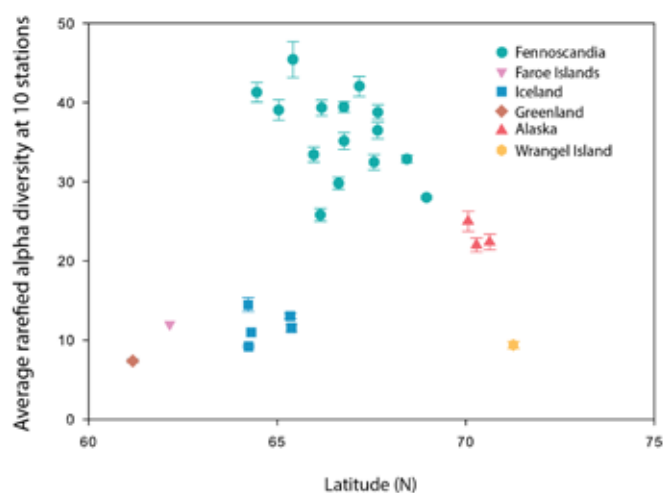


Figure 4-31 Alpha diversity (rarefied to 10 stations, with error bars indicating standard error) of littoral lake benthic macroinvertebrates plotted as a function of the average latitude of stations in each hydrobasin. Hydrobasins are coloured by country/region.

#### 4.6.3.3. Compositional Patterns

The most abundant taxa were compared spatially across highly-sampled areas of the Arctic to identify similarities and differences in composition. Geographic areas for comparison were selected by broadly grouping stations in highly-sampled areas by locale (see Figure 4-33 and Figure 4-34 for locations chosen for lake and river BMI, respectively). Data were summarized by selecting the most abundant taxonomic families in each area, comprising a total of 85% of the organisms found in the area. To account for regional differences at the family level, data were summarized by order level or higher, providing a broad picture of composition across geographic areas. Lake littoral samples

were generally numerically dominated by Dipteran taxa (true flies, primarily chironomids) and oligochaete worms in all Arctic areas (Figure 4-33). The numerical abundance of Diptera and Oligochaeta was strong enough in Greenland that these were the only two groups that contributed to the dominant portion of the assemblage. Ephemeroptera (mayflies) were not generally abundant in littoral samples, but Trichoptera (caddisflies) were among the important taxa in Alaska and Plecoptera (stoneflies) were abundant in

Fennoscandia. Alaska and Fennoscandia also differed with respect to non-insects, as nematode worms were important in Alaska whereas isopods were among the abundant taxa in Fennoscandia. However, differences with respect to

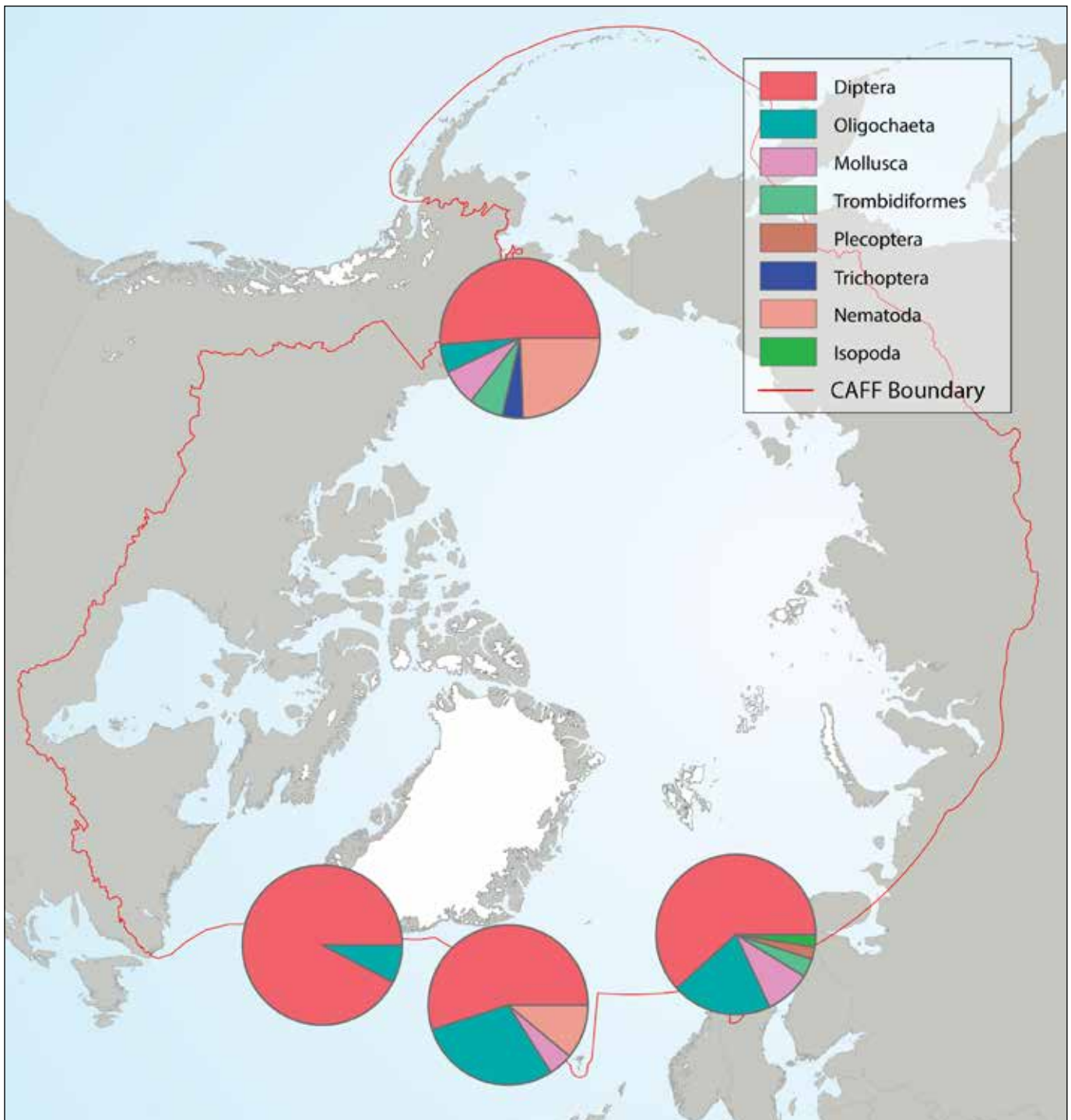


Figure 4-33 Summary of the taxa accounting for 85% of the lake littoral benthic macroinvertebrates collected in each of several highly-sampled geographic areas, with taxa grouped by order level or higher in pie charts placed spatially to indicate sampling area. Pie charts correspond to (1) Alaska, (2) Greenland low Arctic, (3) Iceland, and (4) Fennoscandia.



nematode abundance may have reflected differences in sample sorting, as nematodes are often not counted in lake littoral samples of Fennoscandia.

River benthic invertebrate assemblages were compared across more areas of the Arctic, and showed large differences in composition and dominance, both latitudinally and longitudinally. Diptera alone made up 85% of the assemblage in the high Arctic islands (Ellesmere Island in Canada, and Svalbard), as well as in Iceland (Figure 4-34). The high Arctic in Greenland was dominated by Diptera, but oligochaetes were also abundant in these systems, and composition of the most abundant groups was extremely similar between the low and high Arctic regions of Greenland. At lower

latitudes, other groups contributed more to assemblage composition. Alaska and northern Baffin Island in eastern Canada had similar composition of oligochaetes and nematode worms, but Alaska also had high abundance of mollusks whereas Ephemeroptera were more common on Baffin Island. Ephemeroptera were highly abundant in several areas of eastern and southern Canada (Baffin Island, northern Labrador, and south of Hudson Bay), but were not abundant in other areas of the Arctic. In contrast, Plecoptera and Trichoptera were far more abundant in Fennoscandia, western Canada, and south of Hudson Bay than they were in eastern Canada. Overall, Fennoscandia had the largest contribution from non-Dipteran organisms.

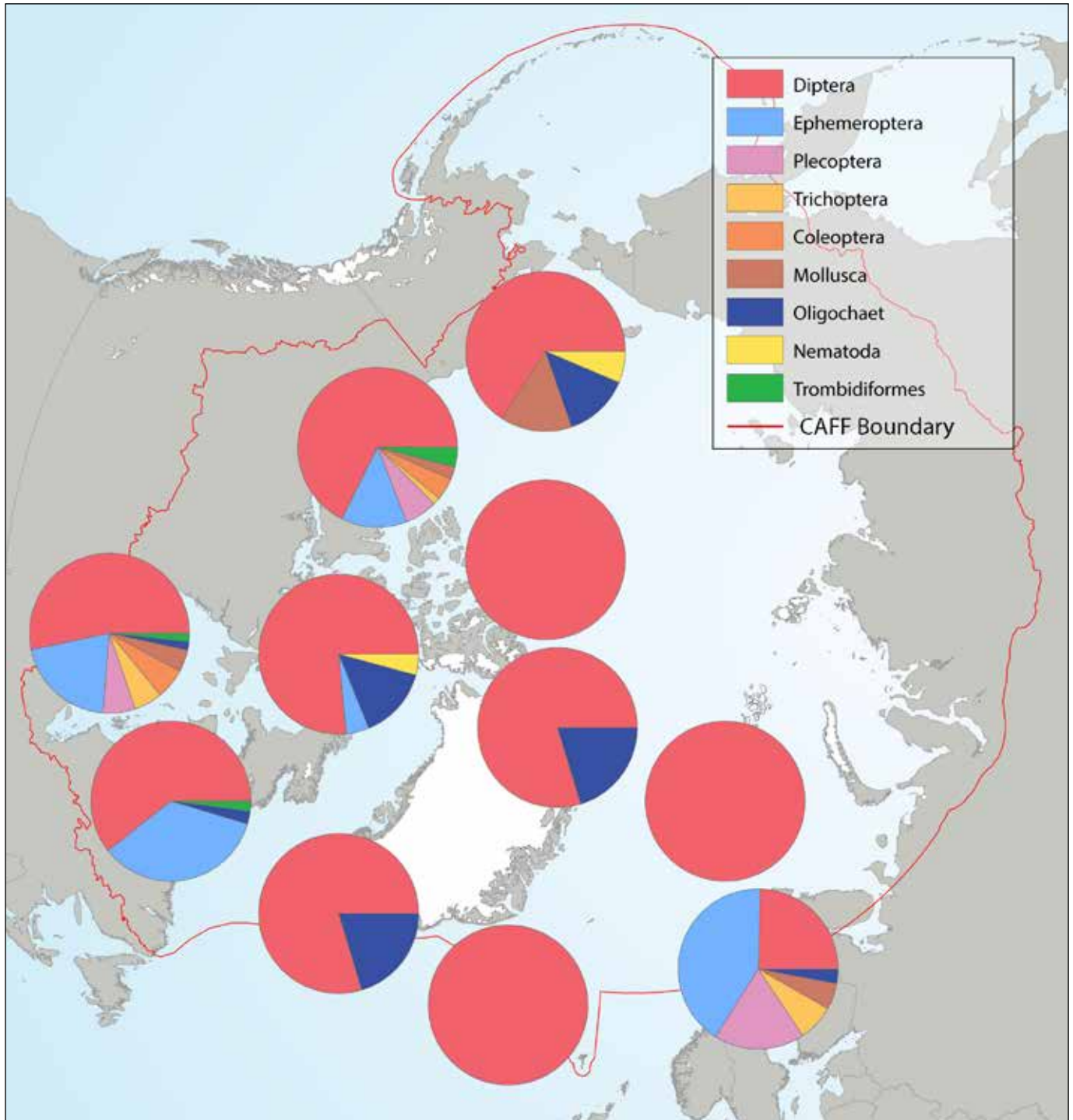


Figure 4-34 Summary of the taxa accounting for 85% of the river benthic macroinvertebrates collected in each of several highly-sampled geographic areas, with taxa grouped by order level or higher in pie charts placed spatially to indicate sampling area. Pie charts correspond to (1) Alaska, (2) western Canada, (3) southern Canada, south of Hudson Bay, (4) northern Labrador, (5) Baffin Island, (6) Ellesmere Island, (7) Greenland high Arctic, (8) Greenland low Arctic, (9) Iceland, (10) Svalbard, and (11) Fennoscandia.

#### 4.6.3.4. Temporal Trends in Lakes

Few long-term records of benthic macroinvertebrates exist from biological monitoring in Arctic lakes. In Lake Abiskojaure (68°N) and Lake Stor-Tjulträsk (66°N) in Sweden, the stony littoral zones (1 m depth) have been monitored annually since 1988 (Figure 4-35). Taxonomic richness (alpha diversity) of littoral macroinvertebrates shows a high inter-annual variability for both lakes. This is mainly due to the low densities of many taxa, i.e., many taxa occur only with a single or few individuals in a sample. While there is no obvious trend in Lake Abiskojaure, richness in the more southern Lake Stor-Tjulträsk has been increasing significantly (Mann-Kendall trend test,  $p < 0.001$ ) since the 1990s. Taxonomic richness has been calculated using a standardized list of taxa. Note, however, that two major groups of benthic macroinvertebrates, the Chironomidae (midges) and Oligochaeta (worms) have not been identified to species. The plots in Figure 4-35 therefore show underestimates of true alpha diversity.

#### 4.6.4. Gaps in Knowledge and Monitoring

There were large gaps in the spatial coverage of lake benthic invertebrate data, due in part to a lack of routine monitoring in many areas. However, a larger issue with regards to lake monitoring is that different countries and researchers focus on a different lake habitats, leading to a heterogeneous dataset that does not allow for broad comparisons. For example, Fennoscandia, Iceland, Alaska, and a few stations in Greenland have data from the littoral zone of lakes, with data collected using kick nets or rock scrapes (broadly comparable with respect to taxonomic composition, though rock scrapes have been shown to collect fewer taxa; Lento and Morin 2014). In contrast, Canada, Russia, and most of Greenland have data from the profundal zone, with grab samplers or dredges used to collect benthic macroinvertebrates. Data from the two quite different habitats and sampler types are not comparable, as profundal samples collected by grabs or dredges are dominated by organisms that prefer to burrow in soft sediments, such as midges and worms. Lake littoral samples, collected using a kick net (i.e., D-net) or rock and sediment scrapes, include more taxa that live on rocky substrates, such as mayflies, stoneflies, and caddisflies. Profundal samples are naturally less diverse than littoral samples, precluding broad comparisons across the circumpolar region. Moreover, in many areas (such as the Canadian high Arctic), only top sediment samples or sediment cores are collected for paleolimnological samples (or training datasets) using chironomids. These samples, although spatially extensive, offer a further limitation on circumpolar assessments, particularly when lake littoral and profundal samples do not identify past the family level for Chironomidae. In order to support future assessment efforts, there should be a standard sampling approach for lake benthic macroinvertebrate assemblages, ideally focused on the more taxonomically-rich littoral zone.

Spatial coverage of river benthic macroinvertebrate data was strong across the circumpolar region, though data were generally lacking for Russia. Despite this gap, river benthic macroinvertebrates had one of the best spatial extents of all the FECs, due in large part to the prevalence of this group in monitoring programs, the relatively standardized

sampling approaches used across the circumpolar region (generally kick nets or similar, with comparable mesh size in most regions), and the fact that it is the only FEC to have a national database in Canada, with data contributed to the database from academia and government. As a result, most ecoregions in Canada were represented by river benthic macroinvertebrate samples, allowing for strong spatial assessments. However, despite the strong spatial coverage, much of the sampling that has occurred (particularly in Canada) has been single-event sampling, and thus time series are scarce. An additional limitation to the strength and scope of diversity assessment is inconsistency in the taxonomic level of identification across the Arctic. In Alaska, Finland, and some stations in Canada, Chironomidae were not identified past family level (or were not counted at all for some samples in Finland). Chironomidae are ubiquitous in the Arctic and make up a large proportion of the benthic macroinvertebrate assemblage, and identification at even the subfamily level can help identify more subtle shifts in composition across broad regions (e.g., Culp et al. In Press). Future assessments can continue to make use of the strong spatial coverage of data and accessibility of data from national databases, but monitoring activities should endeavour to include a focus on Chironomidae and include re-sampling of stations to establish time series if possible.

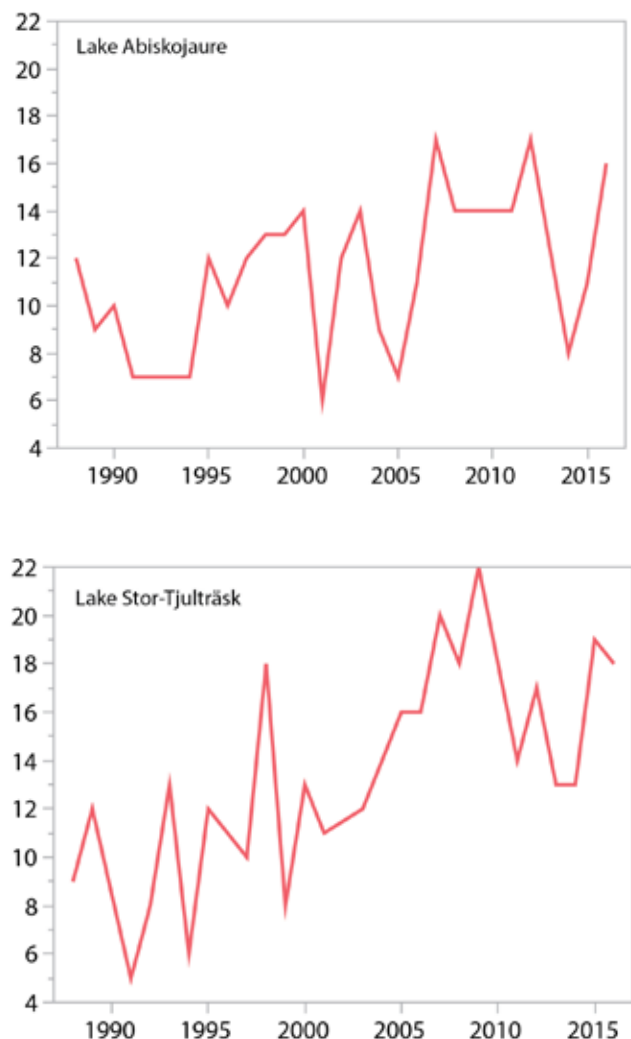


Figure 4-35 30-year trends in alpha diversity of benthic macroinvertebrates in the stony littoral zones (1 m depth) of two Scandinavian Arctic/alpine lakes: Lake Abiskojaure (upper panel) and Lake Stor-Tjulträsk (lower panel).