Daphnia longispina.
Photo: Deiter Ebert / Flickr/CC 2.0

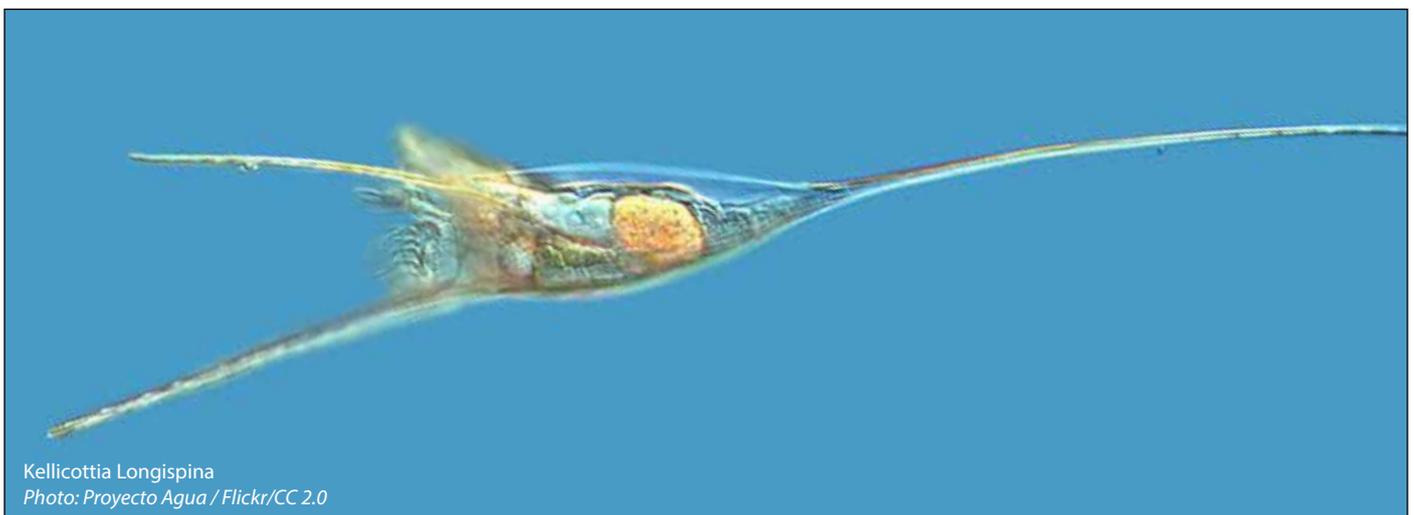# 4.5. Zooplankton

4.5.1. Introduction

Zooplankton are small, heterotrophic invertebrates that live in the water column (pelagic zone) of standing water bodies (i.e., lakes, ponds, pools), although some species have juvenile and resting stages that may occur in benthic habitats. The zooplankton of freshwaters (including the Arctic) are represented by three major groups: rotifers (Rotifera), cladocerans (Cladocera) and copepods (Copepoda). Arctic lakes are dominated by rotifers of the Monogononta class, cladocerans of all families including many genera of Ctenopoda, Anomopoda, Haplopoda and Onychopoda, and copepods of the orders Calanoida and Cyclopoida. In Arctic ponds and small water bodies, cladocerans of the families Chydoridae and Macrothricidae, and copepods from the order Harpacticoida come into account. Zooplankton assemblages are composed of true pelagic taxa, but can also contain benthic species, particularly in small water bodies. In order to obtain a complete picture of biodiversity in these ecosystems and compare them with biodiversity in shallow water bodies, it is necessary to analyze the composition of both aquatic assemblages. However, data for littoral or benthic taxa and stages of zooplankton are generally less available than pelagic data, which may preclude assessment of this component of the zooplankton assemblage.

The distribution of zooplankton species in Arctic lakes differs along a longitudinal gradient, with the greatest species richness corresponding with proximity to areas without recent glaciation (e.g., Alaska, northern Greenland; Wrona et al. 2013). Recolonization of lake zooplankton following the Pleistocene period was from these areas, and thus species richness declines with distance from locations such as Alaska and northern Greenland (Samchyshyna et al. 2008, Rautio et al. 2011). Zooplankton diversity is also increased by proximity to coastal regions, where species richness is increased by freshwater species that originate from marine ecosystems (Rautio et al. 2008).

Zooplankton density, biomass, and community composition are regulated by the abundance of food resources (i.e., planktonic and/or benthic algae and bacteria), predation, and indirectly by the nutrient status of lakes. Despite the low nutrient conditions that are typical of the Arctic, zooplankton density and biomass can be relatively high in shallow Arctic lakes because of the presence of benthic algal mats that are important feeding habitats (e.g., Rautio and Vincent 2006, Mariash et al. 2014). Eutrophication primarily has an indirect effect on zooplankton through increased primary production and changes in food quantity/quality. In low-productivity waters, even small inputs of nutrients may lead to increased production and biomass of zooplankton as well as richness. In contrast, in lakes with higher natural nutrient levels and in lakes with heavy nutrient loads, the main response may be a shift in zooplankton composition. Many zooplankton species are sensitive to predation from macroinvertebrates and fish. In fish-free lakes, zooplankton assemblages include large-bodied species, but the presence of fish will drive the size distribution of zooplankton towards smaller species (O'Brien et al. 2004). Increased fish predation, as a consequence of invasive species or changes in lake trophy, often have strong effects on zooplankton composition, with a shift from larger to smaller cladocerans and copepods and changes in the size distribution of individual species.

Industrial pollution and climate change both have the potential to affect the biodiversity of zooplankton in Arctic lakes. For example, metal and acid contamination in the areas along the boundary between Russia (Kola Peninsula) and Norway (South-Varanger) affects the zooplankton community composition in lakes, leading to reduced species richness, changes in species composition, and reduced complexity of the zooplankton assemblage (Vandysh 2002, Shustova et al. 2009). Lakes on the Kola Peninsula have very simple zooplankton communities with low species numbers (Vandysh 2002), similar to patterns that have been observed in temperate regions of Canada (Yan and Strus 1980). Changes in water temperature influence zooplankton through shifts in the composition of dominant species, changes to phenology of certain species, and introduction of alien species to northern regions (Rautio et al. 2011). Increased water temperature may also affect stratification of deep lakes and cause shifts in the vertical distribution of species in the water column. Other drivers related to climate change, including increased UV, shifts in precipitation, and increased turbidity, have the potential to impact the diversity, biomass, and feeding efficiency of zooplankton.

Kellicottia Longispina
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4.5.2. Objectives and Approach

This assessment provides an evaluation of zooplankton biodiversity and composition across the entire Arctic, which allows for analyses of latitudinal differences and trends across all Arctic regions. At a circumpolar scale, stations were grouped into ecoregions of similar geography and climate (Olson et al. 2001) and alpha diversity, beta diversity, and its component parts (turnover and nestedness) were evaluated within ecoregions. Zooplankton data from 3082 samples representing 482 stations and 421 lakes were used in this report. Of these, 416 lakes included data on crustaceans (Figure 4-25a), and 172 lakes included data on both crustacean zooplankton and rotifers (Figure 4-26a). Thus, diversity was assessed separately for the whole zooplankton assemblage (using stations in which Crustacea and Rotifera were sampled and enumerated) and also for just crustacean zooplankton. Spatial patterns in zooplankton diversity were also assessed at a regional scale (by country and by Arctic region) for the circumpolar Arctic. In the regional assessment, beta diversity was assessed in terms of the dispersion of stations around a group centroid in multivariate space (based on assemblage composition). Using contemporary zooplankton data, we produce a baseline to which future monitoring results can be compared and identify gaps in the current distribution of monitoring.

4.5.3. Overall Patterns and Trends

4.5.3.1. Circumpolar Diversity

For a subset of ecoregions with moderate sample frequency (range 25-72 stations; Figure 4-25a), alpha diversity estimates of crustacean zooplankton were rarefied to 25 stations for comparison. Among these ecoregions, alpha diversity of crustacean zooplankton was highest for lakes in the Northwest Russian-Novaya Zemlya Tundra ecoregion, where on average 29 taxa were found, and the Scandinavian and Russian Taiga ecoregion, where 23 taxa were found (Figure 4-25b). Alpha diversity of crustacean zooplankton was lowest in the Brooks-British Range Tundra in Alaska, where seven taxa were found. For the other four ecoregions, alpha diversity ranged from nine to 16 crustacean taxa, with higher diversity found in coastal Alaska and in Canada than was found in Iceland or Greenland. When all ecoregions were compared at a rarefied alpha diversity level of 10 stations, ecoregions in Russia and Fennoscandia remained the most diverse, with 22 crustacean taxa in the Northwest Russian-Novaya Tundra ecoregion, 19 taxa in the Scandinavian
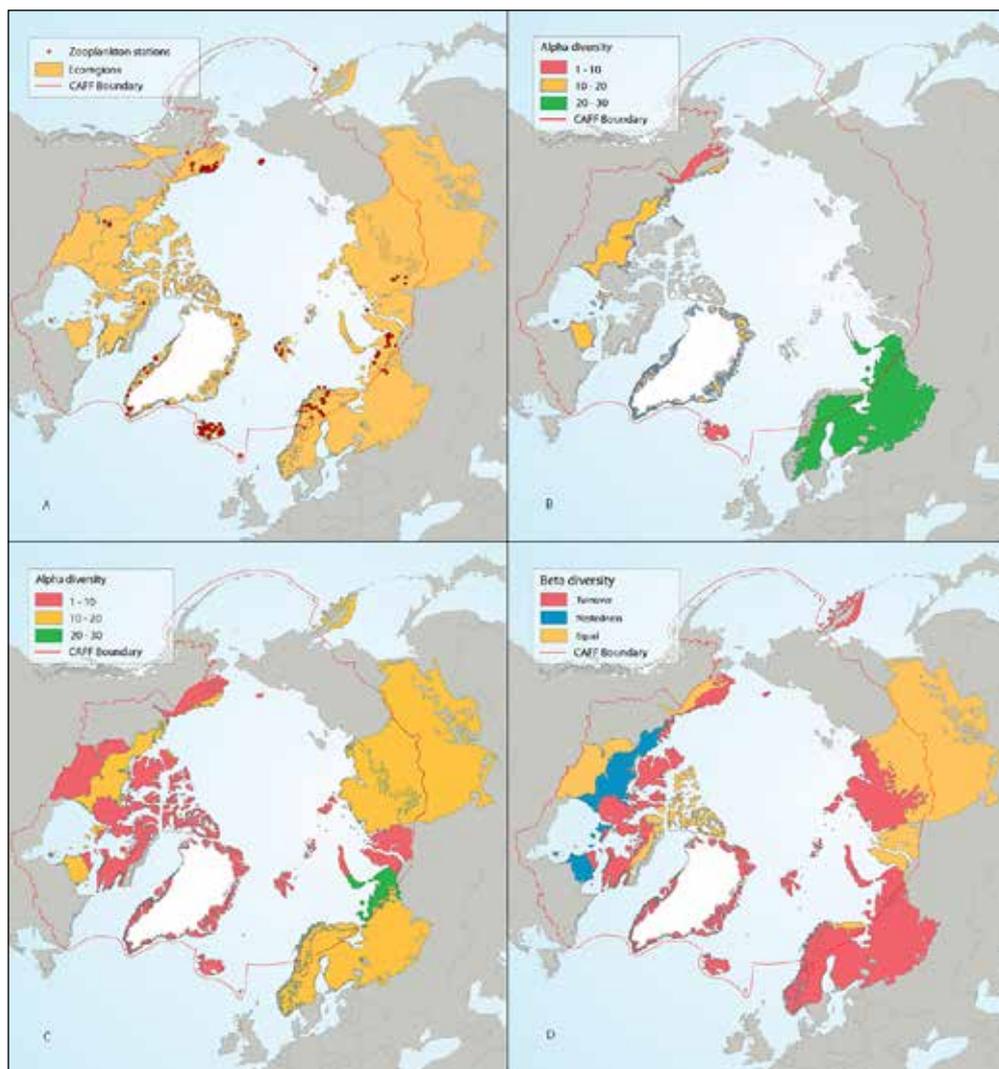

Figure 4-25 Results of circumpolar assessment of lake zooplankton, focused just on crustaceans, and indicating (a) the location of crustacean zooplankton stations, underlain by circumpolar ecoregions; (b) ecoregions with many crustacean zooplankton stations, colored on the basis of alpha diversity rarefied to 25 stations; (c) all ecoregions with crustacean zooplankton 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.

Montane Birch Forest and Grasslands, and 17 taxa in the Scandinavian and Russian Taiga (Figure 4-25c). The majority of ecoregions (18 ecoregions from across the circumpolar region) had similar alpha diversity estimates, ranging from six to 13 taxa (Figure 4-25c). The lowest diversity was found in the Canadian high Arctic (High Arctic Tundra), Svalbard (Arctic Desert) and mountainous regions of Alaska (Brooks-British Range Tundra), where fewer than seven crustacean taxa were estimated to be found at 10 stations.

A limited set of stations also had data for rotifers (Figure 4-26a), allowing for a more inclusive assessment of alpha diversity patterns. Four ecoregions had moderate levels of sampling of both Crustacea and rotifers, and alpha diversity estimates were rarefied to 25 stations for comparison. Similar to the crustacean analysis, the Northwest Russian-Novaya Zemlya Tundra ecoregion was found to be most diverse, having on average 102 taxa (95% confidence interval 92-111; Figure 4-26b). The Arctic Coastal Tundra was also significantly more diverse than the other ecoregions, and had an average of 62 taxa (95% confidence interval 55-70). The remaining two ecoregions had similar alpha diversity estimates (23-26 taxa). All ecoregions with data for both crustaceans and rotifers were compared at a rarefied alpha diversity level of 10 stations. Ecoregions covered a wider range of alpha diversity (which spanned four to 86 taxa on average per ecoregion) than when only Crustacea were considered. Russian and Fennoscandian ecoregions remained the most diverse ecoregions, though the Scandinavian Montane Birch Forest and Grasslands had the highest richness, with an estimated 86 crustacean and rotifer taxa at 10 stations (though this was not significantly different from the Northwest Russian-Novaya Zemlya Tundra, which had an estimated 67 taxa; Figure 4-26c). In this analysis, the Arctic Desert had the lowest diversity with an estimated four taxa (Figure 4-26c).

Assessment of the full zooplankton assemblage and of crustacean zooplankton provided some evidence of high alpha diversity in coastal regions, particularly in coastal ecoregions of Fennoscandia and Russia. This pattern is consistent with predictions that high richness would be found in coastal areas where there would be more influence from the marine habitat (Rautio et al. 2008). Richness was also high in Alaska (Arctic Coastal Tundra), which supports the prediction of high diversity in areas that were unaffected by recent glaciation (Samchyshyna et al. 2008). The high alpha diversity of rotifers observed for some Russian ecoregions (particularly the Northwest Russian-Novaya Zemlya Tundra)
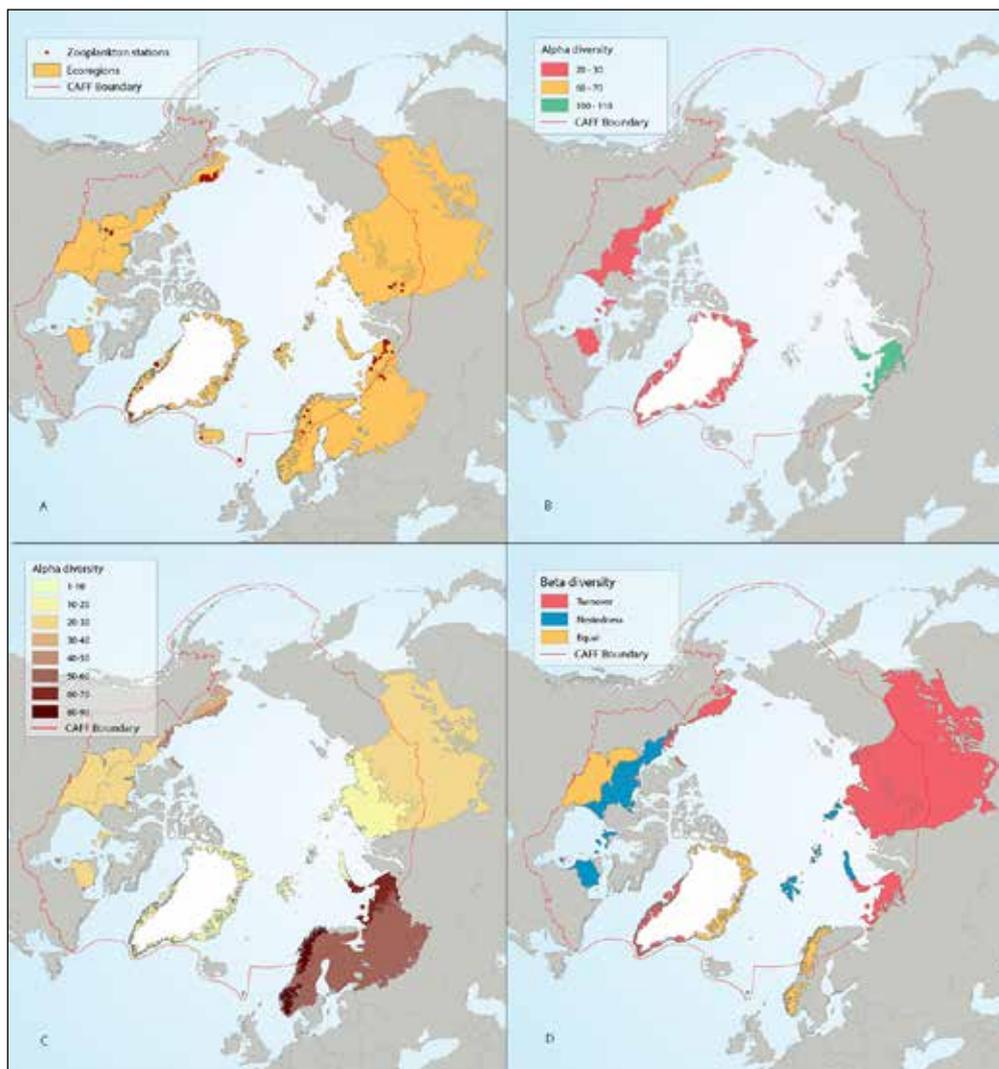

Figure 4-26 Results of circumpolar assessment of lake zooplankton, including crustaceans and rotifers, and indicating (a) the location of zooplankton stations, underlain by circumpolar ecoregions; (b) ecoregions with many zooplankton stations, colored on the basis of alpha diversity rarefied to 25 stations; (c) all ecoregions with zooplankton 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.

may partly reflect differences in the taxonomic identification approaches used by researchers in different regions (e.g., where taxa may be split into multiple species in some regions but grouped in other regions). Further consultation with taxonomic experts from different regions may be required to confirm taxonomic groupings and further develop nomenclature harmonization.

Daphnia pulex *with ephippia from NE Greenland*
Photo: Kirsten S. Christoffersen
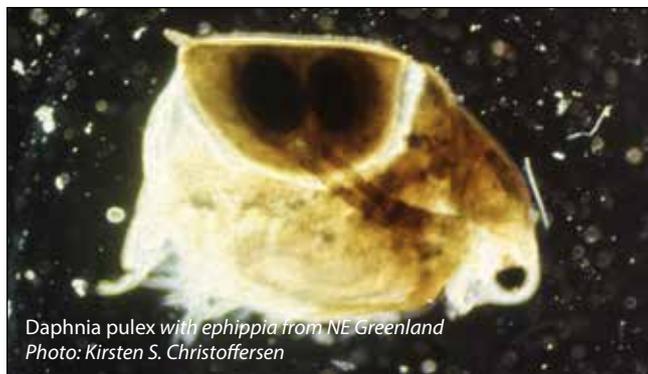
Beta diversity for crustacean zooplankton, calculated for 21 ecoregions, exceeded 0.80 in three of the ecoregions: the Arctic Coastal Tundra, Arctic Desert, and Kamchatka-Kurile Meadows and Sparse Forests. The high beta diversity values indicated that these ecoregions had the highest differences in crustacean zooplankton assemblage composition among lakes. Eight of the 21 ecoregions had low beta diversity (β_{SOR} ≤ 0.50), suggesting that the lakes in these regions were more similar in their crustacean zooplankton assemblages. The lowest beta diversity was in the High Arctic Tundra (β_{SOR} = 0.20), whereas seven other ecoregions had beta diversity ranging from 0.43 to 0.5; however, these ecoregions all had data from between four and seven lakes, and low beta diversity values may have reflected the fact that assemblage composition was compared among few lakes. Beta diversity for the remaining ecoregions ranged from 0.51 to 0.77, indicating intermediate similarities among assemblages. Species turnover was the most important component of beta diversity in 13 of the 21 ecoregions analyzed, accounting for 70–100% of beta diversity in these ecoregions (Figure 425d). Of the remaining ecoregions, one was dominated by nestedness (Low Arctic Tundra in Canada; 80% of beta diversity) whereas all other ecoregions had approximately equal contribution of turnover and nestedness, with the

turnover component accounting for 38-62% of beta diversity. Where nestedness played a larger role, there were generally fewer lakes sampled in an ecoregion, and differences among lakes may not have been captured. These results highlight the importance of monitoring zooplankton in a wide variety of lakes within an ecoregion, as widespread sampling may be necessary to accurately summarize the full diversity of species in an area.

Beta diversity for samples with both crustacean and rotifer data ranged from 0.28 to 0.87 across 12 ecoregions. For some ecoregions, the addition of rotifers resulted in only minor deviations from the results of the crustacean beta diversity analysis. However, there was a strong increase in beta diversity in the Arctic Foothills Tundra (0.5 to 0.8) and the Northern Canadian Shield Taiga (0.51 to 0.73), which indicated that the inclusion of rotifers led to stronger dissimilarity among stations. In contrast, there was a sharp decline in beta diversity estimates for the Arctic Desert (0.81 to 0.29) and Kalaallit Nunaat High Arctic Tundra (0.71 to 0.43), which indicated that consideration of rotifer taxa led to stronger similarity among stations in these high Arctic ecoregions. Nestedness became more important in some ecoregions and contributed approximately equally to beta diversity (e.g., Kalaallit Nunaat High Arctic Tundra and Scandinavian Montane Birch Forest and Grasslands), or even became the dominant component of beta diversity (e.g., Arctic Desert; Figure 426d). Species turnover remained an important component of beta diversity in ecoregions in Alaska, Russia, and southern Greenland.

4.5.3.2. Regional Diversity

Average taxon richness per site decreased with increasing latitude for crustaceans and rotifers. For rotifers, taxa richness was significantly lower in the high Arctic than in the low Arctic ($p < 0.005$), but there was substantial overlap in richness between the high Arctic and the sub-Arctic/alpine zone. When crustacean richness was assessed, there was evidence of significantly lower alpha diversity in the high Arctic than in either low-Arctic or sub-Arctic/alpine lakes ($p < 0.001$; Figure 4-27). Though these patterns in diversity may have been driven in part by lower sample size in the high Arctic, they are also indicative of lower diversity of both crustaceans and rotifers at higher latitudes.
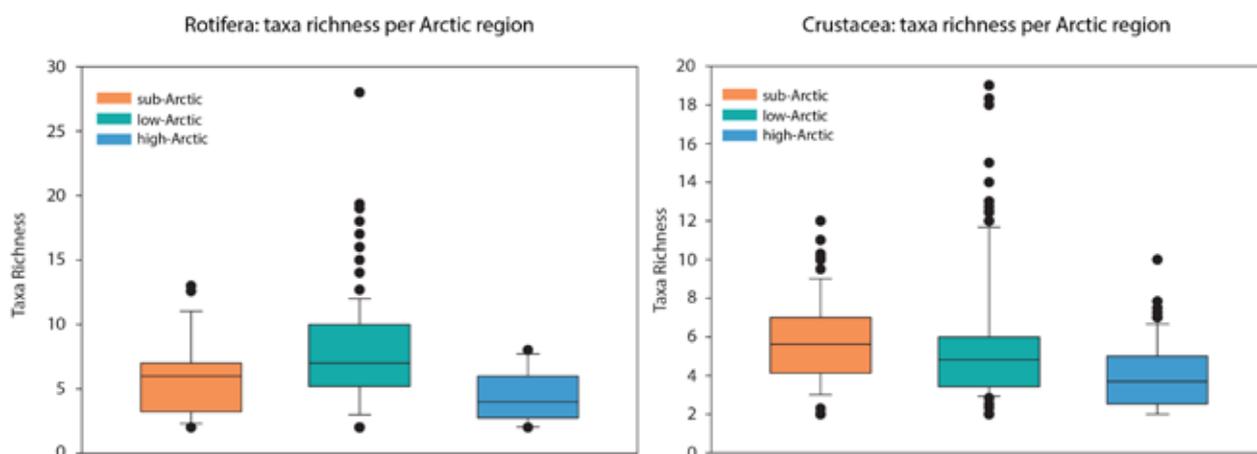

Figure 4-27 Box-plots of taxa richness (average per lake) by Arctic regions for rotifers (upper) and crustaceans (lower). Crustacean taxa are restricted to taxa within Calanoida, Cyclopoida and Cladocera. Samples with only a single taxon have been excluded. Boxes represent median and interquartile range.

4.5.3.3. Compositional Patterns

The zooplankton dataset included 357 taxa, of which 282 were at the species level. The main groups of zooplankton were calanoid copepods (30 spp.), cyclopoid copepods (37 spp.), cladocerans (66 spp.) and rotifers (121 spp.). Other groups like Harpacticoida, Ostracoda and others were represented with <20 species each. Approximately 40% of all taxa were found in only one or two samples, whereas the most common species groups (*Daphnia longispina* gr., which likely included several species), and *Cyclops scutifer* were found in 44% and 37% of the samples, respectively. Among the rotifers, *Kellicottia longispina* was most widespread, found in 69% of the samples with rotifer data.

Distributional patterns differed among species groups. Many of the common and highly abundant species, i.e., crustaceans (*Bosmina longirostris, Bosmina longispina/ coregoni gr., Daphnia longispina gr.*) and rotifers (*Asplanchna priodonta, Conochilus unicornis, Kelicottia longispina*) are common throughout the Holarctic area. Some species were common, but were not found in all regions. For example, the cladoceran *Daphnia pulex* gr., commonly associated with fishless lakes, was observed in 31% of the stations, but was lacking in Scandinavia. The reason for this may be that Scandinavian lakes are relatively large and deep and contain fish. Additionally, *Holopedium gibberum* was observed in 26% of the circumpolar lakes, but was absent in the eastern part of Russia. Other common species with a more restricted spatial distribution were *Bythotrephes longimanus*, *Limnosida frontosa*, and *Heterocope appendiculata*, which were found in Scandinavia and Eastern and Western Siberia, but not in Canada or parts of Beringia (Alaska), in agreement with the described Eurasian distribution of these species. *Leptodora kindtii* and *Cyclops abyssorum* had a similar distribution in the data, but have been found in North America in the past.

Comparison of the relative abundance of each of the main crustacean groups (Calanoida, Cyclopoida and Cladocera) across Arctic zones indicated that the dominance of cladocerans in sub-Arctic lakes(approximately 50% of all specimens) was diminished by an increased presence of cyclopoid copepods in the low Arctic and high Arctic (Figure 4-28). Conversely, the relative abundance of calanoid copepods was similar between the sub-Arctic and low Arctic, and declined in the high Arctic zone (Figure 4-28). It is known that copepods are more cold-adapted than cladocerans, and are thus potentially able to tolerate high Arctic conditions. Cladocerans have advantages in colonization of arctic areas thanks to a cyclic parthenogenesis that includes lentic stages (epiphia), but they are more sensitive to the ratio of P:N in waterbodies (Novichkova and Azovsky 2017), and may be limited in the nutrient-poor systems of the high Arctic.

4.5.3.4. Gaps in Knowledge and Monitoring

Data for this assessment were lacking particularly from Canada and Russia, but there were several regions of the Arctic where spatial coverage was less extensive than for other FECs. Zooplankton are not generally included in routine monitoring in North America, with the exception of monitoring by industry. The lack of data in some European countries may be due to the fact that zooplankton is not a so-called "ecological quality element" according to the

European Water Framework Directive. Greenland and Norway are the primary regions with routine monitoring at established stations, whereas monitoring data from other regions are often from impact studies rather than long-term programs intended to evaluate natural variation or monitor for effects of climate change. Throughout the circumpolar region, therefore, there is a need to rely in part or in whole on data from academia, industry, or other non-government research. As a result, there is limited availability of time series, and in some areas, limited assessment of the full zooplankton assemblage (e.g., areas with research focused on crustaceans or just on cladocerans or copepods).

There were some historical data from Greenland (records from the early 1900s from published papers), but data were generally from within the last 30 years for most countries. Time series were rare, and only nine stations in the database (from Greenland, Norway, and USA) had ≥ 10 years of sampling data. Some paleolimnological cladoceran data were obtained for the database, but these data covered a small spatial scale and additional data would be required to improve assessment of long-term historical changes.

Current assessments are limited by a lack of routine monitoring, which would be necessary to detect changes in response to climate change and anthropogenic stressors. To facilitate the future status assessment for freshwater zooplankton across the circumpolar region, there is need to standardize sampling methods and habitats. For example, data included a variety of samplers (with different mesh sizes) and sampling approaches (depth-specific or depth-integrated sampling), and the depth/region of the lake where samples were collected was not always available. For many of the samples, >50% of the taxa are generally associated with littoral habitats (very few truly pelagic species). We assume that the vast majority of these sites are very shallow, and therefore that most samples represent a mixed habitat (littoral + pelagic). However, future monitoring would preferably include the collection of quantitative samples with vertical net-hauls from open waters and horizontal net-hauls from the littoral zone. Furthermore, identification of the complete sample (crustaceans and rotifers) should be completed using the most recent nomenclature.
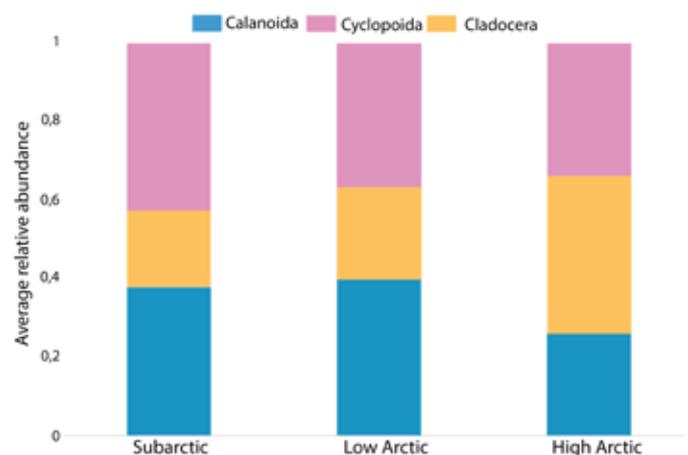

Figure 4-28 Average relative abundance of the main zooplankton groups (calanoid copepods, cyclopoid copepods, cladocerans) for the sub-Arctic (n=150), low-Arctic (n=154), and high-Arctic (n=55) regions. Samples with a single taxon have been excluded.