Biodiversity of Arctic Freshwaters: Developing the CAFF-CBMP Integrated Monitoring Plan

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Executive Summary

The Circumpolar Biodiversity Monitoring Program (CBMP) of the Conservation of Arctic Flora and Fauna (CAFF) is working with partners to harmonize and enhance long-term Arctic biodiversity monitoring efforts in order to facilitate more rapid detection, communication and response to significant trends and pressures. To this end, a Freshwater Expert Monitoring Group (Freshwater EMG) was formed to develop a Freshwater Integrated Monitoring Plan (Freshwater IMP) that details the rationale and framework for improvements related to the monitoring of freshwaters of the circumpolar Arctic, including ponds, lakes, their tributaries and associated wetlands, as well as rivers, their tributaries and associated wetlands. The monitoring framework aims to facilitate circumpolar assessments by providing Arctic countries with a structure and a set of guidelines for initiating and developing monitoring activities that employ common approaches and indicators. The Freshwater IMP presents a list of priority parameters and indicators that will be used for the assessment of the state of Arctic freshwater biodiversity. The Freshwater IMP also outlines biotic and abiotic sampling approaches for lakes and rivers that were designed to establish high-quality, long-term data that can be used to detect the impact of stressors on freshwater diversity. An initial status and trends assessment will evaluate existing (contemporary and historical) monitoring data and traditional knowledge, while subsequent assessments will make use of data from continuing coordinated biomonitoring activity. The collection of data and analysis of status and trends will be completed by national Freshwater Expert Networks (FENs) established in each country. In addition to international bodies of the Arctic Council, other groups involved in the implementation of the Freshwater IMP will include national, sub-national and local jurisdictions across the Arctic that already undertake biodiversity

monitoring. Ultimately, it will be the responsibility of each Arctic country to implement the Freshwater IMP in order for the program to succeed.

Introduction

Maintaining healthy Arctic ecosystems is a global imperative as the Arctic plays a critical role in the Earth's physical, chemical and biological systems. Arctic freshwater ecosystems, here defined as rivers, streams, lakes, ponds, and their associated wetlands, are under increasing threat from stressors including climate change, contaminants, introduced species, increased UV radiation exposure, and resource development (e.g., Hammar 1989; Reist et al. 2006a, c). Climate change, for example, is predicted to cause direct and indirect effects to these systems and the biodiversity they support, including the fish used by Northerners. Changes in the physical and chemical properties of freshwater systems will result in modifications to water temperature and ice cover regimes, thawing permafrost, hydrological processes and water balance (Prowse et al. 2006a, b; Christoffersen et al. 2008). Other transformations in biodiversity will be related to the impact of growing competition from southern species expanding northwards (Reist et al. 2006b). These stressors are expected to produce changes to freshwater fisheries around the Arctic and modify aquatic plant, invertebrate and vertebrate distributions. Ecosystem services to humans also will be affected through various impacts such as changes in fisheries harvest, drinking water source, and disposal of municipal waste.

Despite the growing pressures to freshwater biodiversity noted previously in the Arctic Climate Impact Assessment (Wrona et al. 2006a, b), freshwater monitoring efforts in the Arctic are very limited, largely uncoordinated and lack the ability to detect, understand and respond to biodiversity trends at the circumpolar scale (Culp et al. 2011a). Because of the Arctic's size and its diversity of freshwater habitats, the qualitative and quantitative detection of shifts in biodiversity is extremely challenging. This task demands a rigorous, integrated ecosystem-based approach that identifies circumpolar Arctic trends in biodiversity, indicates the underlying causes of these trends, and has the ability to detect change within a reasonable time frame. Such a strategic approach must be developed over time with the cooperation of various stakeholders, including the northern communities, policy makers and the science community. Indeed, an initial coordination of sampling efforts and assessment of the current state of Arctic freshwaters is required to provide a foundation upon which a long-term monitoring approach can be built.

Towards this end, the Circumpolar Biodiversity Monitoring Program (CBMP) of the Conservation of Arctic Flora and Fauna (CAFF) established the Freshwater Expert Monitoring Group (Freshwater EMG) in January 2010 to develop a framework for an integrated, ecosystem-based approach for monitoring Arctic freshwater biodiversity (see Culp et al. 2012). This framework, or Freshwater IMP, was created during two workshops attended by freshwater experts from the Arctic countries. The first workshop in Uppsala, Sweden identified important elements (stressors, focal ecosystem components (FECs), parameters and indicators) to be incorporated into a pan-Arctic Freshwater monitoring plan. Linkages between environmental or anthropogenic stressors and FECs were described as impact hypotheses (Culp et al. 2011b). A second workshop in Fredericton, Canada refined the lists of FECs, parameters and indices, and produced lists of priority freshwater elements and a draft Freshwater IMP (Culp et al. 2012).

The Freshwater EMG based its work on the principle that the Freshwater IMP should aid Arctic countries in developing monitoring plans to inventory existing Arctic biodiversity monitoring activities. These data would form the basis for status and trend assessments of Arctic freshwaters. The Freshwater IMP should also facilitate the coordination and harmonization of freshwater biodiversity monitoring activities among circumpolar Arctic countries. Additionally, the Freshwater IMP would improve ongoing communication among and between scientists, community experts, managers and disciplines both inside and outside the Arctic.

Objectives of the Freshwater Integrated Monitoring Plan

The Freshwater IMP provides Arctic countries with a common framework and approach for developing monitoring activities and circumpolar freshwater assessments. A basic premise applied by the Freshwater EMG is that the Freshwater IMP will continue to be developed and improved through time. The primary objectives of the Freshwater IMP are to:

- Develop the questions to be addressed by an assessment of Arctic freshwater biodiversity;
- Identify an essential set of FECs and indicators for freshwater ecosystems that are suited for monitoring and assessment on a circumpolar level;
- Identify abiotic parameters that are relevant to freshwater biodiversity and need ongoing monitoring;
- Articulate detailed impact hypotheses that describe the potential effects of stressors on FEC indicators;
- Identify a core set of standardized protocols and optimal sampling strategies for monitoring Arctic freshwaters that draws on existing protocols and activities;
- Create a strategy for the organization of existing research and information (scientific, community-based, and TEK) to evaluate current status and trends;
- Develop a process for undertaking periodic assessments of Arctic freshwaters including details of reporting elements and schedules; and
- Identify the financial support and institutional arrangements required to undertake such a program.

Scoping Process: Selecting the Focus for Freshwater Assessments

Development of the Freshwater IMP was founded on ideas forwarded in a framework document (Culp et al. 2011a) and two international workshops held by the Freshwater EMG. Both workshops included freshwater experts with a broad range of expertise, and contributors from all participating countries (i.e., Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the USA). Workshop participants identified the key elements (FECs, stressors, parameters and indicators) to be incorporated into a pan-Arctic Freshwater monitoring plan. The mechanistic link between environmental or anthropogenic stressors and FECs was identified through the creation of impact hypotheses (Culp et al. 2011b). Workshop participants provided information on available freshwater data for the chosen key elements and summarized existing monitoring activities for each country (see Culp et al. 2011b, 2012 for a summary of existing monitoring data). Although not exhaustive, these monitoring summaries will form an important basis for an initial biodiversity assessment of Arctic freshwaters. Information on existing data will further help in selecting future monitoring sites by highlighting areas and ecosystems for which reasonable, long-term data already exist.

Focal Ecosystem Components

Workshop participants identified a wide variety of potential FECs (biotic or abiotic elements, such as taxa or abiotic processes, which are ecologically pivotal, charismatic or sensitive to changes in biodiversity) for lakes and rivers. The initial list was reduced by ranking each FEC in terms of importance, measurement feasibility, and the availability of existing data. Importance was defined in terms of whether the FEC was likely to be responsive to the effects imposed by environmental and anthropogenic stressors, and if it was important to incorporate into a monitoring plan. Feasibility described the logistical constraints and cost associated with measuring the FEC (sample collection and processing). Finally, assessment of existing data identified gaps in the spatial and temporal data coverage within and among countries and indicated whether sufficient data existed for use in a monitoring context. FECs were further ranked in terms of their immediate importance for an initial assessment of Arctic freshwater condition and long-term importance for future monitoring efforts. The method of using expert rankings of FEC attributes facilitated differentiation between priority FECS, those considered as necessary for immediate and future monitoring, and important FECs, those considered conceptually important for assessing the effects of key environmental and anthropogenic stressors but that were logistically difficult to measure (i.e. moderate to low feasibility).

From the extensive list of potential FECs produced during the first Freshwater EMG workshop (see Culp et al. 2011b for full list of potential FECs, rankings, and justification for rankings), expert consensus determined the priority FECs listed in Table 1 to be practical and responsive measures of stress in Arctic freshwater ecosystems. As the FECs are central to the functioning of an ecosystem, they are most likely to be represented in existing databases for the Arctic, and therefore, best positioned to provide the necessary historical data for trend analyses. Indicators of FEC condition will, therefore, be the primary focus for reporting status and trends in freshwater biodiversity as the various impact hypotheses are evaluated. The inclusive nature of this list reflects the fact that data for all FECs will not be available in existing databases and reports and may not be appropriate for all monitored water bodies. The initial assessment of Arctic biodiversity may need to consider a reduced FEC list that is based on data availability, and is thus expected to focus upon the most commonly monitored FECs from Table 1, namely fish, benthic invertebrates, zooplankton, phytoplankton or benthic algae, and most abiotic FECs. After initial assessment, this list should be adjusted based on the availability of data collected through ongoing monitoring programs of the Arctic countries.

Table 1. Recommended biotic and abiotic Focal Ecosystem Components (FEC) selected for inclusion in the initial phase of the Arctic Freshwater Integrated Monitoring Plan. Expert consensus identified these FECs as central to the functioning of an ecosystem, and most likely to be commonly represented in existing databases for the circumpolar Arctic. It is expected that this list will be streamlined as the Arctic countries determine data availability and undertake the Freshwater IMP.

Focal Ecosystem Component	Applicable Ecosystems
Biotic	
Phytoplankton	Lakes
Zooplankton	Lakes
Benthic algae	Lakes and rivers
Benthic invertebrates	Lakes and rivers
Fish	Lakes and rivers
Macrophytes	Lakes
Aquatic birds	Lakes
Riparian vegetation	Rivers
Abiotic	
Water temperature regime	Lakes and rivers
Hydrological and ice regimes	Lakes and rivers
Water quality	Lakes and rivers
Climatic regime	Lakes and rivers
Permafrost	Lakes and rivers

Environmental and Human Activity Stressors

The identification of priority FECs allowed workshop participants to focus discussion on key environmental stressors related to climate change and human activity stressors believed to have a primary influence on basic biotic components, processes or ecosystem services. The 15 stressors listed below were identified as most likely to have substantial influence on the FECs listed in Table 1 (the order of the list does not indicate the order of importance of the stressors).

1. Atmospheric Deposition of Short and Long Range Contaminants: Addition of toxic stress to Arctic freshwater ecosystems resulting in contaminant exposure and biomagnification.
2. Atmospheric Deposition of SO_x and NO_x (acidification): Direct modification of water chemistry including decreased pH and calcium and increased release of aluminum.
3. Thermal Regime Change: Increasing Arctic temperatures that modify ice regimes and cumulative thermal degree days in lakes and streams.
4. Hydrological Regime Change: Shifts in the seasonal pattern of precipitation and ice cover and the resultant changes to freshwater habitat and seasonal disturbance.
5. Sediment Regime Change: Permafrost degradation and change in the hydrologic regime that increases the intensity, magnitude and frequency of disturbance of

freshwater habitat through increased turbidity and shifts towards finer substrate composition.

6. Wind Regime Change: Shifts in wind force changes snow deposition and water circulation in lakes resulting in habitat modification.
7. UV Radiation Regime Change: Increased exposure to UV radiation in shallow habitats of clear lakes and streams.
8. Increased Nutrient Loading: Permafrost degradation and changes in hydrologic regime that lead to higher input of organic matter and inorganic nutrients to aquatic systems.
9. Shift in Nutrient and Contaminant Levels Due to Biotic Vectors: The role that increased or decreased population abundance of migratory species can have in determining the deposition of nutrients and contaminants to aquatic ecosystems.
10. Fisheries Over-Harvesting: Changes in mortality, demographic characteristics, reduced competition or loss of prey resources that result from unsustainable harvesting of fish stocks by humans.
11. Resource Exploration and Exploitation: All stages and forms of resource extraction (e.g., hydrocarbon extraction, metal mining, water withdrawal) and their associated impacts such as wastewater discharge, spills, habitat disturbance and flow regime disturbance.
12. Transportation and Utility Corridors: Increase in various types of human transportation corridors including roads, powerlines and associated features such as culverts that can affect environmental conditions including flow, nutrient and sediment regimes, and connectivity.
13. Flow Alteration: Modification of flow regimes and habitat fragmentation through the construction of dams used for hydropower generation or stabilization of water supply.
14. Increased Agricultural Activity: The effects on aquatic habitats that result from various agricultural activities such as farming and animal grazing.
15. Introduction of Alien Genetic Types: Modification of composition and native genetic structure of aquatic biota through the introduction of new genotypes or invasive species (e.g., for culturing).Environmental stressors and impact hypotheses

A critical part of the discussion process was the development of impact hypotheses, or predictive statements, that outline a cause-effect framework regarding how change in stressors is expected to affect FECs. The suite of predictions provides a conceptual framework for describing the potential influence of climate change on basic biotic components, processes or ecosystem services. The expected response relationships of priority FECs to environmental and human activity stressors in lakes and rivers are outlined in Tables 2 and 3.

Table 2. List of key environmental stressors and impact hypotheses (prediction statements) and expected response relationships of focal ecosystem components (FECs) of lakes and rivers. Example stressor impacts indicate whether they apply to lake or river ecosystems (or both).

Stressor	Example impacts
Atmospheric deposition of short and long range contaminants	*Lake and River:* Alteration of water chemistry → increased uptake and biomagnification → toxic stress at high trophic levels and human exposure, selection for contaminant tolerant taxa
Atmospheric deposition of SOx and NOx (acidification)	*Lake and River:* 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
Thermal regime change	*Lake and River:* Increased water temperature → [Lake only: 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
Hydrological regime change	*Lake:* 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., change in availability of overwintering habitat, shift in littoral zone and macrophyte zone), increased nutrient availability, change in light regime → shift in community composition and functional diversity, change in productivity *River:* 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
	Lake and River: Changes in snowpack structure and quantity on lake/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, productivity
Sediment regime change	*Lake:* Increased turbidity → decreased light → changes in photosynthesis/respiration balance → shift in community composition and functional diversity, change in productivity *River:* 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
Increased nutrient loading	*Lake:* 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 changes, shift in community composition and functional diversity, productivity *River:* Nutrient enrichment → increased primary producer abundance → shift in community composition and functional diversity, productivity
Shift in nutrient and contaminant levels due to biotic vectors	*Lake and River:* 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
Shift in UV radiation	*Lake:* 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	*Lake:* 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 and habitat accessibility, lake mixing, thermal regime, stratification → shift in community structure and primary productivity

Table 3. List of regional human activity stressors and impact hypotheses describing expected response relationships of focal ecosystem components of lakes.

Stressor	Example impacts
Fisheries over-harvesting	*Lake and River:* 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., hydrocarbon extraction, metal mining, water withdrawal)	*Lake:* 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 *River:* Municipal discharge → nutrient enrichment → increased algal abundance → shift in community composition, functional diversity, productivity
	Lake: 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 *River:* Water abstraction → altered flow regime → habitat fragmentation (and oxygen stress) → shift in community composition and functional diversity, change in productivity
	Lake and River: 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
	Lake and River: Salinization → alteration of water chemistry and adjacent land areas (including river floodplains) → shifts in community composition, selection for saline-tolerant taxa
Transportation and utility corridors	*Lake and River:* Altered overland flow regime → increase in turbidity/sedimentation/contaminants (e.g., salt, oil) → altered habitats (potential degradation of spawning habitats), loss of diversity and species composition, selection for contaminant tolerant taxa
	Lake and River: 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
	River: Habitat fragmentation → decreased connectivity → obstruction for migratory fish, shift in community composition and functional diversity, change in productivity
Flow alteration (e.g., hydropower, dams)	*Lake:* 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 *River:* Habitat fragmentation → decreased connectivity → obstruction for migratory fish, shift in community composition and functional diversity, change in productivity
	Lake: 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 *River:* 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) *Lake and River:* 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	*Lake and River:* 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, productivity
Introduction of alien genetic types	*Lake and River:* 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

Indicators and indices

Development of impact hypotheses facilitated the choice of key parameters that should be monitored either directly or as components of indices. As with the FECs, the initial list of indicators was qualified in terms of importance and feasibility. A final list of priority indicators was developed based on their ranked importance and feasibility for monitoring. The final indicators were chosen for their widespread applicability across the pan-Arctic region and the feasibility of their incorporation into Arctic freshwater monitoring (Table 3). The suite of priority parameters and indicators will be used for assessing the state of Arctic freshwater biodiversity, and should be considered during the development of any future Arctic freshwater monitoring programs.

Table 3. List of monitored parameters for each biotic Focal Ecosystem Component and the indicators/indices that can be derived from those parameters for lake and river ecosystems. The ecosystem to which each FEC applies can be found in Table 1.

<table>
<tr><th>FECs</th><th>Monitored Parameter</th><th>Indicators/Indices</th></tr>
<tr><td rowspan="2">Benthic algae and phytoplankton</td><td>Number of individuals or biomass of each taxon</td><td>Community indices (e.g., abundance and density, taxonomic richness, diversity and dominance, biomass and numbers of keystone taxa)
Numbers of red-listed (endangered) and rare taxa
Distribution and range (e.g., latitudinal and altitudinal)</td></tr>
<tr><td>Biomass (including chlorophyll a and biovolume)</td><td>Bulk algal biomass
Size structure of entire population or of keystone taxon</td></tr>
<tr><td rowspan="6">Fish, benthic macroinvertebrates and zooplankton</td><td>Number of individuals or biomass of each taxon</td><td>Community indices (e.g., abundance and density, taxonomic richness, diversity and dominance, biomass and numbers of keystone taxa, ecological traits)
Numbers of red-listed (endangered) and rare taxa
Distribution and range (e.g., latitudinal and altitudinal, residency/anadromy for fish)</td></tr>
<tr><td>Genotypes and alleles (fish)</td><td>Genetic diversity</td></tr>
<tr><td>Biomass (including biovolume, length, and weight)</td><td>Size structure of an entire population or of keystone taxon</td></tr>
<tr><td>Age of individuals</td><td>Age structure of entire population or of a keystone taxon; growth rates (size at age or age at length (fish), or life cycle stage at length (BMI)) and age at maturity (age combined with biomass)</td></tr>
<tr><td>Timing of key life history events</td><td>Migratory phenology
Emergence timing</td></tr>
<tr><td>Body burden of key contaminants in fish</td><td>Concentrations of contaminants in fish tissues above consumption guidelines or above environmental thresholds for sub-lethal or lethal effects</td></tr>
<tr><td>Macrophytes and riparian vegetation</td><td>Areal cover of each taxon</td><td>Community indices (e.g., abundance and density, taxonomic richness, diversity, and dominance, numbers of keystone taxa)
Numbers of red-listed (endangered) and rare taxa
Distribution and range (e.g., latitudinal and altitudinal)</td></tr>
<tr><td rowspan="3">Aquatic birds</td><td>Number of individuals of each taxon</td><td>Community indices (e.g., abundance and density, taxonomic richness, diversity, and dominance, numbers of keystone taxa)
Numbers of red-listed (endangered) and rare taxa
Distribution and range (e.g., latitudinal and altitudinal)</td></tr>
<tr><td>Age (immature/adult) and sex of individuals</td><td>Age structure of entire population or of a keystone taxon; number of young/breeding pairs</td></tr>
<tr><td>Timing of key life history events</td><td>Migratory phenology</td></tr>
</table>

Sampling Approach and Recommended Protocols

A common and feasible sampling approach that includes protocols and field and laboratory guidelines for comparable standardized sampling and analysis is required for the success of a pan-Arctic monitoring program. Because Arctic countries have existing protocols established by national or regional authorities, the methods outlined in the Freshwater IMP were based on existing protocols wherever possible (see Culp et al. 2012 for details). Such a foundation allows for the harmonization of diverse programs with minimal methodological changes, and will facilitate the comparison of historical and new monitoring data.

It is equally important to define the types of locations and habitats that should be sampled and the spatial and temporal coverage that is necessary to develop a strong and cost-effective monitoring program. General guidelines are provided within the Freshwater IMP, however, more specific details about the selection of monitoring sites and sampling frequencies will follow from trend assessments upon implementation of the Freshwater IMP. During the initial assessment of status and trends in Arctic freshwater biodiversity, incorporation of common sampling approaches and designs will focus on the existing freshwater abiotic and biotic monitoring programs of the Arctic countries. Concurrently, approaches used in non-Arctic regions, including community-based citizen science, will be considered for inclusion after this initial assessment. Monitoring handbooks will be developed to assist implementation of the plan and ensure suitable and comparable measures across the Arctic. Finally, the sampling of wetlands associated with lakes and rivers should follow the protocols set out by the Ramsar Convention on Wetlands (details and protocols can be found at www.ramsar.org).

Freshwater Assessment Process and Broad Questions to be Addressed

The Freshwater IMP establishes the framework by which the national Freshwater Expert Networks and the CBMP Freshwater Steering Group can accumulate existing and new data for the purpose of undertaking circumpolar freshwater assessments (see details in Culp et al. 2012). The framework will facilitate an initial assessment of the status of Arctic freshwater biodiversity and subsequent assessment of trends. Steps in this process include:

1. Establishment of Freshwater Steering Group and national FENs;
2. Collection of existing monitoring data, including historical data where these are available;
3. Assessment of historical and contemporary monitoring data for the initial State of Arctic Freshwater Biodiversity report;
4. Coordination of continued monitoring within each national FEN, and application of the sampling approach recommended in Freshwater IMP;
5. Ongoing assessment of trends in monitoring data and creation of State of Arctic Freshwater Biodiversity reports; and
6. Periodic and ongoing program reviews to assess program effectiveness.

Status and trend assessments will be produced by a CBMP Freshwater Steering Group charged with coordinating the rollup of monitoring information from all Arctic countries into circumpolar assessments. A Freshwater Expert Network (FEN) for each country will be responsible for providing national status and trend information to the CBMP Freshwater Steering Group for periodic assessments. These circumpolar assessments will also inform the public, as well as policy- and decision-makers (local to the international level), on the state of Arctic freshwaters. Furthermore, the assessments will provide a forum for incorporating ongoing scientific input and Traditional Ecological Knowledge (TEK) into existing monitoring programs.

Assessments will focus on the biotic components, processes, and services of lentic and lotic water bodies including ponds, lakes, their tributaries and associated wetlands, as well as rivers, their tributaries and associated wetlands. Abiotic components that strongly affect biotic components, processes, or services will be considered during the planning and resultant interpretation phase. In some instances, changes in abiotic variables may be used as proxies to estimate shifts in biodiversity (e.g., loss of shallow water habitat). The spatial area of interest for these assessments will include freshwaters of the high, low and sub-Arctic north of the treeline. This area incorporates the geographical boundaries identified by CAFF and the Arctic Biodiversity Assessment. More southerly water bodies entering or draining into this prescribed area may also be considered to increase data coverage for assessments (e.g., use of alpine regions as a proxy for higher latitudes).

Over the long-term, the assessments should address the following overarching questions:

1. What is the current status of freshwater biodiversity in the Arctic?

2. Can biodiversity and ecological status in the Arctic be measured with simple variables and indicators, and if so, what suite of variables should be measured?

3. Are alpha and beta biodiversity changing, and if so, are they increasing or declining, and are species moving or disappearing?

4. What are the primary environmental and anthropogenic stressors causing the observed changes in biodiversity?

5. Are boundaries of the Arctic and sub-Arctic ecosystems shifting?

The above questions are highly ambitious because articulation of overarching questions is a basic requirement of such large, integrated programs. The details of how each question is to be addressed will be developed in the specific terms of reference and objectives for future assessments.

Freshwater IMP assessments will be divided into two phases. The first (start-up phase) will rely on existing monitoring data from Arctic freshwater systems, and will be used to establish baseline conditions for inclusion in an initial State of Arctic Freshwater Biodiversity report in 2016. Data collection will be the responsibility of each member country. Where possible, sites will need to be classified as reference or impacted prior to analysis. Contemporary and historical biotic and abiotic data will be evaluated to determine the current status of the priority FECs and indicators and assess historical trends. These analyses will help answer questions about the state of Arctic freshwater biodiversity, and will establish the baseline for future assessments of change in these systems. Data quality assurance and quality control through statistical data screening tools will be an essential part of the data collection process in the initial analysis stage, and will be conducted by each member country.

The second phase of analysis will involve the future assessment of change in Arctic freshwaters through the evaluation of coordinated biomonitoring data from the Freshwater IMP. This analysis of changing status and trends will be summarized in subsequent State of Arctic Freshwater Biodiversity reports that will be completed on a regular basis. In this stage, the collection of data and analysis of status and trends will be completed by the national FENs. However, analytical procedures and approaches will be designed and recommended by the CBMP Freshwater Steering Group to maintain continuity and data quality among the networks.

Reports will include results of the data collection, as well as information on the creation, development, and assessment of aspects of a coordinated monitoring plan. The audiences for this information range from policy-makers to local community residents.

Linkages and Relevance to Other Programs and Activities

Outputs of a coordinated monitoring approach for Arctic freshwater ecosystems will serve a number of mandates at various scales (see Figure 1). The resulting information, as much as possible, will be provided at a local scale to serve decision-making. This will be achieved partly through local-scale, community-based monitoring approaches as discussed above, but also through interpolation and modeling techniques to provide information that residents of the Arctic can use to make effective adaptation decisions.

The outputs will also be of direct value to national and regional governments and departments who have a mandate for monitoring and reporting on the status of Arctic freshwater ecosystems. Optimal sampling schemes and standardized, integrated approaches to monitoring will allow regional and national governments to better understand trends and the mechanisms driving those trends. Only through a structured and collaborative effort can a government or department gain the ability to detect and understand trends experienced in their region, and therefore, effectively respond to those trends. Additional international linkages will include the Group on Earth Observations Biodiversity Observation Network (GEO-BON) Freshwater Working Group as well as the Convention on Biological Diversity (CBD), to contribute to the status and trends information that the CBMP will deliver to meet 2020 CBD targets. The Arctic Council will also be a direct beneficiary of the outputs of this collaborative effort. The outputs of the pan-Arctic freshwater monitoring and assessment process will help populate Arctic Council assessments and raise issues facing Arctic freshwater ecosystems that require a coordinated pan-Arctic or even global response.

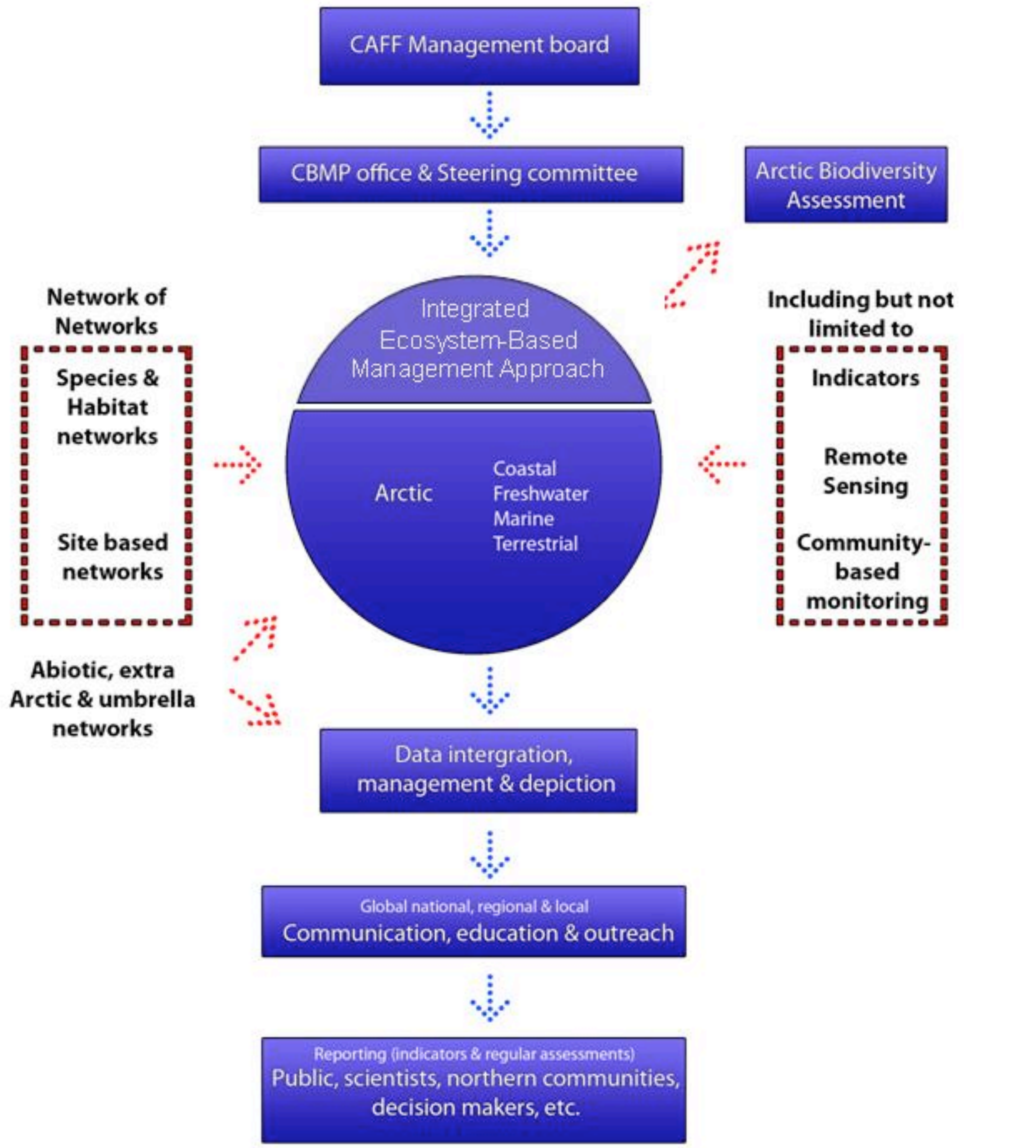

Figure 1. Relationship of Expert Monitoring Groups to the Circumpolar Biodiversity Monitoring Program of the Conservation of Arctic Flora and Fauna.

In conclusion, while most Arctic biodiversity monitoring networks are national or regional in scope, there is substantive added value in establishing circumpolar connections among monitoring networks. The development of a pan-Arctic, long-term freshwater biodiversity monitoring plan will facilitate circumpolar connections between national and regional research and monitoring networks, thereby greatly increasing the power to detect and attribute change for a reduced cost compared to multiple, uncoordinated approaches.

References

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