Conservation of Arctic Flora and Fauna

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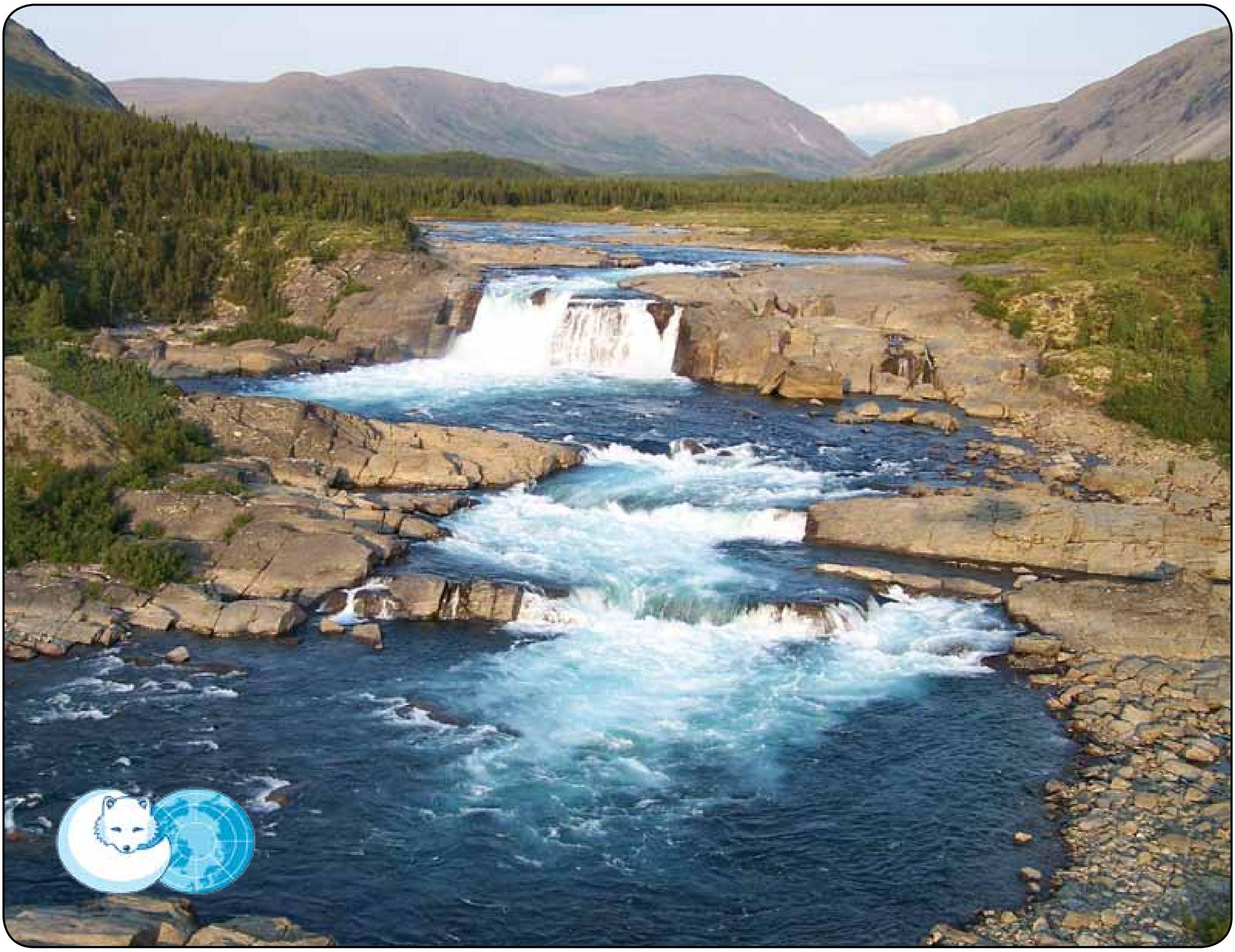
Freshwater Expert Monitoring Group

Report of the CBMP FEMG Workshop: Uppsala, Sweden, November 22-25, 2010



Acknowledgements

CAFF Designated Agencies:

- Directorate for Nature Management, Trondheim, Norway
- Environment Canada, Ottawa, Canada
- Faroese Museum of Natural History, Tórshavn, Faroe Islands (Kingdom of Denmark)
- Finnish Ministry of the Environment, Helsinki, Finland
- Icelandic Institute of Natural History, Reykjavik, Iceland
- The Ministry of Domestic Affairs, Nature and Environment, Government of Greenland
- Russian Federation Ministry of Natural Resources, Moscow, Russia
- Swedish Environmental Protection Agency, Stockholm, Sweden
- United States Department of the Interior, Fish and Wildlife Service, Anchorage, Alaska

CAFF Permanent Participant Organizations:

- Aleut International Association (AIA)
- Arctic Athabaskan Council (AAC)
- Gwich'in Council International (GCI)
- Inuit Circumpolar Conference (ICC) – Greenland, Alaska and Canada
- Russian Indigenous Peoples of the North (RAIPON)
- Saami Council

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Conservation of Arctic Flora and Fauna

CBMP

CAFF Designated Area

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Executive Summary

The CAFF-CBMP Freshwater Expert Monitoring Group (FEMG) was formed in January 2010 to facilitate an integrated, ecosystem-based approach to the monitoring of Arctic freshwater biodiversity. This report summarizes the outcomes of the first international meeting of the FEMG, which was held in Uppsala, Sweden on November 22-25, 2010. Steering Group members and national freshwater monitoring experts identified ecosystem components and processes that should be included in the development of a multi-disciplinary, integrated pan-Arctic monitoring plan describing optimal sampling schemes, common parameters and standardized monitoring protocols. The parameters of primary focus for this plan were classified as Focal Ecosystem Components (FECs), which are biotic or abiotic elements such as taxa or key abiotic processes that are ecologically pivotal, charismatic or sensitive to changes in biodiversity. The identification of FECs allowed participants to focus their discussions on key environmental drivers (e.g., temperature regime) and anthropogenic stressors (e.g., climate change, contaminants, etc.) that have a primary influence on basic biotic components, processes or ecosystem services. A critical part of this process was the development of impact hypotheses, as these narrative statements outline a cause-effect framework regarding how change in environmental drivers and stressors is expected to affect FECs. Development of the hypotheses facilitated discussions surrounding the choice of key variables that should be monitored as components of indices and/or metrics. Workshop participants also identified focal areas for monitoring across the circumpolar countries, with promising areas identified based on factors including data availability, environmental sensitivity and importance to humans. During the workshop, participants reviewed the feasibility of biotic and abiotic FECs for FEMG assessments in terms of data availability and importance based on their ability to detect changes in stressor levels. Gaps in the spatial and temporal coverage of specific FECs across the Arctic countries were also identified. Results from this inaugural FEMG workshop will serve as the core data and conceptual framework upon which the Integrated Monitoring Plan for Arctic freshwaters will be built.

Introduction

Arctic freshwater ecosystems are facing unique challenges through the interactions of natural and human-induced stressors such as climate change and industrial development. Biodiversity is expected to be affected; however, a pan-Arctic monitoring strategy is not in place and is critically needed to improve our ability to detect changes in these systems and understand the causes of these changes. Several of the key challenges that Arctic freshwater monitoring is facing include: the large diversity of Arctic freshwater ecosystems; varying levels of impact of stressors across the Arctic; limited involvement of Arctic peoples in monitoring; lack of research and monitoring coordination; incomplete and irregular monitoring coverage insufficient to detect long-term trends; and poor standardization of sampling protocols.

The CAFF-CBMP Freshwater Expert Monitoring Group (FEMG) was formed in January 2010 to facilitate an integrated, ecosystem-based approach to the monitoring of Arctic freshwater biodiversity. The FEMG is co-led by Canada and Sweden; its steering group includes members from the CBMP Secretariat, Canada, Denmark/Greenland, Finland, Iceland, Norway, Russia, Sweden, USA and two Permanent Participants, the Arctic Athabaskan Council (AAC) and the Gwich'in Council International (GCI). It will support the development of a multi-disciplinary, integrated, pan-Arctic monitoring plan that would include optimal sampling schemes, common parameters and standardized monitoring protocols. This plan will identify critical monitoring gaps, develop strategies to fill gaps, and provide inventories of existing Arctic biodiversity monitoring activity. The output of this monitoring plan will inform the public and policy makers through the completion of periodic assessments on the state of Arctic freshwaters. The FEMG will use existing monitoring data, draw on expertise from relevant disciplines (e.g., climate science), incorporate both community- and science-based approaches, develop standardized protocols and analytical tools, and use existing and emerging technologies, such as remote sensing and genetic bar-coding, where appropriate.

Workshop participants

Workshop Design and Approach for Developing an Integrated Monitoring Plan

The first international meeting of the Freshwater Expert Monitoring Group (FEMG) was held in Uppsala, Sweden on November 22-25, 2010. Steering Group members and national freshwater monitoring experts were assigned to Lake or River working groups such that each group had broad ecological and taxonomic expertise. The workshop began with an overview presentation on the CBMP and objectives of the FEMG, followed by breakout group discussions that produced the primary output of the workshop. This information included: recommendations on the required elements of a freshwater monitoring program; information on the approaches to be used in monitoring these freshwater ecosystems; discussions related to the type of trends and changes that should be detected; and a list of key biodiversity indicators, supporting variables, and approaches to coordinated data management and reporting.

The Marine Expert Monitoring Group (MEMG) had successfully applied an adaptive environmental assessment and management approach as a method to guide workshop discussions, and the FEMG adopted the MEMG methodology. This approach identifies Focal Ecosystem Components (FECs), which are biotic or abiotic elements, such as taxa or key abiotic processes that are ecologically pivotal, charismatic or sensitive to changes in biodiversity. The identification of FECs allowed participants to focus their discussions on key environmental drivers (e.g., temperature regime) and anthropogenic stressors (e.g., climate change, contaminants, etc.) that have a primary influence on basic biotic components, processes or ecosystem services. A critical part of this process was the development of impact hypotheses, as these narrative statements outline a cause-effect framework regarding how change in environmental drivers and stressors is expected to affect FECs. Development of the hypotheses facilitated discussions surrounding the choice of key variables that should be monitored as components of indices and/or metrics. Workshop participants also identified focal areas for monitoring across the circumpolar countries, with promising areas identified based on factors including data availability, environmental sensitivity and importance to humans. During each workshop session, participants recorded a consensus of their discussions in detailed information tables. These tables form the primary data produced by the workshop and are summarized below for the Lakes and Rivers sections. It was decided during the workshop that the FEMG should consider wetlands as extensions of lake and river habitats following the previous decisions and definitions of the Ramsar Convention (Ramsar Convention Secretariat 2006).

The primary outcomes of the workshop included:

1. A clear set of monitoring objectives;
2. Identification of the focal ecosystem components that are ecologically pivotal or sensitive to changes in biodiversity;
3. Development of hypothesis statements regarding the relationship among important drivers, stressors and ecosystem responses;
4. Completion of an overview of existing and recent monitoring programs that could provide data for assessments;
5. Recommended variables for use in monitoring and as assessment indicators; and
6. A draft table of contents for an Integrated Monitoring Plan for Arctic freshwaters.

In the sections below, we briefly summarize Tables 1-12 that contain workshop results for the Lake and River groups and provide timelines for future work. In addition, we provide a list of participants (Appendix A), the workshop agenda (Appendix B), a draft table of contents of the CAFF-CBMP FEMG Integrated Monitoring Plan (Appendix C) and an overview of available data for Arctic freshwaters (Appendix D and E).

Lake Ecosystem Results

Biotic Focal Ecosystem Components (FECs) and the rationale for including each FEC in monitoring programs were identified in the initial discussions by the Lake Group (Table 1). For example, fish species were identified as an FEC that integrates the flow of energy and contaminants, provides food for human populations, and supplies information about linkages to other habitats. Table 1 contains similar information for lower trophic level FECs and a qualitative estimate of the difficulty of measurement for each FEC (classified as low, medium or high). Future discussions should aim at linking biotic FECs to one or more specific stressors and include an analysis of their inherent type-1 and type-2 errors.

Table 2 contains information on important abiotic FECs, the rationale for measuring these FECs, and the difficulty of measurement. Several weather/climate-related variables were identified as important abiotic FECs, but participants also recognized a number of in-lake physical-chemical variables that reflect contaminant levels and that are indicators of climate-change- or human-induced changes in the catchment. For example, an increase in concentrations of dissolved organic carbon would indicate a larger share of deep run-off to lakes, thus negatively affecting light penetration and the extension of benthic primary production in lakes. Workshop participants recognized that several of these physicochemical variables show high temporal variation, requiring multiple sampling occasions during a single season, and thus complicating their use in monitoring programs.

Tables 3 and 4 summarize what workshop participants acknowledged as relevant environmental and human-induced stressors, respectively. For each of these stressors, expected response relationships with FECs were expressed in specific impact hypotheses. For example, permafrost degradation was expected to result in increased sediment loads and turbidity of lakes, thus negatively affecting the light climate of lakes, as well as photosynthesis, and the structural and functional diversity of communities (Table 3). Among human-induced stressors, effects of increased resource exploration/exploitation (e.g. mining of metals or hydrocarbons, oil/gas) were hypothesized to result in increased levels of municipal discharge and concentrations of contaminants, resulting in shifts in nutrient enrichment and toxic stress, respectively, and inducing shifts in aquatic communities (Table 4).

Workshop participants of the Lake Group also produced a list of biotic and abiotic parameters and indicators that have potential for monitoring and detecting change in FECs of Arctic lakes. Parameters and indicators for biotic FECs were divided into three groups reflecting structural, functional, and phenological changes, respectively (Table 5). The indicators of structural changes in FECs include taxon richness, diversity, and evenness, but also the establishment of new taxa. Functional indicators include functional feeding groups, ecological traits of taxa, and shifts in trophic pathways determined from stable isotope analyses. Phenological indicators quantify, for example, changes in the timing of emergence in insect populations, and changes in the size/age structure of fish populations. Abiotic indicators include those that signify change in the temperature regimen of lakes and climate-induced changes in catchment land-use and hydrology (Table 6). Besides a set of physico-chemical and climatic parameters, workshop participants identified stable isotopes as a means to detect changes in catchment hydrology and run-off patterns. Note that the data in the tables do not reflect any priority order.

River Ecosystem Results

Biotic Focal Ecosystem Components (FECs) for river ecosystems and the rationale for including each FEC in monitoring programs are described in Table 7 along with a qualitative estimate of how difficult each FEC will be to assess. The FECs are structural ecosystem components such as taxonomic groups (e.g., fish, benthic invertebrates, aquatic plants) or functional components related to important processes (e.g., community metabolism or trophic structure of food webs). Participants agreed that structural FECs are easier to measure; they also are more likely to have been measured throughout the Arctic. Structural FECs, including fish, benthic invertebrates and benthic algae, often are primary elements of bioassessment programs and as such may be important FECs for consideration as components of the Integrated Monitoring Plan. Migratory fish were identified as the FEC of most direct importance to humans. Although migratory fish were ranked as medium to high in terms of measurement difficulty, they provide important information on the local environment in addition to linkages with other environments (e.g., freshwater, estuary linkages) and food web connectivity. Other structural FECs, including benthic algae and invertebrates, have less direct importance to humans but are critical components of the food webs that supply energy to fish. Finally, although functional FECs may be more difficult to measure, they could be excellent monitors of environmental alteration if simple methods of measurement can be developed (e.g., emerging remote sensing and in situ data logging techniques).

A large number of abiotic FECs were identified (Table 8). These include the hydrological regime, water chemistry variables (i.e., nutrients and other materials in transport), and the water temperature regime and associated variables (e.g., ice freeze-up and breakup regimes). Although FECs such as the hydrological regime can be difficult to measure if discharge gauging stations are not established, governments often have hydrological networks that can provide important long-term data sets for use in assessments. Similarly, water quality data sets may provide important supporting information to the FEMG.

The potential effect of environmental stressors on key riverine FECs was established through a set of impact hypotheses that describe the expected response relationships of the FECs to various stressors (Table 9). For example, a change in nutrient regime from permafrost degradation is expected to increase nutrient loading from the landscape. Higher nutrient loading to oligotrophic Arctic freshwaters would likely increase primary producer abundance and productivity with associated changes in plant community composition. The complete list of priority stressors includes shifts in hydrological, thermal, sediment and nutrient regimes, as well as freshwater acidification through the atmospheric deposition of SOx and NOx.

Many modifications to Arctic river biodiversity will occur as a direct result of increased development and human population growth (Table 10). This group of stressors includes over-harvesting and introduction of species, resource exploration and exploitation, road building and flow alteration (e.g., hydropower, dams). One example is that of overharvesting of fish species that may lead to alteration of population structure and abundance. Such population shifts can cause adjustments in population age and size structure as well as changes in community composition.

A list of parameters and indicators that have potential for monitoring and detecting change in biotic and abiotic FECs of Arctic rivers was produced by the River Group (Tables 11 and 12). Biotic indicators included those that could be used to assess change in the broad categories of structural, functional and phonological FECs. Abiotic indicators included numerous physical and chemical variables covering a range of spatial scales (e.g., thermal regime at designated sites, catchment characteristics such as reach slope and landuse). The data in the tables are not listed in any order of priority.

Review of Biotic and Abiotic Data for Arctic Lakes and Rivers

During the workshop we reviewed the feasibility of biotic and abiotic FECs for FEMG assessments in terms of data availability and importance based on their ability to detect changes in stressor levels. Gaps in the spatial and temporal coverage of specific FECs across the Arctic countries were also identified. In general, for both rivers and lakes, biotic FECs that integrate the environmental conditions over time show a larger feasibility for monitoring purposes than those that show high temporal variability, although the latter have a large potential as early-warning indicators (Table 13). Additionally, functional FECs such as community metabolism, decomposition, and trophic structure were regarded as having low feasibility for monitoring, as they may show large temporal variability and the lack of available data. Feasibility, importance, and gaps were frequently similar for lakes and rivers, except for planktonic communities that are lake-specific and lack importance in rivers. The workshop identified that large data gaps exist for several of the biotic FECs. Furthermore, major differences were noted in the methods of sampling (e.g., effort) and analysis (e.g., taxonomic resolution). Among the abiotic FECs, many hydrological, physicochemical, and climatic parameters were judged to have a high feasibility due to relatively good access to data, and to be highly important for quantifying change in Arctic rivers and lakes (Table 14). Workshop participants recognized stochastic events as important scene-setting factors and drivers that could have a high impact on ecosystems. However, this type of event is difficult for monitoring programs to address unless sample locations serendipitously coincide with the event location.

FEMG Timelines and Future Objectives

Results from this inaugural FEMG workshop serve as the core data and conceptual framework upon which the Integrated Monitoring Plan for Arctic freshwaters will be built. A second workshop will be held in Canada during Autumn 2011 with the primary aim for this meeting being the selection of variables, metrics and methods for the monitoring plan, as well as the development of a short list of candidate lakes and rivers to be included in the initial pan-Arctic assessment. Following the second workshop, the FEMG will complete a draft of the plan by Spring 2012 and submit it for review by external science experts and the CAFF Board. We anticipate that the Freshwater Integrated Monitoring Plan will be ready for review by the Senior Arctic Officials of the Arctic Council in early 2013.

Timeline

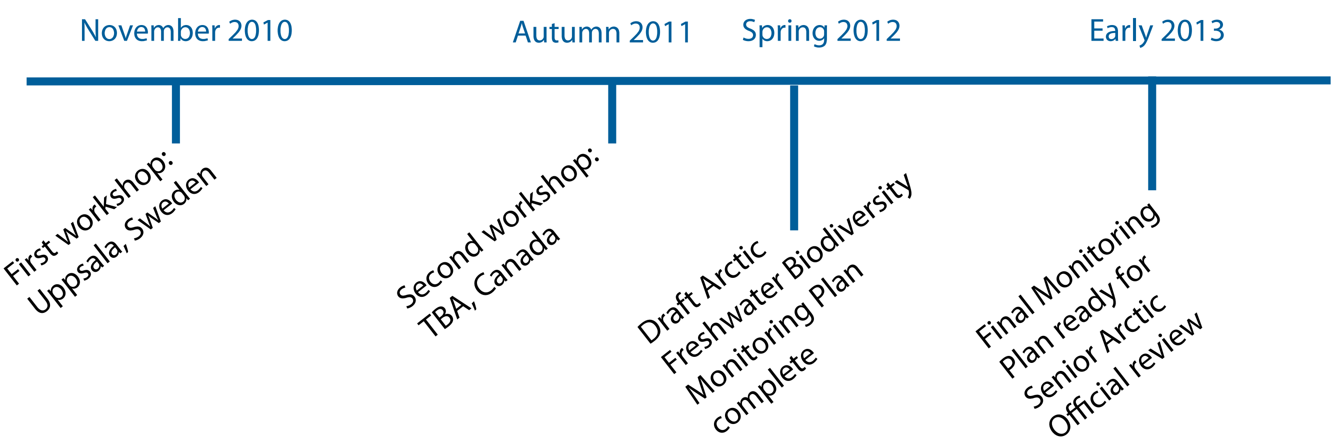


Table 1

Biotic Focal Ecosystem Components (FEC) for lake ecosystems and the rationale for including each FEC in monitoring programs. A qualitative estimate of the difficulty of measurement is provided for each FEC.

Focal Ecosystem Component (FEC)	Rationale (why are we interested?)	Difficulty of measurement?
Structural		
Fish	• Important for biodiversity and food webs; integrated indicators of energy flows, contaminants, etc. • Food for humans • Reflect marine subsidies in migrating populations (e.g. anadromous fish) and provide information on linkages between environments (e.g., freshwater, estuary linkages) • Make use of wetlands as periodic habitat	Low - medium (electrofishing or trapping)
Benthic invertebrates	• Sensitive to many environmental stressors, wide range of tolerances • Integrate a great deal of biodiversity • Food for higher trophic levels, important consumers and secondary producers in the food web • High spatial resolution • Important intermediate host for parasites	Low – medium (collection low, particularly if sample cores used; processing/ identification can be difficult/ costly)
Zooplankton	• Food for higher trophic levels, important consumers and secondary producers in the food web • Size structure reflects temperature changes	Low – medium (collection low, processing/ identification more difficult)
Phytoplankton and benthic algae	• Base of the food web; major source of primary production in Arctic • Respond quickly to both natural and anthropogenic changes; compositional shifts and changes in abundance strongly connected to changes in chemistry, temperature, ice cover, light, etc.	Low – medium (collection low, processing/ identification more difficult)
Bacteria and fungi	• Important for decomposition processes • Reflect changes in catchment characteristics	Low – medium (collection low, processing/ identification more difficult)
Pathogens	• Reflect natural and anthropogenic changes • Shifts in abundance/composition have implications for abundance and composition of other FECs	Low (if pathogens are known)
Macrophytes	• Base of the food web; contribute to primary production • Provide habitat structure for macroinvertebrates, and their presence can affect macroinvertebrate communities (density, structure) • Respond quickly to both natural and anthropogenic changes	Low (easy to sample and identify, but quantitative may be difficult)
Riparian vegetation	• Base of the food web; contribute to primary production • Chemical filter and physical stabilizer of banks • Corridor and habitat for fish and vertebrates	Low (season is important, but method is easy)

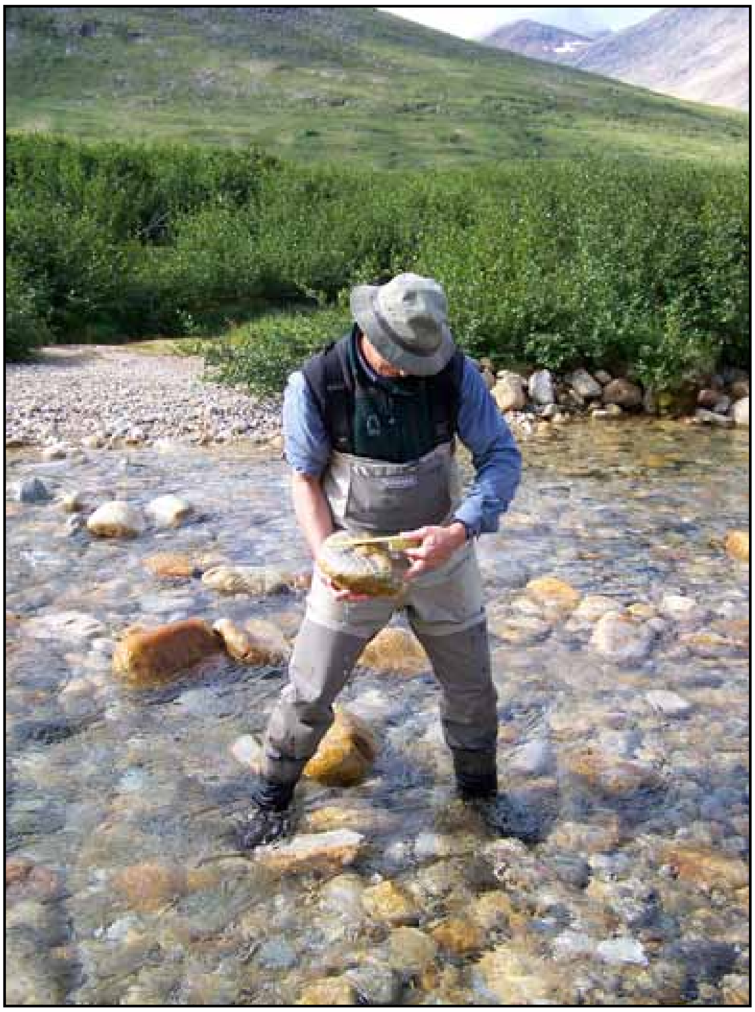
Focal Ecosystem Component (FEC)	Rationale (why are we interested?)	Difficulty of measurement?
Aquatic birds (waterfowl, shorebirds, etc.)	• Make use of aquatic habitat • Food source for humans • Feed on fish	Low (season is important, but method is easy)
Aquatic mammals (seals, muskrats, beavers, etc.)	• Important for human populations • Feed on fish	Low (season is important, but method is easy)
Red-listed taxa (potentially included in general biodiversity)	• Indicator of ecosystem health • Sensitive metric • Policy links • Overall number of species in an area and change in number may indicate general ecosystem health, but most appropriate species would be those that are key to ecosystem function and those that are regionally endemic	Low (assuming regional assessments are done under regular cycles)
Functional		
Community metabolism	• Important aspect of ecosystem function (rates of primary production and community respiration) • Sensitive to changes in key drivers and stressors (e.g., temperature and nutrients) • Informs about fish diversity and species relative abundance • Changes to production in the system alter fish production and shifts fish population or size structure (also relevant to other ecosystem components)	Medium – high (method is easy, but equipment is expensive if deploying meters)
Decomposition	• Integrates microbial and macroinvertebrate community function • High seasonal roles of wetlands in decomposition and carbon fluxes	Medium (Requires at least 2 visits to the site to deploy and retrieve cotton strips)
Trophic structure/ energy flow/ food webs e.g., stable isotopes	• A measure of ecosystem function and connectivity • Identifies keystone species • High quality information • Signal may be best in simple food webs that aren't as resistant to change	Medium – high (Costly, large amount of processing, large number of samples required)

Table 2

Abiotic Focal Ecosystem Components (FEC) for lake ecosystems and the rationale for including each FEC in monitoring programs. A qualitative estimate of the difficulty of measurement is provided for each FEC.

Focal Ecosystem Component (FEC)	Rationale (why are we interested?)	Difficulty of measurement?
Hydrological regime (water quantity, temporal variability, and groundwater and soil surface water level)	• Affects habitat quantity/availability • May be affected by drivers or stressors • Groundwater and soil surface water level are the driving factors for lacustrine wetland habitat • Highly responsive to terrestrial landscape use activities	Low (if data are being collected by government, etc.) to high (if you have to establish new stations)
Water quality • TN/TP – nutrients • DOC • pH • Alkalinity • Sulphur • Metal contaminants (e.g., Hg) • TSS, TDS, turbidity • Persistent organic pollutants • Salinity	• Relates to ecosystem health, habitat quality • Driver and potentially a responder to biodiversity change • Storage and release of elements and contaminants (e.g., sulphur) in wetlands has impacts on lakes • Affects nutrient availability and light penetration; may lead to effects on primary and secondary productions	Medium – high (depending on which variables and number of variables being measured; temporal variation of parameters requires seasonal and inter-annual sampling)
Solar radiation (including UV)	• Affects thermal regimes (e.g. ice cover and stratification) and groundwater inputs of lakes • Affects primary production • Affects water mixing • Determines habitat quality	Medium (not difficult, but expensive)
Climate variables (air temperature, precipitation, etc.)	• Affects hydrological regime and ice breaks • Affects water temperature regime (e.g., ice cover and stratification) • Affects permafrost	Low (if data are being collected by government, etc.) to high (if you have to establish new stations)
Water temperature regime	• Affects species composition • May be affected by drivers or stressors • Spatial coverage ranges from individual loggers to remote sensing techniques	Low – medium (low cost/effort, but loggers require retrieval)
Ice regime (break-up and freeze-up dates)	• Related to hydrological and water temperature regimes, solar radiation • Affects community composition/ development	Low (may be available from local knowledge)
Wind	• Affects circulation • Affects habitat quality (e.g., wave actions) • Determines ice on/off	Low (if data are being collected by government, etc.) to high (if you have to establish new stations)

Focal Ecosystem Component (FEC)	Rationale (why are we interested?)	Difficulty of measurement?
Catchment characteristics (e.g., catchment area, slope, elevation, surficial geology, groundcover)	• Indicator of habitat stability, habitat quality • Related to temperature regime, hydrological regime, etc.	Low – medium (can obtain through GIS and water chemistry)
Permafrost level	• Driving factor for existence of wetland habitat • Changes may affect water quality	Low (but could be expensive; requires installation of equipment to measure the level)
Stochastic events (e.g., volcanism, landslide, avalanches)	• Affects dispersal • Affects habitat quality and availability	High (in terms of prediction and logistics)



Freshwater monitoring in the Canadian Arctic
Photo: Joseph Culp

Table 3

List of key environmental stressors and impact hypotheses describing expected impacts of stressors on focal ecosystem components of lakes

Stressor	Example impacts
Atmospheric deposition of short and long range contaminants	Alteration of water chemistry → increased uptake and biomagnification → toxic stress at high trophic levels and human exposure, selection for contaminant tolerant taxa
Shift in hydrological regime	Changes in precipitation, snowpack quantity, ice on/ice off → increased/decreased lake levels, altered runoff and terrestrial organic matter inputs, increased Thermokarst processes (lake loss or formation) → change in habitat (e.g., shift in littoral zone and macrophyte zone), increased nutrient availability, change in light regime → shift in community composition and functional diversity, change in productivity
	Changes in snowpack structure and quantity on lake ice → altered thermal regime through change in insulation and light regime → altered habitat through change in light penetration and ice thickness → shift in community composition and functional diversity, change in productivity
Shift in thermal regime	Increased water temperature → stratification [diurnal thermoclines] → changes in photosynthesis/respiration balance; shifts in carbon sources, sinks, and availability; changes in sediment-water interactions → changes in phenology, food availability and quality, biomass and decomposition mass, decreases in cold stenotherms (algae, benthic macroinvertebrates, fish), range alteration for cold-intolerant taxa → increased competition, predation, parasites, and diseases from geographic range changes → shift in community composition and functional diversity, change in productivity
Shift in sediment regime (e.g., permafrost degradation)	Increased turbidity → decreased light → changes in photosynthesis/respiration balance → shift in community composition and functional diversity, change in productivity
Shift in nutrient regime (e.g., from permafrost degradation)	Nutrient enrichment → increased nutrient availability and decreased light → changes in food availability and quality → shift in relative importance of benthic and pelagic processes, microbial food web hanges, shift in community composition and functional diversity, change in productivity
Atmospheric deposition of SOx and NOx (acidification)	Alteration of water chemistry (decreased pH and calcium, released aluminum) → increased uptake of aluminum, toxic stress, loss of calcium-dependent taxa → shift in community structure and productivity
Shift in UV radiation	Increased UV → increase in reactive oxygen species → reduced UV-sensitive species and increased UV-tolerant species → shift in species composition and interactions (specific to small, shallow, and clear lakes)
Shift in wind action	Increase/decrease in wind force → change in snow formation pattern (e.g. ice on/off, period of ice cover), increased/decreased water circulation → change in habitat, lake mixing, thermal regime, stratification → shift in community structure and primary productivity
Shift in nutrient and contaminant levels due to biotic vectors (e.g., birds)	Increased populations of biota (e.g., migratory birds, salmon) → altered deposition of nutrients and contaminants to water → nutrient enrichment and alteration of water chemistry → increased primary producer abundance, increased uptake and biomagnification of contaminants → shift in community composition and functional diversity, change in productivity, toxic stress at high trophic levels and human exposure, selection for contaminant tolerant taxa

Table 4

List of key stressors related to human population growth and impact hypotheses describing expected impacts of stressors on focal ecosystem components of lakes.

Stressor	Example impacts
Over-harvesting (new stock / unsustainable fisheries)	Alters population structure/abundance → potential for trophic cascades → shifts in community composition and age/size structure, selection against fast-growing genotypes in harvested populations
Resource exploration/ exploitation (e.g., from mining - metals, hydrocarbons, oil/gas and forestry)	Municipal discharge → nutrient enrichment/eutrophication → increased nutrient availability and decreased light → changes in food availability and quality → shift in relative importance of benthic and pelagic processes, microbial food web changes, shift in community composition and functional diversity, change in productivity
	Water abstraction → reduced water levels → change in habitat (e.g., shift in littoral zone and macrophyte zone) → shift in community composition and functional diversity, change in productivity
	Increase in contaminants (including accidental spills) → alteration of water chemistry → increased uptake and biomagnification → toxic stress at high trophic levels and human exposure, selection for contaminant tolerant taxa
	Salinization → alteration of water chemistry → shifts in community composition, selection for saline-tolerant taxa
Linear structures (e.g., roads, powerlines, culverts)	Altered overland flow regime → increase in sedimentation/contaminants (e.g., salt, oil) → altered habitats, loss of diversity and species composition, selection for contaminant tolerant taxa
	Increased access to formerly inaccessible areas → increased harvesting and introduction of alien species → altered population structure/abundance → potential for trophic cascades → shifts in community composition and shift in age/size structure
Flow alteration (e.g., hydropower, dams)	Habitat alteration → altered lake levels → change in habitat (e.g., shift in littoral zone and macrophyte zone) → shift in community composition and functional diversity, change in productivity
	Change in thermal/hydrological regime (dams) → increased/decreased lake levels → change in habitat (e.g., shift in littoral zone and macrophyte zone) → shift in community composition and functional diversity, change in productivity
	Change in wetland hydrological regime → alteration of habitat for migrating species → alteration of species migration pathways and dispersal → potential for trophic cascades → shifts in community composition and age/size structure
Increased agricultural activity (e.g., grazing domestic animals, farming, grassland management and arable farming)	Nutrient enrichment, increased erosion, (both inorganic and organic materials), change in substrate diversity/composition → altered algal and moss abundance → changes in photosynthesis/respiration balance → shift in community composition and functional diversity, change in productivity
Introduction of alien genetic types (e.g., cultured organisms and invasives)	Interaction with native biota, replacement and altered genetic structure → altered food webs, genetic makeup and fitness → shift in community composition and functional diversity, change in productivity

Table 5

List of monitored parameters and potential indicators for the biotic Focal Ecosystem Components (FECs) identified for lakes.

	Monitored parameters	Indicators/indices
Structural FECs	• Taxa inventory • Abundance (numbers, biomass, density) • Distribution and range	• Taxonomic richness • Taxonomic and genetic diversity, evenness • Biomass (e.g., Chl-a, total take of freshwater resources) • Compositional differences from reference sites • Establishment of new taxa (CPPP – competitors, predators, parasites, pathogens) • Increasing numbers of red-listed taxa • Abundance and/or population structure of keystone taxa (e.g., chironomids, diatoms, zooplankton, char, trout)
Functional FECs	• Body/cell size • Abundance (numbers, biomass, density) • Rate functions (e.g., changes in oxygen consumption/production, decomposition of organic matter, sedimentation of organic C) • Diet (e.g., stable isotopes, radioisotopes, fatty acids) • Ecosystem-induced genotypes	• Functional feeding groups • Size structure of entire population or of keystone taxa (e.g., chironomids, diatoms, zooplankton, char, trout) • Shifts in stressor tolerances • Ecological traits • Food web shifts • Concentration of contaminants (e.g., body burden in fish) • Changes in biological rates (e.g., primary production, decomposition, metabolism, energy and material flow) • Shift in the number of trophic pathways
Phenological FECs	• Age structure • Timing of key life history events	• Growth rates • Migration behaviour • Emergence timing • Age of maturity • Synchronization of taxonomic groups • Recruitment

Table 6

List of monitored parameters and potential indicators for the abiotic Focal Ecosystem Components (FECs) identified for lakes.

Monitored parameters	Indicators/indices
• Water temperature • Light attenuation • Water chemistry (e.g., nutrients, trace metals, DOC) • Turbidity • Inputs of terrestrial C • Water level and quantity • Ground water level • Geospatial landscape variables • Nival/ice regime • Substrate composition • Timing of hydrological events • Land-cover and land-use • Stable isotopes (e.g., O18/O16)	• Physical variables (e.g., degree days, discharge, water retention time, stratification, substrate composition, ice on/off) • Chemical variables (e.g., nutrients, trace metals) • Catchment characteristics (e.g., slope, elevation, land-use, area, ecosystem diversity) • Particle size distribution • Hydrological flow pathways (e.g., distinguish melting water and precipitation)

Freshwater monitoring in the Canadian Arctic
Photo: Joseph Culp

Table 7

Abiotic Focal Ecosystem Components (FEC) for lake ecosystems and the rationale for including each FEC in monitoring programs. A qualitative estimate of the difficulty of measurement is provided for each FEC.

Focal Ecosystem Component (FEC)	Rationale (why are we interested?)	Difficulty of measurement?
Structural		
Migratory fish (e.g., smelt, fish that move between rivers and estuarine areas)	• Provide information about connectivity • Provide information on local environment in addition to linkages with other environments (e.g., freshwater, estuary linkages) • Food for humans • Important for biodiversity and food webs; integrated indicators of energy flows	Medium – high (more expensive sampling than non-migratory)
Non-migratory fish (e.g. small freshwater sculpins)	• Very small home ranges, good indicators of point source pollution • Food for humans • Important for biodiversity and food webs; integrated indicators of energy flows	Low - medium (electrofishing or trapping)
Benthic macroinvertebrates	• Very widely used as indicators of river health; sensitive to many environmental stressors, wide range of tolerances • Integrate a great deal of biodiversity • Food for higher trophic levels, important consumers and secondary producers in the food web • High spatial resolution • Important intermediate host for parasites • Affect downstream areas through drift	Low – medium (more difficult in large rivers, processing more difficult/costly than fish)
Benthic algae	• Widely used as indicators of river health • Base of the food web; major source of primary production in Arctic • Respond quickly to both natural and anthropogenic changes; compositional shifts and changes in abundance strongly connected to changes in chemistry, temperature, ice cover, light, etc.	Low – medium (collection low, processing/ identification more difficult)
Bacteria and fungi	• Important for decomposition processes • Reflect changes of catchment characteristics	Low – medium (collection low, processing/ identification more difficult)
Pathogens	• Reflect natural and anthropogenic changes • Shifts in abundance/composition have implications for abundance and composition of other FECs	Low (if pathogens are known)
Bryophytes/macrophytes	• Provide habitat structure for macroinvertebrates, and their presence can affect macroinvertebrate communities (density, structure) • Measure of stream stability (substrate stability)	Low (easy to sample and identify, but quantitative may be difficult)

Focal Ecosystem Component (FEC)	Rationale (why are we interested?)	Difficulty of measurement?
Riparian vegetation	• Base of the food web; contribute to primary production • Chemical filter and physical stabilizer of banks • Corridor and habitat for fish and vertebrates	Low (season is important, but method is easy)
Aquatic birds (waterfowl, shorebirds, etc.)	• Make use of aquatic habitat • Food source for humans • Feed on fish	Low (season is important, but method is easy)
Aquatic mammals (seals, muskrats, beavers, etc.)	• Important for human populations • Feed on fish	Low (season is important, but method is easy)
Red-listed taxa (potentially included in general biodiversity)	• Indicator of ecosystem health • Sensitive metric • Policy links • Overall number of species in an area and change in number may indicate general ecosystem health, but most appropriate species would be those that are key to ecosystem function and those that are regionally endemic	Low (assuming regional assessments are done under regular cycles)
Functional		
Community metabolism	• Important aspect of ecosystem function (rates of primary production and community respiration) • Sensitive to changes in key drivers and stressors (e.g., temperature and nutrients) • Informs about fish diversity and species relative abundance • Changes to production in the system alter fish production and shifts fish population or size structure (also relevant to other ecosystem components)	Medium – high (method is easy, but equipment is expensive if deploying meters)
Decomposition	• Integrates microbial and macroinvertebrate community function • High seasonal roles of wetlands in decomposition and carbon fluxes	Medium (Requires at least 2 visits to the site to deploy and retrieve cotton strips)
Trophic structure/energy flow/ food webs e.g., stable isotopes	• A measure of ecosystem function and connectivity • Identifies keystone species • High quality information • Signal may be best in simple food webs that aren't as resistant to change	Medium – high (Costly, large amount of processing, large number of samples required)

Table 8

Abiotic Focal Ecosystem Components (FEC) for river ecosystems and the rationale for including each FEC in monitoring programs. A qualitative estimate of the difficulty of measurement is provided for each FEC

Focal Ecosystem Component (FEC)	Rationale (why are we interested?)	Difficulty of measurement?
Hydrological regime (water quantity, temporal variability, and groundwater and soil surface water level)	• Affects habitat quality/availability • May be affected by drivers or stressors • Riverine wetlands may be created by back-flooding, ice jams, or delta diking • Highly responsive to terrestrial landscape use activities	Low (if data are being collected by government, etc.) - high (if you have to establish new stations)
Import/Export (of organic material, sediment, heat energy, etc.)	• Measure of connectivity • Implications for downstream areas • Short/long term storage and removal of nutrients by wetlands (denitrification	High (large amount of monitoring data required, large amount of processing; temporal variation of parameters requires seasonal and inter-annual sampling)
Water quality • TN/TP – nutrients • DOC • pH • Alkalinity • Sulphur • Metal contaminants (e.g., Hg) • TSS, TDS, turbidity • Persistent organic pollutants • Salinity	• Relates to ecosystem health, habitat quality • Driver and potentially a responder to biodiversity change • Storage and release of elements and contaminants (e.g., sulphur) in wetlands has impacts on rivers • Affects nutrient availability and light penetration; may lead to effects on primary and secondary productions • Episodic marine incursions alter delta habitats	Medium – high (depending on which variables and number of variables being measured; temporal variation of parameters requires seasonal and inter-annual sampling)
Climate variables (air temperature, precipitation, etc.)	• Affects hydrological regime and ice breaks • Affects water temperature regime (e.g., ice cover and stratification) • Affects permafrost	Low (if data are being collected by government, etc.) to high (if you have to establish new stations)
Water temperature regime	• Affects species composition • May be affected by drivers or stressors • Spatial coverage ranges from individual loggers to remote sensing techniques	Low – medium (low cost/effort, but loggers require retrieval)
Ice regime (break-up and freeze-up dates)	• Related to hydrological, temperature regimes • Affects community composition/development • Affects habitat stability	Low (may be available from local knowledge)
Water source (e.g., glacier, groundwater, precipitation, snowmelt, lake, wetlands)	• Shift among sources is a good indicator of change • Indicator of habitat stability • Related to hydrological regime	Low – medium (can obtain through GIS and water chemistry)

Focal Ecosystem Component (FEC)	Rationale (why are we interested?)	Difficulty of measurement?
Catchment characteristics (e.g., catchment area, slope, streambed characteristics, elevation, surficial geology, groundcover)	• Indicator of habitat stability, habitat quality • Related to water source, temperature regime, hydrological regime, etc.	Low – medium (can obtain through GIS and water chemistry)
Tracers (e.g., mercury, some contaminants)	• Allow you to look at flow of materials from one part of the ecosystem to another part of the ecosystem	Medium – high (requires large number of samples, large amount of processing, expensive processing)
Permafrost level	• Driving factor for existence of wetland habitat • Changes may affect water quality	Low (but could be expensive; requires installation of equipment to measure the level)
Stochastic events (e.g., volcanism, landslide, avalanches)	• Affects dispersal • Affects habitat quality and availability	High (in terms of prediction and logistics)

Arctic char drying in Torngat National Park, Northern Labrador
Photo: Joseph Culp

Table 9

List of key environmental stressors and impact hypotheses describing expected impacts of stressors on focal ecosystem components of rivers

Stressor	Example impacts
Atmospheric deposition of short and long range contaminants	Alteration of water chemistry → increased uptake and biomagnification → toxic stress at high trophic levels and human exposure, selection for contaminant tolerant taxa
Shift in hydrological regime	Changes in precipitation, snowpack quantity, ice on/ice off → increased/ decreased flood magnitude, shift between thermodynamic and dynamic breakup, altered connectance → change in frequency of bed disturbance → altered habitat through change in median particle size → shift in community composition and functional diversity, change in productivity
	Changes in snowpack structure and quantity on river ice → altered thermal regime through change in insulation and light regime → altered habitat through change in light penetration and ice thickness → shift in community composition and functional diversity, change in productivity
Shift in thermal regime	Increased water temperature → changes in phenology, decreases in cold stenotherms (algae, benthic macroinvertebrates, fish), change in food availability and quality, range alteration for cold-intolerant taxa → increased competition, predation, parasites, and diseases from geographic range changes → shift in community composition and functional diversity, change in productivity
Shift in sediment regime (e.g., permafrost degradation)	Increased turbidity, shift in substrate composition towards fine particles, increased embeddedness → decreased light, loss of substrate diversity, shifts in habitat and delta sedimentation processes → changes in photosynthesis/ respiration balance → shift in community composition and functional diversity, change in productivity
Shift in nutrient regime (e.g., from permafrost degradation)	Nutrient enrichment → increased primary producer abundance → shift in community composition and functional diversity, change in productivity
Atmospheric deposition of SOx and NOx (acidification)	Alteration of water chemistry (decreased pH and calcium, released aluminum) → increased uptake of aluminum, toxic stress, loss of calcium-dependent taxa → shift in community structure and productivity
Shift in nutrient and contaminant levels due to biotic vectors (low-order streams)	Increased populations of biota (e.g., migratory birds, salmon) → altered deposition of nutrients and contaminants to water → nutrient enrichment and alteration of water chemistry → increased primary producer abundance, increased uptake and biomagnification of contaminants → shift in community composition and functional diversity, change in productivity, toxic stress at high trophic levels and human exposure, selection for contaminant tolerant taxa

Table 10

List of key stressors related to human population growth and impact hypotheses describing expected impacts of stressors on focal ecosystem components of rivers.

Stressor	Example impacts
Over-harvesting (new stock / unsustainable fisheries)	Alters population structure/abundance → potential for trophic cascades → shifts in community composition and age/size structure, selection against fast-growing genotypes in harvested populations
Resource exploration/ exploitation (e.g., from mining - metals, hydrocarbons, oil/gas and forestry)	Municipal discharge → nutrient enrichment → increased algal abundance → shift in community composition and functional diversity, change in productivity
	Water abstraction → altered flow regime → habitat fragmentation (and oxygen stress) → shift in community composition and functional diversity, change in productivity
	Increase in contaminants (including accidental spills) → alteration of water chemistry → increased uptake and biomagnification → toxic stress at high trophic levels and human exposure, selection for contaminant tolerant taxa
	Salinization → alteration of water chemistry and adjacent land areas (floodplains) → shifts in community composition, selection for saline-tolerant taxa
Linear structures (e.g., roads, powerlines, culverts)	Altered overland flow regime → increase in sedimentation/contaminants (e.g., salt, oil) → altered habitats (potential degradation of spawning habitats), loss of diversity and species composition, selection for contaminant tolerant taxa
	Increased access to formerly inaccessible areas → increased harvesting and introduction of alien species → altered population structure/abundance → potential for trophic cascades → shifts in community composition and shift in age/size structure
Flow alteration (e.g., hydropower, dams)	Habitat fragmentation → decreased connectivity → obstruction for migratory fish, shift in community composition and functional diversity, change in productivity
	Change in thermal / hydrological regime (dams) → change in habitat (e.g., sedimentation) downstream (and upstream - change from lotic to lentic system) → shift in community composition and functional diversity, change in productivity, increased mortality rates in fish (turbines)
	Change in wetland hydrological regime → alteration of habitat for migrating species → alteration of species migration pathways and dispersal → potential for trophic cascades → shifts in community composition and age/size structure
Increased agricultural activity (e.g., grazing domestic animals, farming, grassland management and arable farming)	Nutrient enrichment, increased erosion, (both inorganic and organic materials), change in substrate diversity/composition → altered algal and moss abundance → changes in photosynthesis/respiration balance → shift in community composition and functional diversity, change in productivity
Introduction of alien genetic types (e.g., cultured organisms and invasives)	Interaction with native biota , replacement and altered genetic structure → altered food webs, genetic makeup and fitness → shift in community composition and functional diversity, change in productivity

Table 11

List of monitored parameters and potential indicators for the biotic Focal Ecosystem Components (FECs) identified for rivers.

	Monitored parameters	Indicators/indices
Structural FECs	• Taxa inventory • Abundance (numbers, biomass, density) • Distribution and range	• Taxonomic richness • Taxonomic and genetic diversity, evenness • Biomass (e.g., Chl-a, total take of freshwater resources) • Compositional difference from reference sites • Establishment of new taxa (CPPP – competitors, predators, parasites, pathogens) • Increasing numbers of red-listed taxa • Abundance and/or population structure of keystone taxa (e.g., chironomids, diatoms, char, trout)
Functional FECs	• Body/cell size • Abundance (numbers, biomass, density) • Rate functions (e.g., changes in oxygen consumption/production, decomposition of organic matter) • Diet (e.g., stable isotopes, radioisotopes, fatty acids) • Ecosystem-induced genotypes	• Functional feeding groups • Size structure of entire population or of keystone taxa (e.g., chironomids, diatoms, zooplankton, char, trout) • Shifts in stressor tolerances • Ecological traits • Food web shifts and degree of trophic connectivity • Concentration of contaminants (e.g., body burden in fish) • Changes in biological rates (e.g., primary production, decomposition, metabolism, energy and material flow) • Shift in the number of trophic pathways
Phenological FECs	• Age structure • Timing of key life history events	• Growth rates • Migration behaviour • Emergence timing • Age of maturity • Synchronization of taxonomic groups • Recruitment

Table 12

List of monitored parameters and potential indicators for the abiotic Focal Ecosystem Components (FECs) identified for rivers.

Monitored parameters	Indicators/indices
• Water temperature • Water chemistry (e.g., nutrients, trace metals, DOC) • Turbidity • Inputs of terrestrial C • Discharge/surface water level • Ground water level • Geospatial landscape variables • Nival/ice regime • Substrate composition • Timing of hydrological events • Land-cover and land-use • Stable isotopes (e.g., O18/O16)	• Physical variables (e.g., degree days, discharge, substrate composition, ice on/off, flood frequency) • Chemical variables (e.g., nutrients, trace metals) • Catchment characteristics (e.g., slope, elevation, land-use, area, ecosystem diversity) • Particle size distribution • Hydrological flow pathways (e.g., distinguish melting water and precipitation)

Sampling benthos via kick net in Torngat National Park in Northern Laborador
Photo: Daryl Halliwell, Environment Canada

Table 13

Summary of existing monitoring activities for biotic Focal Ecosystem Components (FEC) in rivers and lakes. Feasibility indicates whether there are sufficient data for use in a monitoring context ranging from low to high feasibility. Importance refers to whether the FEC is likely to contribute to assessing stressor effects, and if it is important to incorporate into a monitoring plan. Gaps in spatial and temporal coverage within and among countries are identified and priority locations for sites suggested.

FEC	Lakes	Rivers
Structural		
Fish	**Feasibility**: Low – medium (more data in locations with existing environmetal impacts. May have large amounts of data locally, but regional distribution of data is spotty. Range of electronic databases may be available.) **Importance**: High (important part of the food web, impacting other FECs; provide context for local anthropogenic effects; provide information about local effects in inland areas.) **Gaps**: Temporal and spatial gaps within areas. Data may focus on particular species, which may not be comparable across circumpolar region. Moderate priority for establishment and linking new stations to current stations. Inland areas key for expansion of spatial coverage of data.	**Migratory fish:** **Feasibility**: High, but need to address CPUE issues with respect to fisheries data **Importance**: High (integrative over large spatial areas) **Gaps**: Moderate gaps exist on a circumpolar scale. Comparable data collection does not exist across countries. **Non-migratory fish:** **Feasibility**: Low – medium (more data in locations with existing environmental impacts. May have large amounts of data locally, but regional distribution of data is spotty. Range of electronic databases may be available.) **Importance**: Medium (provide context for local anthropogenic effects because don't move from local area; integrate local effects. Provide information about local effects in inland areas.) **Gaps**: Temporal and spatial gaps within areas. Data may focus on particular species, which may not be comparable across circumpolar region. Moderate priority for establishment and linking new stations to current stations. Inland areas key for expansion of spatial coverage of data.
Benthic macroinverte-brates	**Feasibility**: Low-Medium (not a great deal of data, and much of it is recent) **Importance**: High (important for other FECs, present in fishless lakes) **Gaps**: Many spatial gaps, and long-term data are largely lacking. Priority to establish new sites and fill in the spatial gaps. Also priority to continue sampling in current locations to strengthen temporal aspect.	**Feasibility**: Medium (not a great deal of data, and much of it is recent) **Importance**: High (important for other FECs, present in fishless streams) **Gaps**: Many spatial gaps, and long-term data are largely lacking. Priority to establish new sites and fill in the spatial gaps. Also priority to continue sampling in current locations to strengthen temporal aspect.

Zooplankton	**Feasibility**: Low - medium (not very much data for taxonomy/ counts, more data for chl a) **Importance**: High (important for other FECs, measure of primary productivity, present in fishless lakes) **Gaps**: Many spatial gaps, and long-term data are largely lacking. Priority to establish new sites and fill in the spatial gaps. Also priority to continue sampling in current locations to strengthen temporal aspect.	**Feasibility**: Low - medium (not very much data for taxonomy/counts, more data for chl a) **Importance**: High (important for other FECs, measure of primary productivity, present in fishless streams) **Gaps**: Many spatial gaps, and long-term data are largely lacking. Priority to establish new sites and fill in the spatial gaps. Also priority to continue sampling in current locations to strengthen temporal aspect.
Phytoplankton and benthic algae	**Feasibility**: Low - medium (not very much data for taxonomy/ counts, more data for chl a) **Importance**: High (important for other FECs, measure of primary productivity, present in fishless lakes) **Gaps**: Many spatial gaps, and long-term data are largely lacking. Priority to establish new sites and fill in the spatial gaps. Also priority to continue sampling in current locations to strengthen temporal aspect.	**Feasibility**: Low - medium (not very much data for taxonomy/counts, more data for chl a) **Importance**: High (important for other FECs, measure of primary productivity, present in fishless streams) **Gaps**: Many spatial gaps, and long-term data are largely lacking. Priority to establish new sites and fill in the spatial gaps. Also priority to continue sampling in current locations to strengthen temporal aspect.
Bacteria and fungi	**Feasibility**: Low (no/few data) **Importance**: Low – medium (important aspect of ecosystem function due to role in decomposition) **Gaps**: Immense	**Feasibility**: Low (no/few data) **Importance**: Low – medium (important aspect of ecosystem function due to role in decomposition) **Gaps**: Immense
Pathogens	**Feasibility**: Low (no/few data) **Importance**: Low – medium (affects other FECs) **Gaps**: Immense	**Feasibility**: Low (no/few data) **Importance**: Low – medium (affects other FECs) **Gaps**: Immense
Macrophytes/ bryophytes	**Feasibility**: Low (no/few data) **Importance**: Low – medium (could be an important supporting variable because of its importance as habitat) **Gaps**: Immense	**Feasibility**: Low (no/few data) **Importance**: Low – medium (could be an important supporting variable because of its importance as habitat) **Gaps**: Immense
Riparian vegetation	**Feasibility**: Low (no/few data) **Importance**: Low – medium (could be an important supporting variable) **Gaps**: Immense	**Feasibility**: Low (no/few data) **Importance**: Low – medium (could be an important supporting variable) **Gaps**: Immense

Aquatic birds (waterfowl, shorebirds, etc.)	**Feasibility**: Low – medium (May have data locally, but regional distribution of data is spotty. Range of electronic databases may be available.) **Importance**: Possible importance in relation to interactions with wetlands and marine, e.g., harlequin duck role in marine food web. **Gaps**: Likely spatial and temporal gaps.	**Feasibility**: Low – medium (May have data locally, but regional distribution of data is spotty. Range of electronic databases may be available.) **Importance**: Possible importance in relation to interactions with wetlands and marine, e.g., harlequin duck role in marine food web. **Gaps**: Likely spatial and temporal gaps.
Aquatic mammals (seals, muskrats, beavers, etc.)	**Feasibility**: Low – medium (May have data locally, but regional distribution of data is spotty. Range of electronic databases may be available.) **Importance**: Possible importance in relation to interactions with wetlands and marine food webs **Gaps**: Likely spatial and temporal gaps.	**Feasibility**: Low – medium (May have data locally, but regional distribution of data is spotty. Range of electronic databases may be available.) **Importance**: Possible importance in relation to interactions with wetlands and marine food webs **Gaps**: Likely spatial and temporal gaps.
Red-listed taxa (potentially included in general biodiversity)	**Feasibility**: Medium – high (Data and action plans exist because of responsible organizations; however, lists are assessed on a national basis, and data may need to be adjusted for Arctic regions) **Importance**: High (Sensitive to change) **Gaps**: Lists are assessed on a national basis, and data may need to be adjusted for Arctic regions. Probably don't know enough about whether they actually are rare or not in the Arctic. List may not include taxa that are actually rare in the Arctic, due to high abundances elsewhere.	**Feasibility**: Medium – high (Data and action plans exist because of responsible organizations; however, lists are assessed on a national basis, and data may need to be adjusted for Arctic regions) **Importance**: High (Sensitive to change) **Gaps**: Lists are assessed on a national basis, and data may need to be adjusted for Arctic regions. Probably don't know enough about whether they actually are rare or not in the Arctic. List may not include taxa that are actually rare in the Arctic, due to high abundances elsewhere.
Functional		
Community metabolism	**Feasibility**: Low (no/few data; however, if O_2 data are available, this could be estimated) **Importance**: Medium (important aspect of community function) **Gaps**: Immense	**Feasibility**: Low (no/few data; however, if O_2 data are available, this could be estimated) **Importance**: Medium (important aspect of community function) **Gaps**: Immense.
Decomposition	**Feasibility**: Low (sporadic distribution of data/data availability) **Importance**: Medium (important aspect of community function) **Gaps**: Immense	**Feasibility**: Low (sporatic distribution of data/data availability) **Importance**: Medium (important aspect of community function) **Gaps**: Immense.
Trophic structure/ energy flow/food webs e.g., stable isotopes	**Feasibility**: Low (sporadic distribution of data/data availability) **Importance**: Medium (important measure of community/ ecosystem interactions) **Gaps**: Immense	**Feasibility**: Low (sporatic distribution of data/data availability) **Importance**: Medium (important measure of community/ecosystem interactions) **Gaps**: Immense

Table 14

Summary of existing monitoring activities for abiotic Focal Ecosystem Components (FEC) in rivers and lakes. Feasibility indicates whether there are sufficient data for use in a monitoring context ranging from low to high feasibility. Importance refers to whether the FEC is likely to contribute to assessing stressor effects, and if it is important to incorporate into a monitoring plan. Gaps in spatial and temporal coverage within and among countries and suggested priority locations for site re-establishment.

FEC	Lakes	Rivers
Hydrological regime (water quantity, temporal variability, and groundwater and soil surface water level)	**Feasibility**: Medium-high (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian high Arctic, Greenland, unregulated lakes in Europe (spatial and temporal). Priority to establish new sites, fill in the spatial gaps, and continue sampling in current locations to strengthen temporal aspect.	**Feasibility**: High (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian high Arctic, Greenland (spatial and temporal for both)
Import/Export (of organic material, sediment, heat energy, etc.)	**Feasibility**: Low (little/no data) **Importance**: Medium (measure of connectivity (link between streams, lakes, and the sea), change in catchment, including melting of glaciers) **Gaps**: Immense	**Feasibility:** Low (little/no data) **Importance:** Medium (measure of connectivity (links streams, lakes, and the sea), change in catchment including melting of glaciers) **Gaps:** Immense
Water quality • TN/TP – nutrients • DOC • pH • Alkalinity • Sulphur • Metal contaminants (e.g., Hg) • TSS, TDS, turbidity • Persistent organic pollutants • Salinity	**Feasibility**: High (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Iceland (spatial and temporal), low temporal coverage for Canada, Svalbard, Greenland. Priority to establish new sites and fill in the spatial gaps. Also priority to continue sampling in current locations to strengthen temporal aspect.	**Feasibility**: High (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian high Arctic, Greenland (spatial and temporal for both)
Solar radiation (including UV)	**Feasibility**: Medium-high (Large amount of data available for most countries) **Importance**: Medium-high (Key driver in Arctic systems) **Gaps**: Likely spatial and temporal gaps	**Feasibility**: Medium-high (Large amount of data available for most countries) **Importance**: Medium-high (Key driver in Arctic systems) **Gaps**: Likely spatial and temporal gaps

Climate variables (air temperature, precipitation, etc.)	**Feasibility**: Medium-high (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Likely spatial and temporal gaps	**Feasibility**: Medium-high (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Likely spatial and temporal gaps
Water temperature regime	**Feasibility**: Low-medium (Inconsistent data records for many Arctic lakes, spot measurements are common. Higher data availability for sub-Arctic lakes) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian high Arctic, European Arctic (spatial and temporal for both)	**Feasibility**: High (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian high Arctic, Greenland (spatial and temporal for both)
Ice regime (break-up and freeze-up dates)	**Feasibility**: Medium-high (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian Arctic	**Feasibility**: High (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian high Arctic, Greenland (spatial and temporal for both)
Wind	**Feasibility**: Medium (Data are regional, may be substantial gaps) **Importance**: Medium-high (Linked to other FECs) **Gaps**: Likely spatial and temporal gaps	**Feasibility**: High (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian high Arctic, Greenland (spatial and temporal for both)
Catchment characteristics (e.g., catchment area, slope, elevation, surficial geology, groundcover)	**Feasibility**: High (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian high Arctic, Greenland (spatial and temporal for both	**Feasibility**: High (Large amount of data available for most countries) **Importance**: High (Key driver in Arctic systems) **Gaps**: Canadian high Arctic, Greenland (spatial and temporal for both)
Tracers (e.g., mercury, some contaminants)	**Feasibility:** Low (little/no data) **Importance:** Medium – high (measure of anthropogenic impacts, pathways in the ecosystem, fluxes) **Gaps:** Immense	**Feasibility**: Low (little/no data) **Importance**: Medium – high (measure of anthropogenic impacts, pathways in the ecosystem, fluxes) **Gaps**: Immense
Permafrost level	**Feasibility**: Low-medium (No specific monitoring for this, but data may exist in association with other climatic parameters) **Importance**: Medium-high (Linked to other FECs) **Gaps**: Likely spatial and temporal gaps	**Feasibility**: Low-medium (No specific monitoring for this, but data may exist in association with other climatic parameters) **Importance**: Medium-high (Linked to other FECs) **Gaps**: Likely spatial and temporal gaps
Stochastic events (e.g., volcanism, landslide, avalanches)	**Feasibility**: Low (little/no data) **Importance**: Medium (Large potential effects on Arctic systems, when they occur) **Gaps**: Immense	**Feasibility**: Low (little/no data) **Importance**: Medium (Large potential effects on Arctic systems, when they occur) **Gaps**: Immense

Appendix A
List of workshop participants

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Appendix B
Workshop agenda

The First Workshop of the CAFF-CBMP Freshwater Expert Monitoring Group
Uppsala, Sweden, November 22-25, 2010

Workshop "Icebreaker" Social – Monday Evening, November 22nd

19:00 – 22:00 Katalin & All That Jazz, Roslagsgatan 1 – Just east of the Central Railway station (map attached)

DAY 1 – Tuesday, November 23rd

8:15 – 8:45 Registration and Coffee

8:45 – 9:00 Welcome and Introductions (Willem Goedkoop, Joseph Culp, FEMG co-chairs)

9:00 – 9:20 Overview of the Circumpolar Biodiversity Monitoring Program, background and scope of CBMP Monitoring Groups (Michael Svoboda, CBMP Office)

9:20 – 9:40 Introduction to objectives and scope of the Freshwater Expert Monitoring Group (Joseph Culp and Willem Goedkoop, FEMG Co-Chairs)

9:40 – 10:15 Discussion of geographical area of Integrated Monitoring Plan, system size and other key attributes for monitoring sites (Joseph Culp and Willem Goedkoop)

10:15 – 10:30 Coffee

10:30 – 11:30 Brief overviews from each country on monitoring programs in the Arctic

- What existing monitoring networks can contribute to the FEMG assessments?
- What is monitored and how long has monitoring been done?

11:30 – 12:00 Introduction to Work Group Sessions, objectives and products (Culp/Goedkoop)

12:00 – 12:30 Begin Work Group Session 1 (details below)

12:30 – 13:30 Lunch

WORK GROUP SESSION 1: Determining Ecosystem Components and Scales (*Work in your assigned groups: Lakes or Rivers*)

13:30 – 15:30 Determining Focal Ecosystem Components and Temporal /Spatial Scales for Monitoring

Key Objectives:

- Prioritize focal ecosystem components such as valued species, trophic level, community type, ecosystem processes
- Discussion of ecosystem components and indicators used in circumpolar countries, including information and arguments (evidence of specific responses) about their usefulness as indicators of the types of stress occurring in Arctic systems
- Develop clear recommendations on the spatial and temporal scale of biodiversity

monitoring needed for the Arctic (e.g., program could be stratified on basin size)

Session 1 Products

- Strategic list of focal ecosystem components for lake and river ecosystems
- Summary presentation for Plenary Session 1

15:30 – 15:45 Coffee

PLENARY 1: Chaired by Joseph Culp

15:45 – 16:30 **Results from Work Group Session 1**: commonalities and differences between lake and rivers, conclusions on focal ecosystem components and scale

WORK GROUP SESSION 2: Linking Ecosystem Components to Stressors (*Work in your assigned groups: Lakes or Rivers*)

16:30 – 17:30 Linking Focal Ecosystem Components and Environmental Stressors Key Objectives:

- Identification of key drivers and stressors affecting Arctic freshwater biodiversity
- Development of cause-effect / impact hypothesis for key drivers / stressors)
- Strategic list of focal component indicators used for freshwater biodiversity assessment and definition of their responses (response types) to the stressors that act on Arctic freshwaters

Session 2 Products

- Identify key relationships between environmental-drivers and ecological effects (i.e., "impact hypotheses"); produce a table of these impact hypotheses
- Strategic list of biotic and abiotic monitoring components and indicators for reporting on the status and trends of biodiversity in lake and river ecosystems
- Summary presentation for Plenary Session 2

19:00 – 21:30 Workshop dinner

DAY 2 – Wednesday, November 24th

8:30 – 10:15 Work Group Session 2 (continued)

10:15 – 10:30 Coffee

10:30 – 11:30 Work Group Session 2 (continued)

PLENARY 2: Chaired by Willem Goedkoop

11:30 – 12:30 **Results from Work Group Session 2**: Conclusions on environmental driver-effect relationships, impact hypotheses, strategic list of monitored components and indicators (lake vs stream assessment)

12:30 – 13:30 Lunch

WORK GROUP SESSION 3: Critical Wetlands Linkages (*Plenary format: Lakes and River Groups together*)

13:30 – 15:00 Identifying Critical Inputs and Linkages of Freshwater and Estuarine Wetlands to Lakes and Rivers

Key Objectives:

- What are the primary wetlands of concern?
- Identification of physical and chemical inputs from wetlands that may affect biodiversity of lakes and rivers
- Develop key cause-effect / impact hypothesis for key drivers / stressors) if possible
- Strategic list of wetland indicators for freshwater biodiversity assessment of lakes and rivers

Session 3 Products:

- Identify key relationships of wetlands to downstream effects
- Develop "impact hypotheses" of environmental drivers and ecological effects
- Summary presentation for Plenary Session 3

15:00 – 15:15 Coffee

PLENARY 3: Chaired by Joseph Culp

15:15 – 16:00 **Results from Work Group Session 3**: Conclusions on key relationships between wetlands and biodiversity of lakes and rivers, environmental driver-effect relationships and impact hypotheses, strategic list of wetlands indicators that provide insight into change in lake and river biodiversity

WORK GROUP SESSION 4: Review of Existing Monitoring Activities (*Work in your assigned groups: Lakes or Rivers*)

16:00 – 17:30 Taking Stock of Ongoing Monitoring activities (Detailed listing to be completed before and after workshop)

Key Objectives:

- Review of existing and recent aquatic programs in the context of the impact hypotheses and indicators identified in Sessions 2 and 3.
- Gap assessment of current monitoring: How do the existing data and/or monitoring programs align with these hypotheses and indicators?
- Develop strategic recommendations for future data collection

Session 4 Products:

- Table of monitoring activities and data bases useful for assessments of pan-Arctic freshwater biodiversity (This is to be completed before the workshop)
- Strategic list of monitoring gaps and data needs

17:30 Adjorn for the day

17:45 – 18:45 Guided city walk: "Sights and Lights"

DAY 3 – Thursday, November 25th

WORK GROUP SESSION 5: Developing the Monitoring Plan (*Work in your assigned groups: Lakes or Rivers*)

8:30 – 10:30 Connecting the Dots: Linking Sessions 1-4 to Develop a Monitoring Approach for Freshwater Ecosystems in the Circumpolar Arctic

Key Objectives:

- Assessment of linkages and commonalities of focal components, scale, drivers/ stressors and data gaps for lakes and rivers

- Summary of the key questions (i.e., impact hypotheses) to be addressed by the monitoring plan

Session 5 Products:

- Final tables of impact hypotheses, monitored components and indices for lakes and rivers
- Draft monitoring framework for Arctic freshwater biodiversity of lakes and rivers
- Define the specific role of protected areas (e.g., natural reserves, national parks, Natura-2000 areas) in this work

10:15 – 10:30 Coffee

10:30 – 12:00 Work Group Session 4 (continued)

12:00 – 13:00 Lunch

PLENARY 4: Chaired by Willem Goedkoop

13:00 – 13:45 **Results from Work Group Session 5**: Presentation of key questions targeted by the monitoring program; tables of impact hypotheses, monitored components and indicators; and concept for circumpolar monitoring framework

14:45 – 15:15 Integration of monitoring ideas from Lakes and Rivers Groups

15:15 – 15:30 Coffee

15:30 – 16:30 Discussion of table of contents for ideal status and trends report

16:30 – 17:00 Summary and the way forward

Appendix C
Draft table of contents of the CAFF-CBMP Freshwater Expert Monitoring Group Integrated Monitoring Plan

Arctic Freshwater Integrated Monitoring Plan

1. Introduction and Background
    a. Overall Goals and Objectives of the Arctic Freshwater Biodiversity Monitoring Plan
    b. Scope and Approach to the Monitoring Plan
    c. Links and Relevance to Other Programs and Activities
    d. Benefits of Contributing to a Circumpolar, Coordinated Effort

2. Arctic Freshwater Areas
    a. Criteria Used to Delineate Areas

3. Conceptual Model of Arctic Freshwater Ecosystems

4. Selecting Priority Focal Ecosystem Components, Parameters, and Indicators
    a. Process for Identifying and Selecting Candidate Focal Ecosystem Components, Parameters, and Indicators
    b. Background paper and workshop process
    c. Scoping process
    d. Criteria for selecting parameters and indicators

5. Coordinated Arctic Freshwater Biodiversity Monitoring: Priority Focal Ecosystem Components, Parameters, and Indicators
    a. Focal Ecosystem Components
    b. Drivers
    c. Monitoring Objectives
    d. Priority Parameters and Indicators

6. Sampling Design
    a. Focal Ecosystem Components to be sampled
    b. Sampling protocols

7. Data Management Framework

8. Data, Samples, and Information Analysis Basis for Analysis

9. Reporting

10. Administration and Implementation of the Monitoring Program

11. Literature Cited

12. Glossary of Acronyms

Appendix A. Sampling Coverage Maps by Discipline
Appendix B. Arctic Freshwater Areas
Appendix C. Research Needed to Support Monitoring
Appendix D. Workshop Participants

Appendix D

Overview of available biotic monitoring data for Arctic freshwaters.

FEC	Lake Sampling History and Data Availability	River Sampling History and Data Availability	
		Structural	
Fish		Migratory fish	Non Migratory Fish
General	Data sets of contaminants (e.g., metals, PCB) in fish are generally extensive, gaps exist as target species are different among Arctic countries; spatial and temporal gaps also exist; untouched lake systems (e.g., in Svalbard, Greenland) are valuable data sources; genetic data (for indicating fish diversity) are relatively old that may not reflect changing population structures; diseases and pathogens of fish are not routinely monitored	Monitoring of fish has been going on since late 1800s, intermittent data available for most Nordic countries	
Canada	Long-term catch data for Lake Hazen (44 yrs) and nearby lakes (14 yrs). Short-term monitoring of fish populations and episodic research items at a small number of sites.	Short-term monitoring of fish populations and episodic research items for a large number of areas. Best location is on Labrador coast. Mostly salmonids.	Several species, but episodic monitoring data; some detailed medium-term (i.e., 15 yrs) studies associated with mining monitoring.
Sweden	3 lakes have been fished annually since 1994, 1996, and 2006, respectively. Another 3 lakes have been sampled every 3rd year since 1996 (4–5 y data since then).	Monitoring program using electrofishing in ~3 streams, one contains salmon (12 yrs data). There are migratory fish within the rivers also.	Monitoring program using electrofishing in ~2 streams (19 yrs data). Several species.
Norway	Catch data for Linnévatn and Diesetvatn on Svalbard, Takvatnet, Troms, Stuorajavri, and Finnmark in mainland Norway. Lakes in Pasvikelva, Finnmark in mainland Norway.	Electrofishing in several rivers in mainland (10-20 yrs). Long-term (100 yrs) catch statistics for anadromous salmon, trout and Arctic char for most major rivers in north. Limited monitoring of runs. Video registration of descending/ascending salmon in Tana tributary since 2002. Svalbard: little monitoring, but several short-term studies.	Limited monitoring in connection with hydropower. Long term data from mountains of southern Norway (sub-Arctic).
Iceland	Lake Myvatn, catch statistics 110 years, Veidivötn ~ 25 years.	Catch stats for salmonids (35 yrs +), fish counters in ~15 rivers (10-15 yrs). Annual juveniles data for ~20 rivers (25 yrs).	Catch statistics on brown trout in one river, River Laxa for 35 years. Data on invasive flatfish (flounder) – good indicator of colonization and changes.

Greenland	Some data exist from sites all over Greenland that have been sampled one or more times (often only one time); data are not easily assessable. Short-term monitoring program exists in one lake in Zackenberg.	Sporadic studies of charr population structure and migration pattern for Zackenberg.	Sporadic studies of charr population structure and migration pattern for Zackenberg.
USA	Most lake sampling has been one-time surveys related to agency inventories, industry water-use permits, or episodic research (although total number of sampled lakes on Arctic Coastal Plain likely exceeds 300). Some sites have repeat surveys, although typically <5 years. Research associated with the Arctic LTER probably has longest data sets.	Short term monitoring programs and episodic research (typically <5 yrs) for Dolly Varden, Pacific salmon, whitefishes, and ciscoes. Long term monitoring includes Dolly Varden in Wulik River (>15 yrs) and Arctic cisco in the Colville River delta (>35 yrs).	Longest data sets (>15 yrs) likely for Arctic grayling and lake trout from Toolik Lake area. Shorter term repeat sampling (<5 years total) in lower Fish Creek region around industrial sites.
Finland	Long-term data on commercially important species on Lake Inari, Lake Kemijärvi and reservoirs Lokka and Porttipahta. Individual studies from other lakes. Included in present national monitoring.	Long-term abundance and productivity data from major rivers (salmon rivers, regulated water courses). Individual studies from research and restoration projects. Included in present national monitoring.	Long-term abundance data from major rivers (salmon rivers, regulated water courses). Individual studies from research and restoration projects. National monitoring includes c. 60 streams with monitoring in 3-6-yr cycle, 3 (Rivers Teno, Tornionjoki and Vuotosjoki) sampled annually.
Russia	Not available	Not available	Not available

Benthic Macroinvertebrates		
General	Seldom monitored (except Iceland and WFD), therefore, spatial gaps among countries; only biomass and abundance are monitored.	
Canada	Spatially extensive data on Chironomidae from lake cores, little to no community data. Little to no long-term monitoring	Extensive data for western low Arctic (short term), little data for eastern low Arctic and high Arctic (short term). All primarily from last decade
Sweden	For 3 lakes annual invertebrate data are available from 1988 until present. For another 6 lakes invertebrate data are available since 1996. Include data on littoral, sublittoral and profundal fauna. Survey data for ~100 lakes are available from 1995 and 2000 (littoral samples only)	5 streams with fish sampling also sampled for benthic invertebrates. 6 streams are annually monitored for benthic invertebrates (medium term data for some, long term for others). Survey data for ~90 streams are available from 1995 and 2000
Norway	Some short-term research data; more long-term data from the mountains of southern Norway (sub-arctic)	A few medium term (5-10 yrs) datasets from northern Norway. Svalbard: sporadic research data from around Ny-Ålesund. One year-around study in rivers in Lake Linné watershed, Isfjord, Svalbard (Svenning et al. 2007)
Iceland	Lake Myvatn, indicator on Chironomus, fly-trap, ~ 25 years.	2 rivers (13 and 20 yrs)
Greenland	Sporadic sampling	No long term datasets, episodic sampling

USA	Most lake sampling for macroinvertebrates are one-time surveys related to episodic research. Likely exception is Toolik Lake area. New annual sampling program initiated for lakes in Fish Creek watershed. Data for seasonal variability lacking	Wulik River has 15 yr dataset. Upper Kuparuk River likely has extensive data. Milner has 30 yr dataset. Episodic beyond that. 2 years into annual sampling program established for streams in Fish Creek watershed.
Finland	Few individual studies since 1960's. Part of national monitoring since 2005	Some older data of individual studies from several rivers. National monitoring includes c. 60 streams with monitoring in 3-6-yr cycle, 3 rivers (Rivers Teno, Tornionjoki and Vuotosjoki) sampled annually. Part of national monitoring since 2005
Russia	Not available	Not available
Zooplankton		
General	rotifers are not monitored; time-series and seasonal data (e.g., growth rates) are lacking; limited number of sites monitored	Generally not applicable in Arctic rivers
Canada	Species composition and abundance data (since 70s, but not monitored now), no seasonal measurements, no consideration of size structure, pathogens, diseases.	
Sweden	For Abiskojaure, data since 2000. Otherwise sparse data for a few other lakes.	
Norway	Sampling from several years in Takvatnet, Stuorajavri and lakes in Pasvik, mainland Norway. Large spatial gaps exist, only abundance and biomass are monitored but secondary production, growth rates are not measured. Some research data from Svalbard.	
Iceland	Lake Myvatn, for 18 years.	
Greenland	Large spatial gaps exist, only abundance and biomass are monitored but secondary production, growth rates are not measured.	
USA	Most lake sampling for zooplankton are one-time surveys related to episodic research. Exception is Toolik Lake area (>100 lakes). New annual sampling program initiated for lakes in Fish Creek watershed. Data for seasonal variability lacking.	Zooplankton viable fish prey resource in extremely low-gradient Arctic Coastal Plain tundra streams - two years into annual sampling program for streams in Fish Creek watershed.
Finland	Scarce data, not included in national monitoring. Species composition and abundance data (since 90s), no seasonal measurements, no consideration of size structure, pathogens, diseases.	
Russia	Not available	
Phytoplankton and benthic algae		
General	Benthic algae have to be monitored (only benthic diatoms are included in WFD). Algal biomass data exist, but little species composition data; seasonality of phytoplankton is not considered	

Canada	Spatially extensive data on benthic diatoms from lake cores, no long-term data; little benthic algae community data. Spatially and temporally limited phytoplankton data	Little taxonomy data for eastern low Arctic and high Arctic (short term, all primarily from last decade). Little to no taxonomy data for western Arctic. Some chl a data available
Sweden	Data (species composition, BioV) are available for 3 lakes, monthly samples during April–October since 1988. However, due to method change, data are comparable only from 1992. For another 6 lakes, data for summer samples (species composition, BioV) available since 1996. Samples of benthic diatoms collected only in research projects in recent years	9 streams regularly monitored for diatoms and some non-diatoms. 4-7 yrs.
Norway	Limited data series from research studies	Long term data on non-diatoms (taxonomy). Svalbard: limited chl a data
Iceland	No monitoring programs	No monitoring programs. Short term Chl a
Greenland	Not available	Chl a data sporadic
USA	Toolik Lake area has phytoplankton (chl a) monitoring data. Episodic research with phytoplankton (chl a) sampling. New annual sampling program (chl a) initiated for lakes in Fish Creek watershed. Phytoplankton and benthic diatoms will be sampled by Alaska Department of Environmental Conservation at 50 randomly selected lakes beginning in 2012	Wulik river has ongoing chl a annual program (since 95). Upper Kuparuk River area has data. Beyond that, short term and episodic (some taxonomy). Two years into annual sampling program established for streams in Fish Creek watershed, including continuous monitoring of chl a trend
Finland	Phytoplankton monitored in big lakes (Lake Inari, Lake Kilpisjärvi etc.) since 1980's, number of lakes increased in national monitoring since 2009. Littoral benthic algae sampled on pilot projects, possibly included in national monitoring in 2012	Benthic algae sampled on national monitoring programme since 2005-2009. National monitoring includes c. 60 streams with monitoring in 3-6-yr cycle, 3 rivers (Rivers Teno, Tornionjoki and Vuotosjoki) sampled annually. Some older data from individual studies (River Tana, River Torne etc.)
Russia	Not available	Not available
Bacteria and fungi		
General	Mostly hasn't been monitored (except in a few lakes in Finland)	Mostly hasn't been monitored
Canada	Lack of monitoring data; limited data from research projects	Lack of monitoring data; limited data from research projects
Sweden	No data	No data
Norway	No data	No data
Iceland	No data	No data
Greenland	Not available	Not available
USA	E. coli to be included in sampling of 50 randomly selected lake on Alaska's Arctic Coastal Plain in 2012	No data
Finland	Lack of monitoring data; possible limited data from research projects	Lack of monitoring data; possible limited data from research projects
Russia	Not available	Not available

Pathogens		
General	Lack of monitoring data; diseases and pathogens of fish are not routinely monitored; new techniques are under development for monitoring purposes (e.g. pathogen diversity)	Lack of monitoring data; diseases and pathogens of fish are not routinely monitored; new techniques are under development for monitoring purposes (e.g. pathogen diversity)
Canada	Little to no data	Little to no data
Sweden	Possibly only some data for fish pathogens for monitored lakes.	Possibly only some data for fish pathogens for monitored streams/ rivers
Norway	Sporadic data, largely research or management based	Sporadic data, largely research or management based (e,g. Gyrodactylus (salmon parasite), PKD
Iceland	No data	No data
Greenland	Not available	Not available
USA	Algal toxins to be included in sampling of 50 randomly selected lake on Alaska's Arctic Coastal Plain in 2012	Episodic research
Finland	Sampled in some lakes as part of water quality monitoring	Sampled in some rivers as part of water quality monitoring
Russia	Not available	Not available
Macrophytes and Brophytes		
General	Little to no data, increased sampling may begin under WFD	Little to no data, increased sampling may begin under WFD
Canada	Lack of monitoring data; limited data from research projects	Little to no data
Sweden	Survey data (no time series) for a number of lakes available. Old data for single lakes from research projects.	No data thus far, sampling is initiated as part of new monitoring activities
Norway	Sporadic data from research projects and mapping surveys	Sporadic data from research projects and mapping surveys.
Iceland	No data	No data
Greenland	Not available	No data
USA	Sparse data	Sparse data
Finland	Some surveys during 1970-80s. Macrophytes included in national monitoring since 2005-2009	Some individual studies, tested in national monitoring in 1 circumpolar river (macrophyte monitoring)
Russia	Not available	Not available
Riparian Vegetation		
General	Little to no data	Little to no data
Canada	Lack of monitoring data; limited data from research projects	Lack of monitoring data; limited data from research projects
Sweden	No data	No data
Norway	Limited data from mapping surveys	Monitoring of phytobenthos in Altaelva (ca. 10 yrs). Limited data from mapping surveys

Iceland	No data	No data
Greenland	Not available	Not available
USA	Sparse data	Episodic research
Finland	Some individual studies (flood fields)	Some individual studies (flood fields)
Russia	Not available	Not available
Aquatic Birds (waterfowl, shorebirds, etc.)		
General	Large amounts of data likely exist, but FEMG steering committee needs to determine which species should be included, which data would be beneficial. Expertise in this area should be brought in for the scoping exercise	Large amounts of data likely exist, but FEMG steering committee needs to determine which species should be included, which data would be beneficial. Expertise in this area should be brought in for the scoping exercise
Canada	Arctic Avian Monitoring Network has data on waterfowl from 1920s (not temporally continuous); spatial scale is limited	Arctic Avian Monitoring Network has data on waterfowl from 1920s (not temporally continuous); spatial scale is limited
Sweden	No monitoring data	No monitoring data.
Norway	Bird migration is monitored but mostly in breeding areas; spatial scale is limited	Bird migration is monitored but mostly concentrated on breeding and resting areas (e.g. Tana estuary; goosanders); spatial scale is limited
Iceland	Lake Myvatn from 1975	Dataset on harlequins for 35 yrs, one river, Rivar Laxa from 1975
Greenland	Bird migration is monitored but mostly concentrated on breeding areas; spatial scale is limited.	Not available
USA	US Fish and Wildlife Service has conducted surveys of molting geese at lakes in the Teshekpuk Lake Special Area for ~ 30 years	None
Finland	Voluntary monitoring network for national fauna survey (Bird Atlas) since 1970's. Waterfowl populations continuously monitored by FGFRI	Voluntary monitoring network for national fauna survey (Bird Atlas) since 1970s
Russia	Not available	Not available
Aquatic Mammals (seals, muskrats, beavers, etc.)		
General	Large amounts of data likely exist, but FEMG steering committee needs to determine which species should be included, which data would be beneficial. Expertise in this area should be brought in for the scoping exercise.	Large amounts of data likely exist, but FEMG steering committee needs to determine which species should be included, which data would be beneficial. Expertise in this area should be brought in for the scoping exercise.
Red Listed Taxa (potentially included in general biodiversity)		
General	Taxonomic issues complicate the use of simple changes in this parameter as good indicators. In addition, Norway redlist doesn't apply to Svalbard, Denmark redlist doesn't apply to Greenland	Taxonomic issues complicate the use of simple changes in this parameter as good indicators. In addition, Norway redlist doesn't apply to Svalbard, Denmark redlist doesn't apply to Greenland

Canada	COSEWIC assesses general status on 5 yr rotational periods and if taxon appears to be in trouble, full assessment conducted. Freshwater fish and invertebrates included	COSEWIC assesses general status on 5 yr rotational periods and if taxon appears to be in trouble, full assessment conducted. Freshwater fish and invertebrates included.
Sweden	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups
Norway	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups.	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups.
Iceland	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups.
Greenland	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups.	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups.
USA	Similar process to Canada	Similar process to Canada
Finland	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups.	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups.
Russia	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups.	IUCN criteria used for evaluation; formal listing by countries. Includes all taxonomic groups.
Functional		
Community Metabolism		
General	Little/no data; research studies may exist	Little/no data; research studies may exist
Canada	Few data, could be long-term datasets on O_2 levels.	Few data, could be long-term data on O_2 levels.
Sweden	No data	No data
Norway	No data	No data
Iceland	No data	No data
Greenland	Not available	No data
USA	Occasional research project at Toolik Lake may include community metabolism	Long-term fertilization study of Kuparuk River and some other streams conducted through Toolik Lake LTER may include metabolism.
Finland	Few data, could be long-term datasets on O_2 levels.	No data
Russia	Not available	No data
Decomposition		
General	Scattered research studies could be accessed to build dataset.	Scattered research studies could be accessed to build dataset.
Canada	May be scattered research studies	May be scattered research studies
Sweden	No data	No data

Norway	May be scattered research studies	May be scattered research studies
Iceland	May be scattered research studies	May be scattered research studies
Greenland	May be scattered research studies	May be scattered research studies
USA	No data	No data
Finland	May be scattered research studies	May be scattered research studies
Russia	May be scattered research studies	May be scattered research studies
Trophic structure/energy flow/food webs (e.g., stable isotopes)		
General	Scattered research studies could be accessed to build dataset	Scattered research studies could be accessed to build dataset
Canada	May be scattered research studies	IPY data for eastern Arctic (algae and invertebrates). IPY charr project. Fairly extensive SIA dataset for anadromous fishes in western Arctic. Other individual datasets for some river fish
Sweden	May be scattered research studies	May be scattered research studies
Norway	May be scattered research studies	Some SIA and energy flow data from Svalbard
Iceland	No data	No data
Greenland	May be scattered research studies	May be scattered research studies
USA	May be scattered research studies	May be scattered research studies
Finland	May be scattered research studies	May be scattered research studies
Russia	May be scattered research studies	May be scattered research studies

Appendix E

Overview of available abiotic monitoring data for Arctic freshwaters

FEC	Lake Sampling History and Data Availability	River Sampling History and Data Availability
Hydrological regime (water quantity, temporal variability, and groundwater and soil surface water level)		
	Lake water level	
Canada	Data from regulated and unregulated lakes available since 1930s.	Extensive long-term low Arctic data, less extensive data for high Arctic for generally <12 years (Hydat).
Sweden	Extensive and routinely monitored data in regulated lakes.	40 streams with hydrological data, some from 1911, most about 60 yrs data.
Norway	Extensive and routinely monitored data in selected regulated lakes (Pettersson, 2003).	~50 stations in northern Norway, some long-term (50-60 yrs) (Pettersson, 2003; 2004). Svalbard: 3 stations, 10-15 yrs data (Sund, 2008).
Iceland	Lake Myvatn, catch statistics 110 years, Veidivötn ~ 25 years.	Good spatial distribution, about 70 rivers with annual data. In some cases since ca 1950.
Greenland	Not available	10 yrs of data from one river, additional data on glacier-fed rivers.
USA	Increased monitoring over last decade with numerous lakes now instrumented, although typically <5 yrs data for specific sites – focal areas include Teshekpuk Lake region and lower Fish Creek watershed. Toolik Lake area potentially with longer data sets.	Kuparuk River watershed with longest historical records (~40 years). Shorter-term historical monitoring elsewhere. Increased continuous monitoring of rivers and streams over last decade, especially on Arctic Coastal Plain.
Finland	Extensive and routinely monitored data in regulated lakes and major lake basins. National monitoring programme.	Extensive national monitoring data.
Russia	Not available	Extensive data
		Note: see Hydra – circumpolar hydrologic network
	Groundwater level	
Canada	Unclear; data can be patchy (from different kinds of monitoring stations).	
Sweden	Some data (2x per month since 1966) are available from monitoring stations run by the Swedish Geological Survey.	
Norway	Measurements taken for several years.	
Iceland	Unclear; data can be patchy (from different kinds of monitoring stations).	
Greenland	Data available since 1995	
USA	Not available	
Finland	Measurements started from 1960s. National monitoring programme	

Russia	Not available	
Water source (e.g., glacier, groundwater, precipitation, snowmelt, lake, wetlands)		
General	Data available online	Data available online
	Note: Glacier and ice sheet change (melt) will be monitored, important to consider because of the likely drastic changes over the next 100 years. 2011 SWIPA report: benchmark reporting of these elements and projections. Similar information for snow, permafrost. 40 streams with hydrological data, some from 1911, most about 60 yrs data.	
Import/Export (of organic material, sediment, heat energy, etc.)		
Canada	Lack of monitoring data; limited data from research projects.	Lack of monitoring data; limited data from research projects
Sweden	Possibly limited data from research projects	No data
Norway	Limited data from research projects	Sediment transport (organic and inorganic) measured at 2 stations on Svalbard. Limited data from other sites (Sund, 2008). 4 or 5 stations in Northern Norway with sediment transport data (Pettersson, 2003)
Iceland	No data	No or limited data
Greenland	Not available	Not available
USA	Toolik Lake LTER	Mass balance studies at McCall Glacier for 20+ years.
Finland	Limited data from research projects	National programme on export of substances in large rivers draining to Baltic sea. Two circumpolar rivers included
Russia	Not available	Not available
		Note: Link to water quality – variables like turbidity could be used as proxy
Water quality: TN/TP – nutrients; DOC; pH,;Alkalinity; Sulphur; Metal contaminants (e.g., Hg); TSS, TDS, turbidity; Persistant organic pollutants; Salinity		
Canada	Extensive eastern low Arctic data from as early as 1960s; less extensive data for western low Arctic and for high Arctic, primarily from 90s and with little repetition	Extensive eastern low Arctic data from as early as 1960s; less extensive data for western low Arctic and for high Arctic, covering generally <12 years. Continuing long-term monitoring in western low Arctic and limited high Arctic sites.
Sweden	At least 9 time series lakes that have been sampled at least 4x per year since 1988 (n=3) or 1996 (n=6). Same lakes as biological FECs.	9 streams with annual monitoring (4-20 yrs)
Norway	Routinely monitored water chemistry data from a number of lakes. Svalbard: data available for 4-5 lakes since 2005	Some rivers on mainland with monitoring of water quality (up to 30 yrs data). Single measurements for some rivers on Svalbard
Iceland	Lacking routinely monitored water chemistry data	One river monitored for 8 yrs
Greenland	Extensive data for 4 lakes since 1997 and 2005	No data

USA	Mostly one-time surveys related to episodic research. Exceptions include Toolik Lake area (longest records) and Fish Creek watershed in area of industrial activity (although typically <5 yr data currently). New annual sampling program initiated for lakes in Fish Creek watershed	Kuparuk River watershed with longest historical records. Shorter-term water quality sampling elsewhere. Increased monitoring of rivers and streams over last decade, especially on Arctic Coastal Plain, including some continuously monitored sites. Episodic research
Finland	National monitoring programmes with annual monitoring of water chemistry water quality. Lake Inari, Lake Kilpisjarvi and several other lakes, especially regulated lakes and reservoirs, monitored since 1960-70s	National monitoring programmes with annual monitoring of water chemistry. Major rivers monitored intensively since 1960s
Russia	Not available	Not available
	Note: not all variables measured at all sites	
Solar radiation (including UV)		
General	Moderate-high availability among all Arctic countries	Moderate-high availability among all Arctic countries
Climate variables (air temperature, precipitation, etc.)		
General	Moderate-high availability of air temperature and precipitation data among all Arctic countries. Snow cover data are available; snow-on-ground data are relatively rare, e.g., only available in Iceland, Greenland, Norway, Finland, and possibly in Sweden	Moderate-high availability of air temperature and precipitation data among all Arctic countries. Snow cover data are available; snow-on-ground data are relatively rare, e.g., only available in Iceland, Greenland, Norway, Finland, and possibly in Sweden
Water temperature regime		
General	Standardized method is difficult for ice-covered lakes; spot measurements common	
Canada	Inconsistent data records. Proxy data may be available through climate data.	Isolated short-term studies; some researchers starting long-term studies. Proxy data may be available through climate data
Sweden	Recorded in conjunction with sampling for water chemistry variables in at least 9 lakes since 1988/1996. Daily measurements in one lake since 2002. Several nearby weather stations (run by Swedish Meteorological and Hydrological Institute) have long-term recordings of air temp	9 streams, recordings in conjunction with sampling for water chemistry. Several nearby weather stations (run by Swedish Meteorological and Hydrological Institute) have long-term recordings of air temp
Norway	Temperature profiles are available for selected lakes	20 stations in Northern Norway with long-term (up to 20 yrs) continuous measurements (Pettersson, 2003). Svalbard: 2 stations with continuous long-term measurements. 3 more short-term (up to 3 yrs) (Sund, 2008). Groundwater temperature measured at some stations.
Iceland	Extensive data are available (number of lakes unknown)	~20 rivers with data loggers. Longest series is 40 yrs.
Greenland	Extensive data for 4 lakes since 1997 and 2005.	No data

USA	Increased monitoring over last decade with numerous lakes now instrumented, although typically <5 yrs data for specific sites – focal areas include Teshekpuk Lake region and lower Fish Creek watershed. Toolik Lake area likely with longer data sets.	Kuparuk River watershed with longest historical records. Shorter-term historical temperature monitoring elsewhere. Increased continuous monitoring of rivers and streams over last decade, especially on Arctic Coastal Plain
Finland	National monitoring programmes with annual monitoring of temperature. Lake Inari, Lake Kilpisjarvi and several other lakes, especially regulated lakes and reservoirs, monitored since 1960-70s.	National monitoring programmes with annual monitoring of temperature. Major rivers monitored intensively since 1960s.
Russia	Not available	Not available
Ice regime (break-up and freeze-up dates)		
General	Ice data (e.g., ice in/out, thickness) are available, but may be limited	(See hydrological and temperature regime)
Canada	Limited data available from Canadian Ice Service. Additional data may be available from research studies	May be estimated from hydrological and temperature regime data. Additional data may be available from Canada Ice Service and research studies.
Sweden	Ice-on/off observations for several lakes, recorded by Swedish Meteorological and Hydrological Institute. Long time series (at most since 1939) for some lakes. Ice thickness recordings for Torneträsk and Gäutajaure since 1939.	1 river, River Torneälv, with data from 1700s.
Norway	Limited data from Northern Norway, more data from subarctic lakes in the mountains of southern Norway (Pettersson, 2003).	10 rivers in Northern Norway where ice conditions have been reported (e.g. Tana, Altaelva), although several discontinued (Pettersson, 2003). Ice break in Tana back to 1882.
Iceland	Lake Myvatn from 1979.	No data
Greenland	Not available	Not available
USA	Episodic research studies	Episodic research studies
Finland	National monitoring of ice regime on major lakes. Long-term data available.	National monitoring of ice regime on major rivers. Long-term data available.
Russia	Not available	Not available
Wind		
General	Moderate-high availability among all Arctic countries, but data are rather regional.	Moderate-high availability among all Arctic countries, but data are rather regional.
Catchment characteristics (e.g., catchment area, slope, elevation, surficial geology, groundcover)		
General	Data available online	Data available online

Permafrost level		
General	No specific monitoring of permafrost level (except a few sites in Norway); usually associated with other climatic parameters or weather stations. May be additional data available from research studies.	No specific monitoring of permafrost level (except a few sites in Norway); usually associated with other climatic parameters or weather stations. May be additional data available from research studies.
Stochastic events (e.g., volcanism, landslide, avalanches)		
General	Sporadic research studies	Sporadic research studies

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