



Water milfoil (Myriophyllum alterniflorum).
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4.4. Macrophytes

4.4.1. Introduction

Macrophytes are a diverse group of aquatic plants large enough to see with the naked eye. There are 644 described species of vascular macrophytes in the Nearctic region and 497 species in the Palearctic region (Chambers et al. 2008), though Arctic zones of these biogeographical regions are expected to be less diverse. Macrophytes are taxonomically and phenologically wide ranging, from macroalgae (such as macroscopic species of green algae or Chlorophyta), to mosses and liverworts (Bryophyta), ferns (Pteridophyta) and seed-bearing plants (Spermatophyta) (Chambers et al. 2008). Macroscopic forms of Cyanobacteria, Xanthophyta (yellow-green algae) and Rhodophyta (red algae) can also be classified as aquatic macrophytes. Morphological forms of aquatic macrophytes include emergent (rooted plants with foliage extending into the air), floating-leaved (plants rooted to the lake or stream bottom with leaves that float on the water surface), submersed (plants growing completely submerged under the water and attached to, or closely associated with the substrate), and free-floating macrophytes (plants that typically float on or under the water surface) (Chambers et al. 2008). In addition, the depth distribution of macrophytes in lakes and rivers is often determined by the light penetration through water.

Macrophytes are an important functional component of lake ecosystems. They remove nutrients (e.g., nitrogen and phosphorus) from the water column (e.g., Gumbrecht 1993, Jeppesen et al. 1998) and decrease wave energy and water currents, which leads to increased sedimentation and stabilization of sediment within macrophyte beds (e.g., Carpenter and Lodge 1986, Sand-Jensen 1997). Moreover, these beds provide habitat for fish, invertebrates, and epiphytes, and are an important food source for some invertebrates (e.g., insects) and vertebrates (e.g., fish, birds, moose) (Lodge 1991, Newman 1991). Wrona et al. (2013) indicate there are several major environmental factors that affect macrophyte distribution including nutrient levels, water clarity and water temperature (including ice regimes). Because macrophyte presence and abundance is closely associated with these environmental factors as well as substrate type, the composition of macrophyte communities can provide diagnostic information on water quality and is part of many countries' assessment criteria (Jeppesen et al. 1998, Søndergaard et al. 2010).

4.4.2. Objectives and Approach

This circumpolar assessment provides a summary of broad spatial patterns of aquatic macrophyte biodiversity in the Arctic. To accomplish this we examined presence/absence data for macrophyte species-level data compiled for 440 lakes in all Arctic countries except Russia (Figure 4-22a). We examined spatial distribution patterns of macrophyte species composition, alpha diversity (i.e., species richness), and beta diversity and its component parts (i.e., turnover and nestedness) for regions with numerous data records. Using this approach, we produced a baseline for current macrophyte species distribution and composition to which future monitoring results can be compared. Knowledge gaps related to macrophyte monitoring in lakes and rivers were also identified.

4.4.3. Overall Patterns and Trends

4.4.3.1. Circumpolar Diversity

Among the three ecoregions with the largest number of sampling stations, there was significantly lower alpha diversity in the Iceland Boreal Birch Forests and Alpine Tundra (estimate of 35 species at 70 stations) than in either the Scandinavian and Russian Taiga or the Scandinavian Montane Birch Forest and Grasslands (estimate of 111 and 112 species at 70 stations, respectively; Figure 4-22b). Macrophyte distribution ranges are thought to be largely determined by seed dispersal via migratory birds and human activity, though continental drift and geographic proximity may have influenced dispersal patterns (Les et al. 2003, Chambers et al. 2008). These processes may have contributed to lower observed alpha diversity in Iceland compared to the continental Scandinavian ecoregions. When compared to one another using 100 stations, alpha diversity estimates were similar for the two Scandinavian ecoregions (120 species in the Scandinavian and Russian Taiga and 130 species in the Scandinavian Montane Birch Forest and Grasslands), indicating generally high diversity within these two ecoregions.

Rarefaction of species across all ecoregions, using 10 stations as the assessment threshold, showed alpha diversity estimates were lowest (< 15 species) for the tundra ecoregions of the Brooks-British Range, Kalaallit Nunaat High Arctic, Kola Peninsula and High Arctic (Figure 4-22c). Three of the ecoregions with the lowest species richness were located at the highest latitudes (average latitude > 70°N for the stations in the ecoregion), suggesting that alpha diversity of macrophytes declines in high-latitude Arctic regions. This is consistent with past research, which has suggested that there are latitudinal and altitudinal gradients in alpha diversity (Chambers et al. 2008), with aquatic vascular macrophytes showing a decline in species richness with latitude (Wrona et al. 2013). The highest alpha diversity (> 45 species) was in lakes of the Arctic Coastal Tundra, Northwest Territories Taiga, Scandinavian and Russian Taiga and Scandinavian Montane Birch Forest and Grasslands (Figure 4-22c). Interestingly, the Scandinavian and Russian taiga ecoregion had the highest estimated alpha diversity when only 10 samples were used (60 species), whereas it generally had lower alpha diversity than the Scandinavian Montane Birch Forest and Grasslands when a more representative sample size (e.g., over 70 stations) was considered. This result highlights the importance of sampling a sufficient number of stations across these regions.

Beta diversity of macrophyte assemblages ranged between 0 (no inter-station differences in species composition) and 1 (no inter-station overlap in species) within the ecoregions. Ecoregions with the highest inter-station differences ($\beta_{\text{SOR}} > 0.80$) included the Arctic Coastal Tundra, Brooks-British Range Tundra, Kalaallit Nunaat High Arctic Tundra, Kalaallit Nunaat Low Arctic Tundra, Northwest Territories Taiga, Scandinavian Coastal Conifer Forests, and Scandinavian Montane Birch Forest and Grasslands. Beta diversity was lowest (high inter-station composition overlap) in the remote ecoregions with low connectivity, such as the Faroe Islands Boreal Grasslands, High Arctic Tundra, and Kola Peninsula Tundra. For most ecoregions, turnover was the dominant component of beta

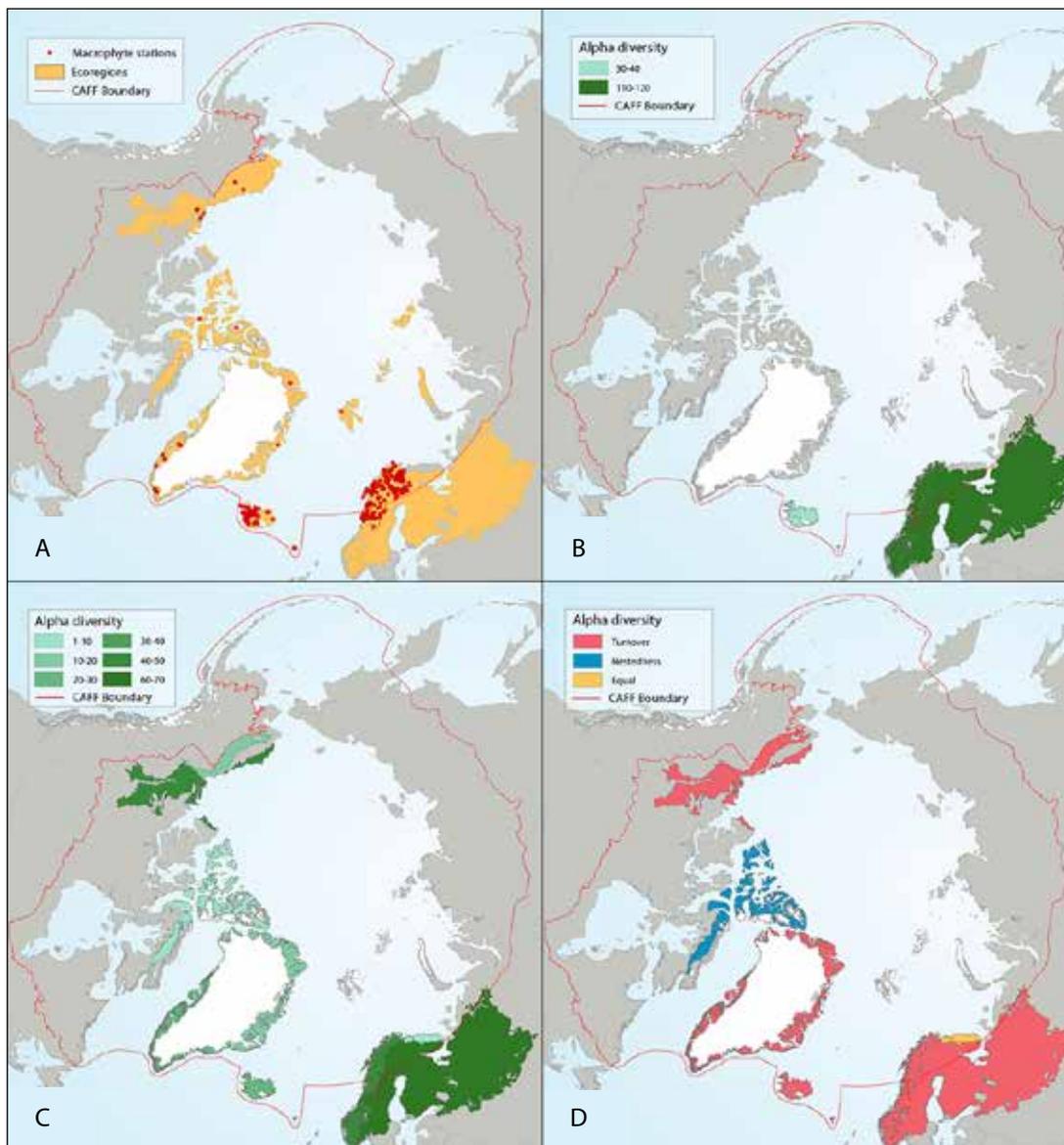


Figure 4-22 Results of circumpolar assessment of lake macrophytes, indicating (a) the location of macrophyte stations, underlain by circumpolar ecoregions; (b) ecoregions with many macrophyte stations, colored on the basis of alpha diversity rarefied to 70 stations; (c) all ecoregions with macrophyte 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.

diversity as it accounted for more than 70% of the total beta diversity (Figure 4-22d). This indicates that variation in diversity within an ecoregion is due species replacement across stations, rather than finding a subset of the species found at the richest station. The High Arctic Tundra ecoregion had no beta diversity as species composition was the same among stations, and beta diversity of the Kola Peninsula Tundra was a result of both turnover and nestedness.

4.4.3.2. Regional Diversity

Species richness of circumpolar macrophytes varied widely among lakes in the sub-Arctic region, ranging from 0 to a maximum of 29 species when mosses and algae were excluded (Figure 4-23). The highest alpha diversity was observed in Fennoscandia and the Faroe Islands, and alpha diversity was significantly lower in Greenland (Figure 4-23). Species richness was highly variable in Fennoscandia, owing in part to the wide variety of stations and ecoregions sampled in that area (Figure 4-23). Beta diversity in these regions was

primarily driven by species turnover, indicating that differences among stations were due to the replacement of species.

4.4.3.3. Compositional Patterns

All major taxonomic groups were included in the circumpolar dataset, although there were several lakes without macrophytes or with only aquatic mosses. The most common taxa were *Myriophyllum alterniflorum*, *Potamogeton gramineus*, and *Ranunculus reptans*. Aquatic moss species comprised a higher percentage of total species richness with increasing latitude. Bryophytes (or charophytes) commonly dominate the macrophyte assemblages in high latitude lakes (e.g., Welch and Kalff 1974, Vincent and Hobbie 2000) where macrophyte growth rate is extremely low (e.g., Sand-Jensen et al. 1999). Multivariate analysis of macrophyte assemblages for highly-sampled regions indicated some separation among countries based on species composition (Figure 4-24). In particular, macrophyte species composition in Greenland and Norway differed from stations in Sweden and Finland,

which were highly similar (Figure 4-24). Species composition in a number of Greenland stations was distinct from all other countries included in the analysis.

In Arctic lakes, aquatic macrophyte abundance and composition is largely driven by physicochemical conditions including climate, which imposes latitudinal and altitude zonation patterns; local weather that modifies the regional patterns; water clarity, which is largely determined by natural or anthropogenic erosional activities; and nutrients, which are inherently in low supply and increase with human activity (Chambers et al. 2008). Harsh climate and ice conditions restrict the distribution of helophytes (i.e., perennial marsh plants with overwintering buds underwater) in the littoral zone, and the number of submerged vascular plants decreases as they are successively replaced by mosses at northern latitudes. This compositional change is likely due to the superior competitive ability of mosses under low light and temperature conditions (Sand-Jensen et al. 1999). Most of the lakes included in the analysis were in pristine condition, but there was some evidence of nutrient enrichment as indicated by the presence of freely-floating lemniids (*Lemna trisulca*) and ceratophyllids (*Ceratophyllum demersum*).

4.4.3.4. Temporal Trends

Paleoecological analysis has identified shifts in macrophyte taxonomic composition in response to changing environmental conditions. For example, pollen records from a number of lakes in Greenland show a loss of aquatic angiosperms and their replacement by aquatic mosses (8000 - 1000 BP), associated with lake oligotrophication (i.e., the reduction in salt concentrations, ions and nutrients) (Fredskild 1983, 1992). Similarly, analysis of the depth distribution and abundance of aquatic pollen taxa from six Alaskan lakes indicated increases in macrophyte abundance 14,000-12,000 and 8000 BP, likely due to temperate-linked changes in productivity and/or changes in water depth (Edwards et al. 2000).

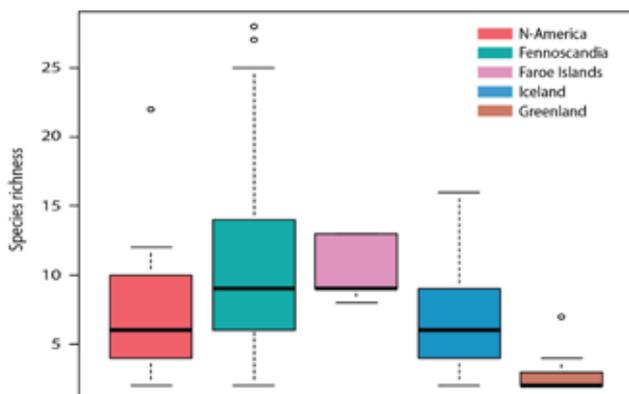


Figure 4-23 Species richness of aquatic macrophytes excluding mosses and algae in five geographic regions of the Arctic. Ame = North America, Fen = Fennoscandia, Far = Faroes, Ice = Iceland, Gre = Greenland.

4.4.4. Gaps in Knowledge and Monitoring

Extensive data were available for some areas of the Arctic (e.g., Fennoscandia), but data were sparse elsewhere, particularly for Canada, Alaska, and Russia. No data were obtained from Russian lakes, and data for Canada and Alaska were extracted from a small number of published papers. In the case of Canada, this resulted in a moderate number of samples covering a small geographic area. Data from Alaska included a single species list that summarized observations from over 100 lakes that covered a wide geographic area, with no details about the lakes in which macrophyte species were found. Macrophyte monitoring is not part of regular assessments in these countries, thus limiting the spatial scope of available data.

Across the entire circumpolar region, there are very few lakes that are monitored regularly. As a result, time series data are generally not available, and many lake observations are outdated (e.g., 1970s or earlier) with no repeated visits to the same lakes. Such data do not allow for the detection of shifts in macrophyte distribution and may not provide an accurate view of contemporary patterns in diversity.

There may also be inconsistencies in sampling methods and taxonomic identification; this can introduce variability that constrains data comparisons. For example, identification of aquatic mosses and Charophytes is sometimes difficult and may result in errors. Moreover, monitoring may not include the identification or enumeration of aquatic mosses, helophytes, or bryophytes, which may be of particular concern if these groups are dominant in a region. Improvements to the monitoring of macrophytes are necessary across the circumpolar region, and should focus on regular and repeated monitoring of representative lakes with standardized monitoring protocols.

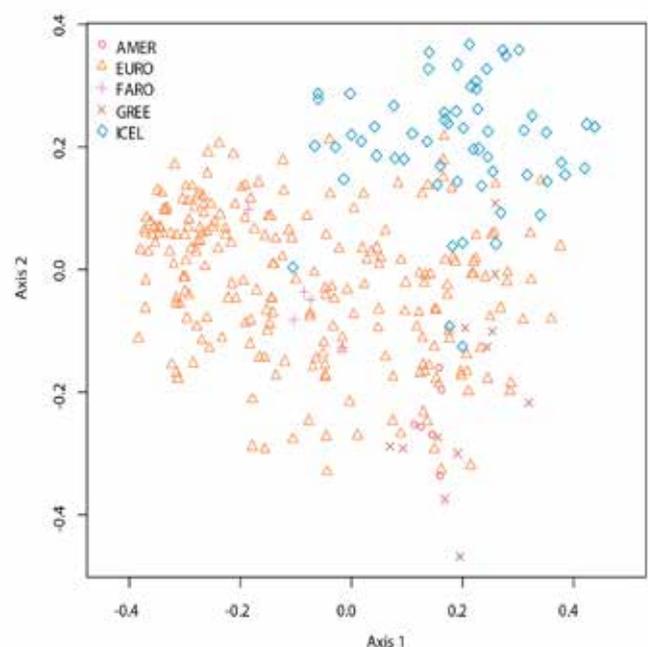


Figure 4-24 Principal coordinates analysis of aquatic macrophytes presence-absence data for North America (AMER), Fennoscandia (EURO), Faroes (FARO), Iceland (ICEL) and Greenland (GREE).