6 Life in cold waters

SECTION OVERVIEW

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Freshwater environments are so abundant in the North that the Arctic is sometimes thought of as a vast circumpolar wetland (Kling 2009), and when seen on maps or from the air, some parts of the Arctic landscape seem like an archipelago of islands in a freshwater sea (Figure 6.1). An analysis of the distribution of the world's lakes by area shows that the vast majority of waterbodies greater than 0.1 km^2 occurs on northern *permafrost* catchments and collectively totals more than 300,000 km^2 (Grosse and others 2013). However, it is not only the abundance of freshwater that has captured the interest and imagination of *limnologists* (scientists who study inland waters), but it is also the diversity of these northern *ecosystems* (Figures 6.2 and 6.3) and their importance as habitats for aquatic life.

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Oulanka River, running nearby the Oulanka Research Station (•17), Northeast Finland (Riku Paavola).

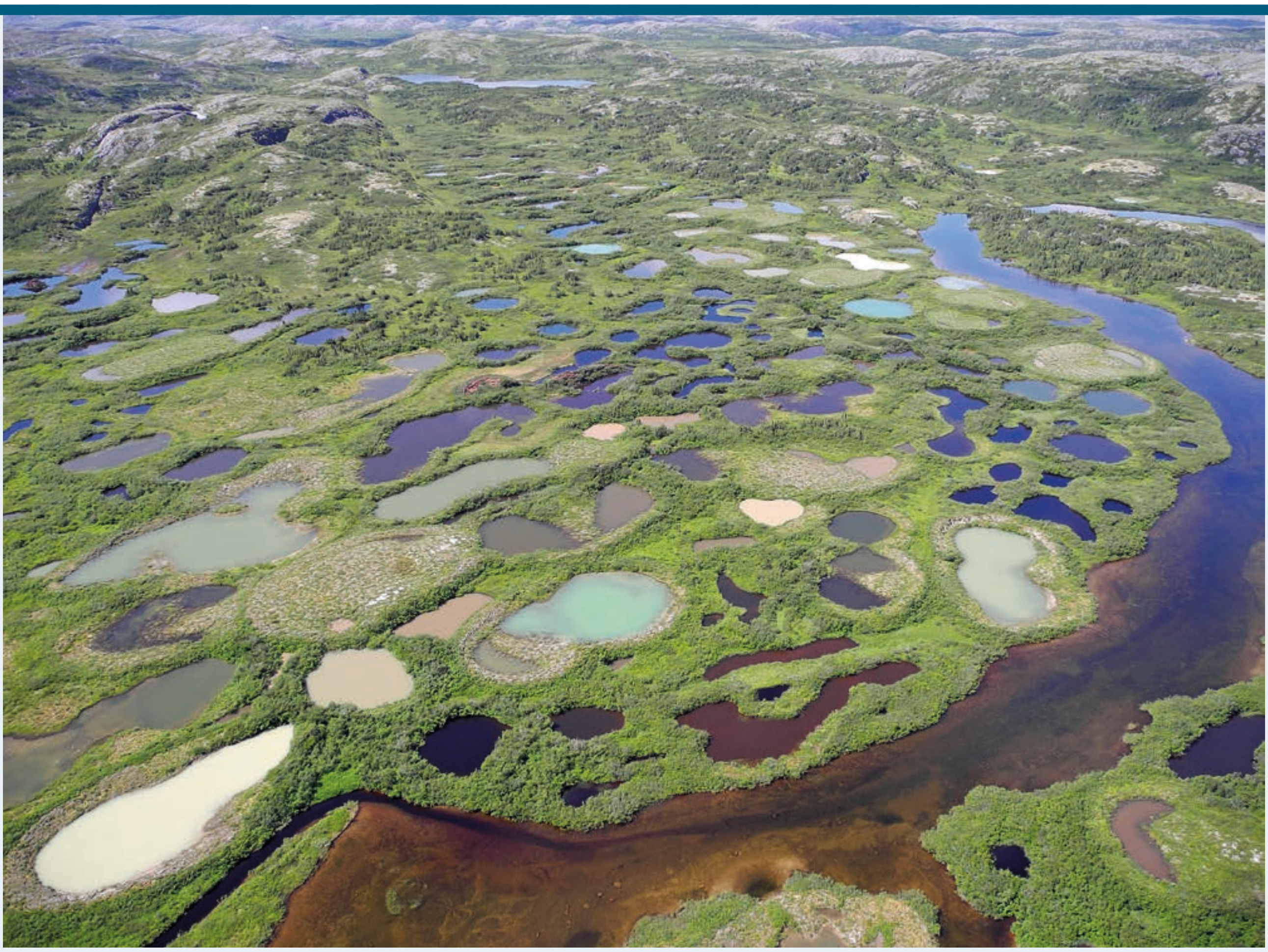


Figure 6.1 Lakes abound in the North and many, such as these near Umiujaq, sub-Arctic Canada, are affected by rapidly thawing permafrost (Warwick F. Vincent).

Figure 6.2 There is a great diversity of freshwater systems in the Arctic. The photo shows a glaciated rock-basin lake in Nunavik, sub-Arctic Canada (Warwick F. Vincent).

Figure 6.3 Lake Hazen, the deepest lake in the Canadian high Arctic (Warwick F. Vincent).

High latitude lakes also have broader global significance as sentinels as well as integrators of environmental change, and for this reason they are important sites for the study of climate fluctuations in the past by analysis of the preserved remains of plants, animals and microbes in their sediments (the study of *palaeolimnology*), as well as for monitoring climate warming and other changes that are taking place in the present at local, regional and planetary scales (Williamson and others 2009). Some northern freshwaters also affect adjacent ecosystems; for example the large Arctic rivers discharge massive quantities of water, solutes, particulate materials and heat into the Arctic Ocean; the large lakes of the North affect the thermal regime of their surrounding watershed; and *thermokarst* lakes (formed when permafrost thaws: see Sections 1 and 3 for lake formation and drainage) and wetlands (areas of seasonally water logged soils) may emit globally significant quantities of *greenhouse gases* into the atmosphere (Vincent and others 2013).

Northern freshwaters are of special significance to the people who live and work in the North, and whose health, cultural well-being and economic prosperity depend on these vital resources. Arctic and sub-Arctic waters provide many essential geosystem and ecosystem services for municipalities, industries and (increasingly) agriculture. These services include drinking water supplies, hydroelectricity, waste disposal and treatment systems, water for mining activities and resource extraction, transport routes (including the extensive networks of river and lake ice-roads in North America and Russia), traditional and recreational fisheries, and habitats for water fowl that are traditionally hunted such as ducks and geese. These economic, societal and cultural values are also setting many of the research priorities in parts of the circumpolar North such as northern Canada.

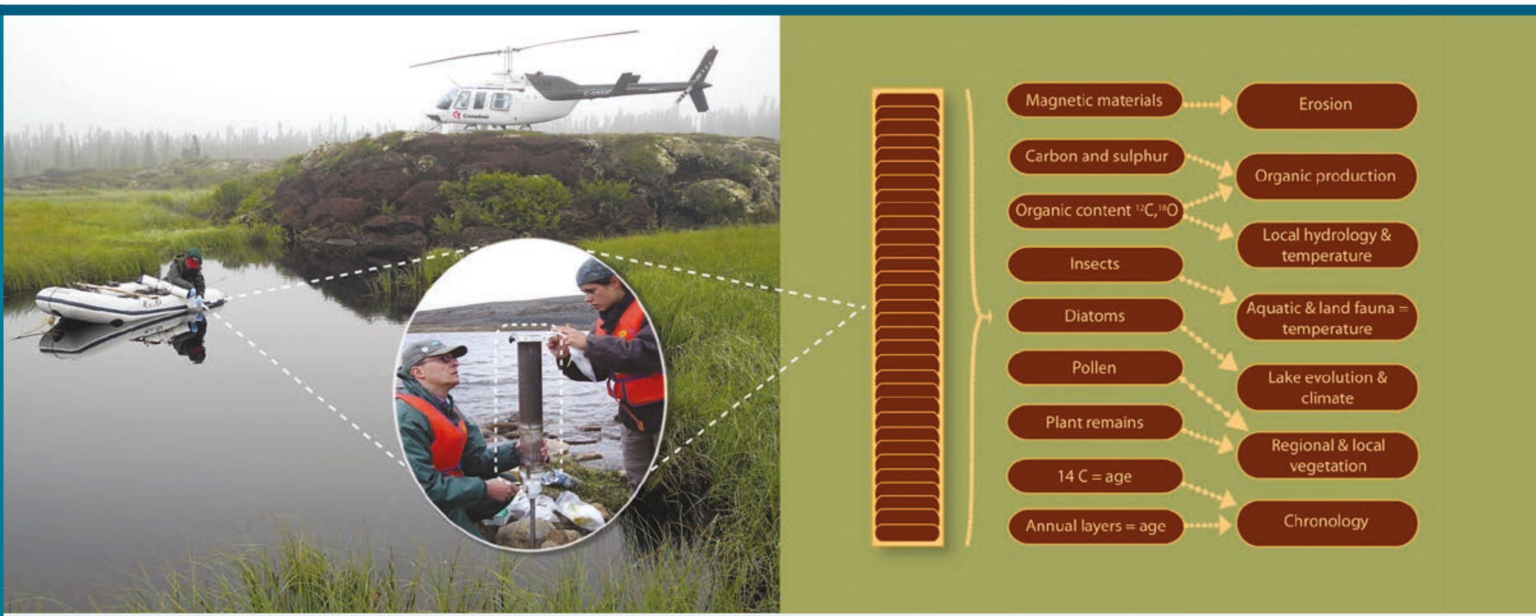
In this section we introduce some of the current themes and questions in northern freshwater research, including projects taking place through the INTERACT network of terrestrial field stations. We draw upon recent results about the physical, biogeochemical and biological characteristics of high latitude aquatic ecosystems, including reference to a subsample of INTERACT supported projects that are described in more detail below.

RECONSTRUCTING THE PAST

The bottom sediments of northern lakes provide a rich storehouse of information that can be used to describe and understand past variations in the environment (Hodgson and Smol 2008: see also Section 1). Many types of *sediment corers* are available for sampling lake sediments from a boat or through a hole in the lake ice (Figure 6.4), and the resultant core samples can be split into sections, dated with ^{14}C and ^{210}Pb (*radio-isotopes* of carbon and lead), or other techniques, and the environmental proxies then analysed in each section to reconstruct past conditions (Figure 6.5). Diverse microfossils are routinely measured in northern lake sediments by this palaeolimnological approach, including fossil *diatoms* (algae with silica walls), larval insect remains and pollen. Diatoms have proven to be especially informative given their enormous species diversity. By establishing relationships between the composition of modern diatom communities and the environment, models can be applied to convert the species composition of a fossil diatom assemblage into quantitative estimates of past conditions such as temperature, pH, phosphorus, dissolved organic carbon or even underwater UV radiation. A wide range of chemical constituents are also often analyzed including stable isotopes of carbon and nitrogen, heavy metals and other pollutants.

Figure 6.4 Drilling through lake ice on northern Ellesmere Island in the Canadian high Arctic, near the CEN Ward Hunt Island Research Station (•55) (Warwick F. Vincent).

The application of these palaeolimnological approaches has provided insights into lake development and ice cover, vegetation dynamics, climate and sea level change, fish and wildlife shifts, and the magnitude of local and long range pollution (Hodgson and Smol 2008). In the INTERACT project of Long and others (Science Story 6.1), sediment cores were taken from lakes at a site near the margin of the Greenland Ice Sheet to analyze variations in temperature over the last 6,000 years. A complementary INTERACT project by McGowan and others (Science Story 6.2) is examining sediment cores from lakes at Disko Bay, Greenland, to reconstruct lake and catchment processes during periods of warming and cooling over the last few thousand years.



Fgure 6.5 Left: paleolimnological analysis of a sediment core, for example from a thaw pond pond formed by a degrading *palsa* (permafrost mound) near the CEN Whapmagoostui-Kuujjuarapik Research Station (•61), sub-Arctic Canada. The core (middle) is split into sections and each section is then dated based on its radiocarbon (^{14}C) content. The different chemical and biological analyses (right) of these sections then provide information about historical changes in different features of the lake and its surrounding environment. Modified by Hannele Heikkilä-Tuomaala from Berglund and others 1996 (Warwick F. Vincent and Reinhard Pienitz).

Figure 6.6 Lake A in the Canadian high Arctic near the CEN Ward Hunt Island Research Station (•55). The lake had lost its perennial ice cover after a summer of record warming (August 2008) (Warwick F. Vincent).

Figure 6.7 Thawing permafrost resulting from experimental accumulation of snow (a) creates moist depressions and eventually thermokarst ponds (b) in the Swedish sub-Arctic. In contrast, in other areas ponds are draining and evaporating, for example on Disko Island, West Greenland between 1970 (c) and 2009 (d). (a) Margareta Johansson, (b and d) Torben. R. Christensen, (c) Terry V. Callaghan.

LAKE AND RIVER ICE

Prolonged ice-cover and persistent low temperatures are major features of all high latitude waters, and these properties influence the structure and productivity of their biological communities (Prowse and others 2011). The aquatic *biota* of these habitats must therefore be adapted to cold water conditions for growth and reproduction, and to the highly seasonal availability of solar radiation, from continuous darkness in winter to continuous sunlight in summer. The thick ice-cover greatly affects the availability of light for underwater photosynthesis, and also influences many other important features of the lake such as mixing of water layers and oxygen levels (Section 4). Several projects at INTERACT stations have examined changes in lake ice cover in the past and present, and long-term records are now available at some locations; e.g., >100 years for Lake Torneträsk at Abisko, Sweden. At many locations, ice cover is now decreasing in thickness and duration as a result of climate warming (Figure 6.6). For example, in the River Oulakajjoki near Oulanka Research Station (•17), Finland, there has been a reduction of ice cover by about 3 weeks in recent years (R. Paavola, unpublished data), and at Ward Hunt Lake near INTERACT's most northern station (CEN Ward Hunt Island Research Station (•55) in the Canadian high Arctic, the summer ice cover has thinned from >4 m to complete melt out over the last 60 years (Paquette and others 2015). Many questions remain about how changes in ice cover affect the functioning of Arctic aquatic ecosystems, and these will be an important focus of limnological research.

GREENHOUSE GAS EMISSIONS

Throughout the circumpolar Arctic, there is a major effort to understand the chemicals in northern lake waters, and the biological and mineral (geochemical, geophysical) processes that regulate them. One of the reasons for this intense interest in the chemical nature of northern lakes is their production of greenhouse gases (Section 4). This is especially the case for thermokarst lakes and ponds (small, shallow waterbodies) that form by the thawing and *erosion* of permafrost landscapes (Figure 6.7a) and ponds that drain (Figure 6.7c). Work throughout the North has shown that these waters are *biogeochemical hotspots* on the *tundra*, converting soil organic carbon (Science Story 6.3) to carbon dioxide and methane that are then released to the atmosphere (Vincent and others 2013). Many questions remain, for example about the role of

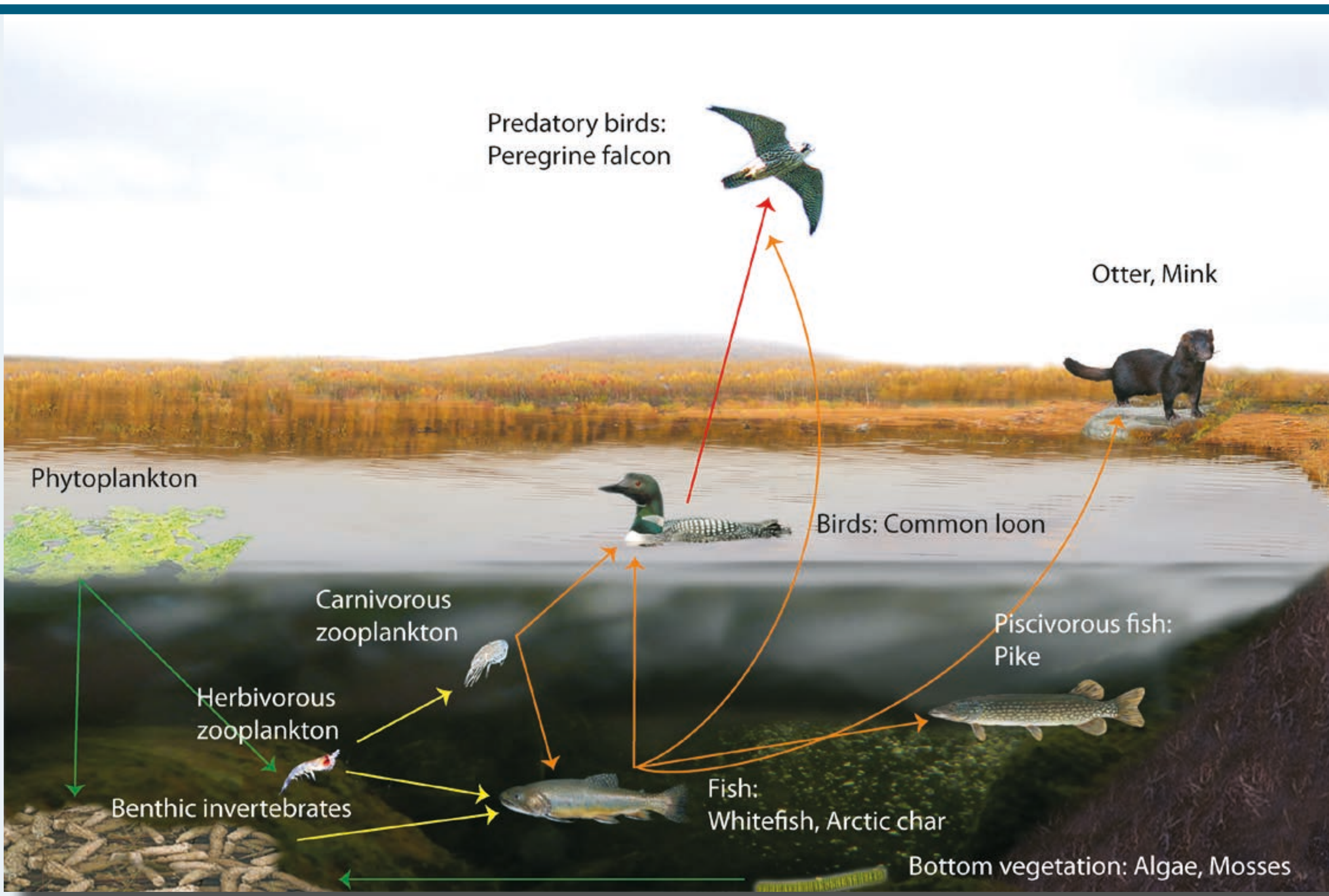


Figure 6.8 There is great inter-connectedness through food webs in Arctic lakes (left) and ponds (right). Deep lakes support fish but shallow ponds that freeze to the bottom in winter cannot. The primary production in the freshwaters even eventually supports wildlife on land (Modified by Hannele Heikkilä-Tuomaala from ACIA, 2005).

oxygen in controlling the net emission of methane, and concerning the seasonal, interannual and long-term variations in the abundance and activity of these microbe-rich ecosystems.

CHARISMATIC MICROFLORA

One of the rapidly emerging frontiers in polar ecology is the *biodiversity* and function of microbial communities. It has long been known that microbes are abundant and play key roles in the ecosystem, including *primary production*, control of gas fluxes and nutrient recycling, but it is only recently that microbiologists have become equipped with the necessary tools to address basic ecological questions such as: what types of microscopic life are present, how are they distributed, what is their function, and how do they respond to environmental change? Many of these questions are being answered by using new tools that are derived from breakthroughs in medical technologies, for example based on DNA analysis, and these approaches are now being applied with enormous success to aquatic environments throughout the world, including northern freshwaters. The result is that we are now entering an exciting new era of deep insights into the life support structures that underpin Arctic aquatic food webs (Figure 6.8) and ecosystems (Lovejoy 2013). Molecular approaches are also generating important insights into how pollutants are broken down and detoxified in natural waters. In the INTERACT study by Michaud and others (Science Story 6.4), microbial DNA techniques were applied to sediments affected by the Pasvik River, the largest river system in northern Fennoscandia. These analyses revealed the presence of bacteria capable of degrading *polychlorinated biphenyls*, a major class of potentially hazardous *persistent organic pollutants*.

Cyanobacteria ("blue-green algae") (Figure 6.9) are a microbial group of special interest in the Polar Regions because they often constitute a large fraction of the total *biomass* in freshwater ecosystems in both the Arctic and Antarctica, and many are *nitrogen (N_2)-fixers*, bringing new nitrogen into the ecosystem. These organisms tolerate a wide range of conditions of water availability, including short-term fluctuations, and they therefore also thrive in semi-aquatic habitats and intermittent flow regimes such as water tracks (Steven and others 2013). In the terrestrial environment, cyanobacteria are found on and even within rocks, and they occur over polar desert soils as biological crusts. The nature of these cyanobacterial communities, their photosynthetic activity and their influence on Arctic soil formation are the subjects of the project by Ventura

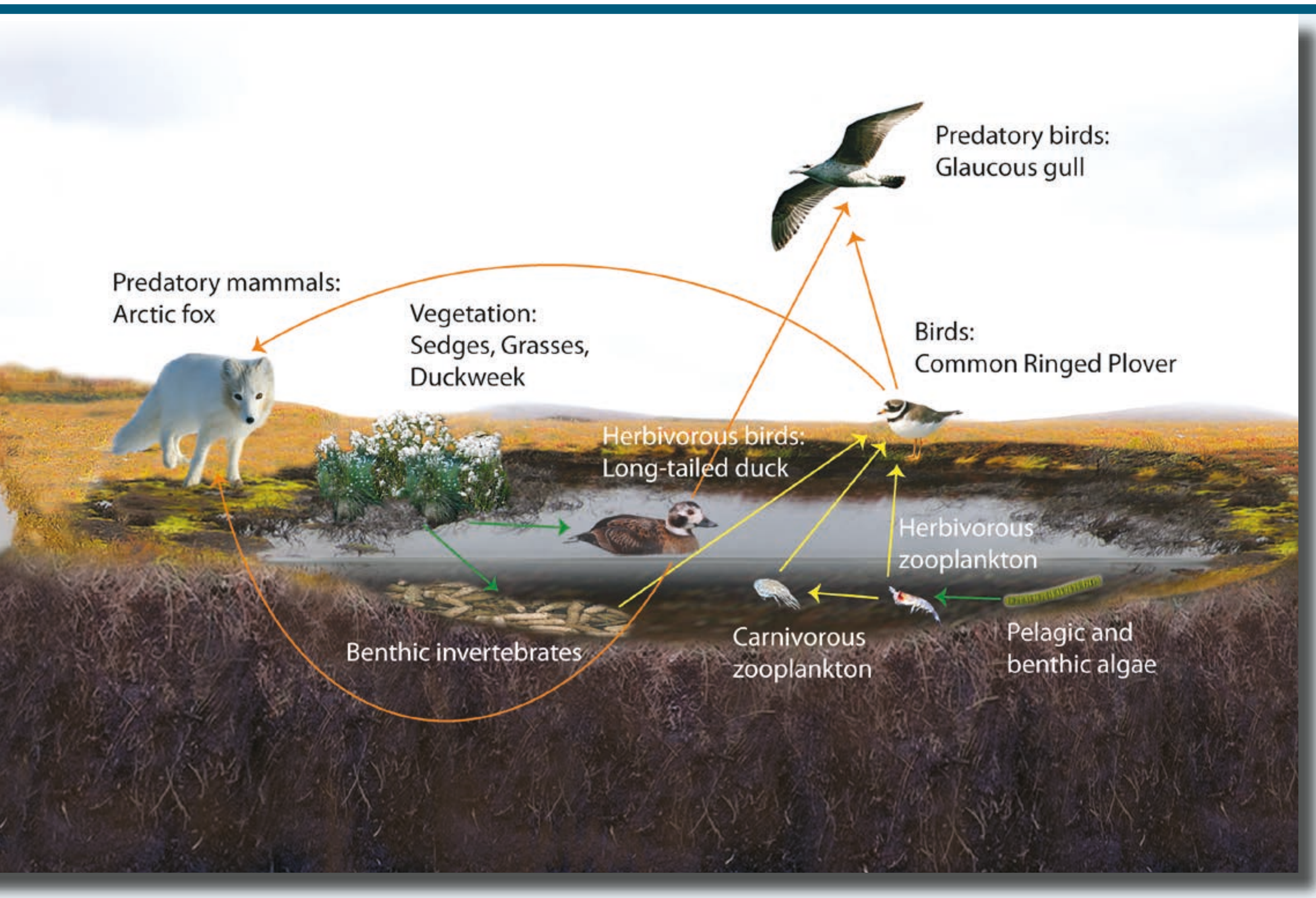


Figure 6.9 Photomicrograph of a nitrogen-fixing cyanobacterium (*Nostoc* colony) from the Canadian high Arctic (Warwick F. Vincent).

and others (Science Story 6.5), and sampling has taken place in a wide range of high latitude environments of different degrees of water availability. Cyanobacteria are also the focus of the project by Sabbe and others (Science Story 6.6), who visited Greenland to sample the prolific cyanobacterial *biofilms* that coat the bottom of Arctic lakes and to compare with similar biofilms from Antarctic lakes.

AQUATIC VEGETATION

When the Swiss natural historian François Forel founded the science of limnology at Lake Geneva in the 19th century, he described the inter-connectedness of all components of the ecosystem (Figure 6.8). One such component that he drew attention to was the underwater plant life distributed across the bottom of lakes, especially in the near-shore zone. He noted that some of these plant communities grew on the lake floor in such great profusion that "they form true underwater forests, as picturesque, mysterious and attractive as the most beautiful forests of our mountains" (Forel 1904). In northern lakes, mosses are often an important component of these "*underwater forests*", ranging from extensive *Sphagnum* bog communities in shallow waters and wetlands in the sub-Arctic, to slow growing but prolific moss stands in the deep cold waters of high Arctic lakes. Semi-aquatic plants such as *Carex* and *Eriophorum* are important elements of the tundra vegetation, and play biogeochemical as well as ecological roles, for example as methane conduits from the sediments to the atmosphere.

Forel (1904) noted with some alarm the arrival of the Canadian water weed *Elodea canadensis* in Lake Geneva, and its "exuberant and frightening expansion" throughout the lake. Unfortunately, this invasive species is now also well established in Finland where its growth has proven difficult to manage (Huotari and others 2011), and the sub-Arctic lakes of Fennoscandia may be increasingly prone to invasion by this species. The ecological impacts of invasive plants and animals will likely be important themes of aquatic research in the future as the lake and river environments continue to warm and temperate species move northward, aided by increased human activity and transport.

COLD-LOVING ANIMALS

Many species of invertebrates and vertebrates thrive within the cold waters of northern aquatic ecosystems, and their vulnerability to warming is a source of increasing concern. Work at INTERACT stations has especially focused on insects, zooplankton and wetland birds (Figure 6.10), but research on freshwater fish (Figure 6.11) and aquatic mammals, including freshwater seals, are also the subjects of ongoing projects. There are large uncertainties about how these animals will respond to increased temperatures in the future, with some species likely to move further northwards, while others may be driven to extinction by physiological stress and competition by invading species from the South. For example, stone flies (Plecoptera) prefer cold water streams and unlike many *taxa*, their species richness increases with latitude (Palma and Figueroa 2008). They may therefore be prone to warming, although this may be offset in part by increased terres-

Figure 6.10 Greater snow goose near the CEN Bylot Island Field Station (•56). The wetlands in this region have the largest breeding colony of this species in the Canadian high Arctic (Nicolas Bradette).

Figure 6.11 Arctic char caught at lac Laflamme in sub-Arctic Canada (Reinhard Pienitz).

trial vegetation and leaf litter as a food source. Arctic Char (*Salvelinus namaycush*) (Figure 6.11), a member of the salmon family, is nutritionally and culturally important to *Inuit* communities, and is a cold-adapted fish species that is restricted to low temperature, highly oxygenated waters. Increased lake production and food availability could stimulate the growth of this species, but changes in temperature, oxygen and migration patterns may counter such effects (Power and others 2008).

Key messages and needs for further research

- From microbes to fish and waterfowl, northern lakes and rivers contain many cold-dwelling species of great biological, ecological and resource use interest.
- These aquatic environments are biogeochemical reactors that convert tundra carbon to greenhouse gases, and they are sentinels and integrators of environmental change in the past and present.
- Arctic freshwaters are also a vitally important resource for northern indigenous communities.
- Given the abundance of these ecosystems, their wide ranging importance, and the many questions that relate to them, freshwater ecology will continue to be a major research focus well into the future, particularly as these northern waters continue to respond to the warming Arctic environment.

Further information and references

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