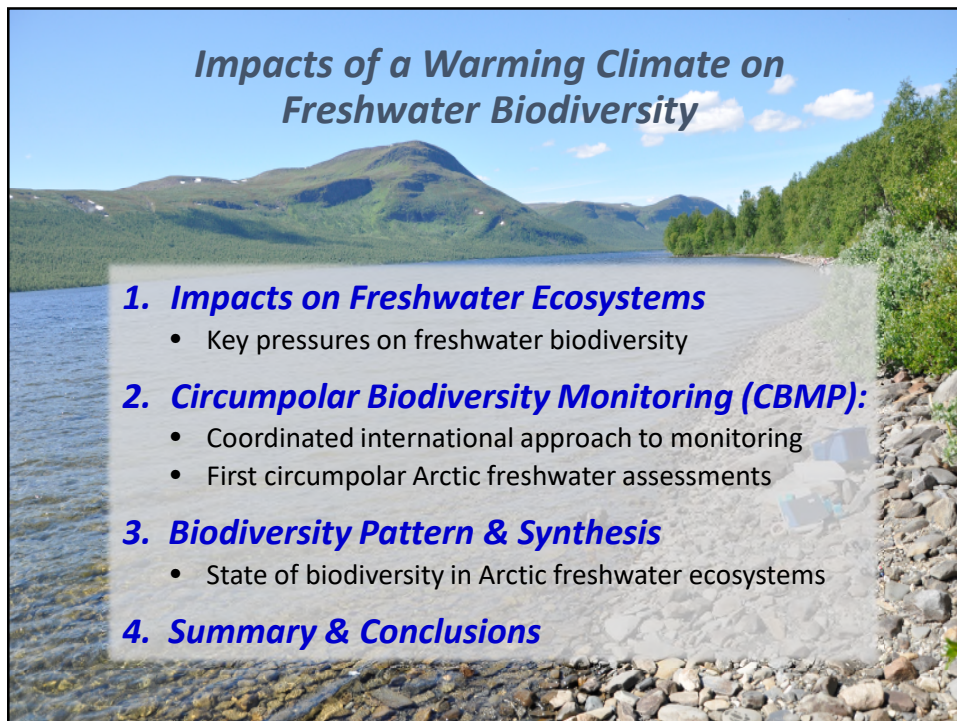




1



2

Arctic Biodiversity: Globally Significant

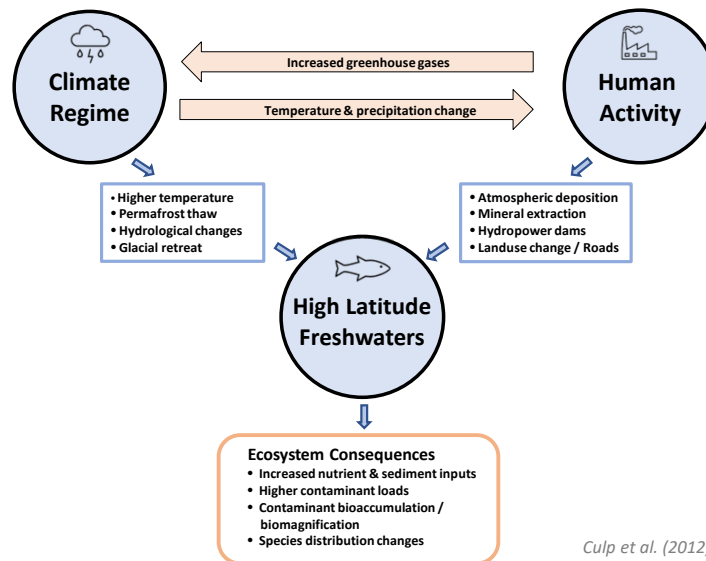
- Jurisdiction of 8 countries
- 5% of earth surface (3X size Europe)
- Vast wilderness areas, some of it protected (dark green →)
- Unique biological diversity
- Largest freshwater resources (with Antarctic)
- Unique and diverse indigenous cultures (Knowledge co-production)



1. Impacts on Freshwater Ecosystems

3

Overview of Key Drivers of Arctic Biodiversity Change



Culp et al. (2012)
Biodiversity 13:215-227

1. Impacts on Freshwater Ecosystems

4

Lakes and Rivers: 'Mirrors of Their Landscape'

- Reflect catchment hydrology, biogeochemistry, and land use
- Water quality is an early-warning indicator of change
- Water chemistry as the habitat template for freshwater organisms
- Land and water are closely intertwined in Arctic landscapes



Original by MC Escher

1. Impacts on Freshwater Ecosystems

5

Climate Change Drivers of Ecosystem Shifts

— Biodiversity Drivers —

- Temperature regime: Mediates all physiological processes
- Nutrients (Nitrogen, Phosphorus): Increases algal and microbial production and provides food for consumers
- Terrestrial vegetation: Increased input (e.g., leaves) of carbon and nitrogen enhances food web productivity
- Physical disturbance regime (ice/floods, sediment): Establishes key environmental template for biodiversity

1. Impacts on Freshwater Ecosystems

6

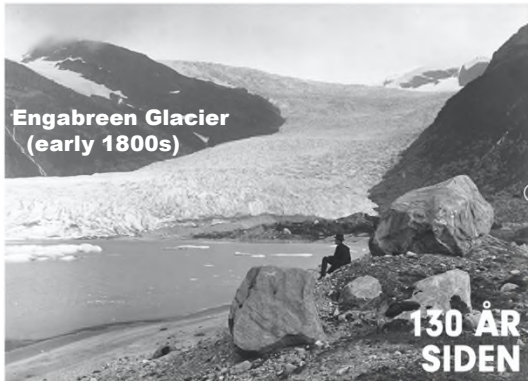



Photo Evidence of Climate Warming

<https://www.naturiendring.no>



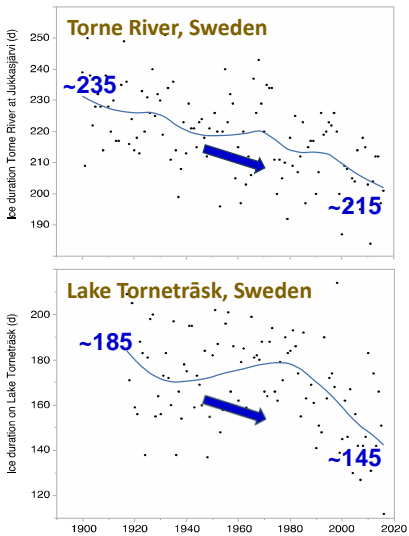


1. Impacts on Freshwater Ecosystems

7

Climate Warming Trends (Swedish example)

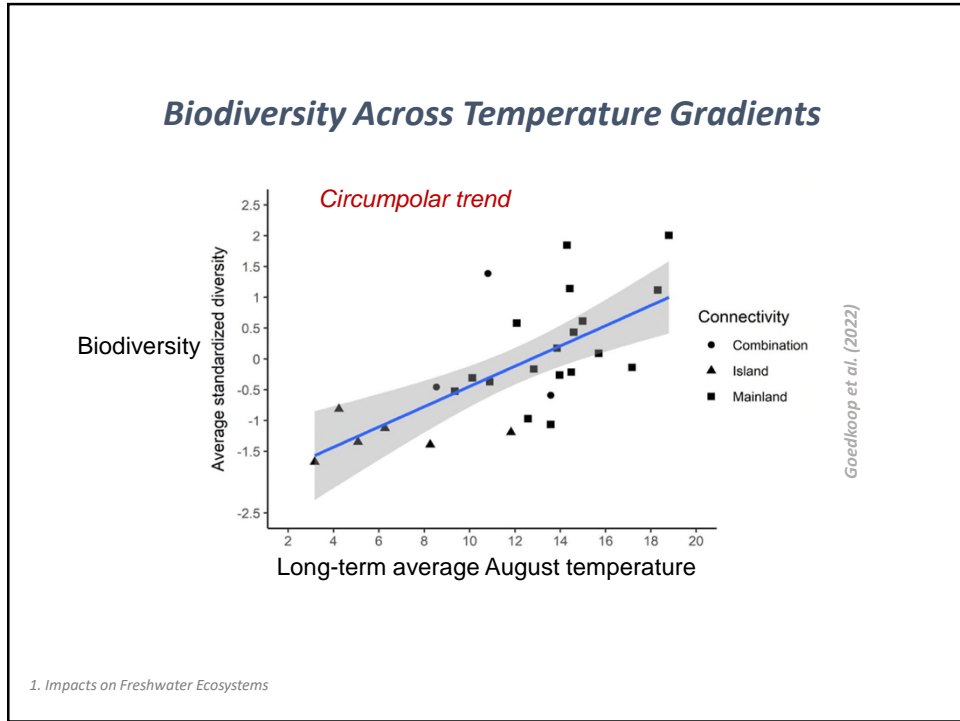
(Source: Swedish Meteorological & Hydrological Institute)



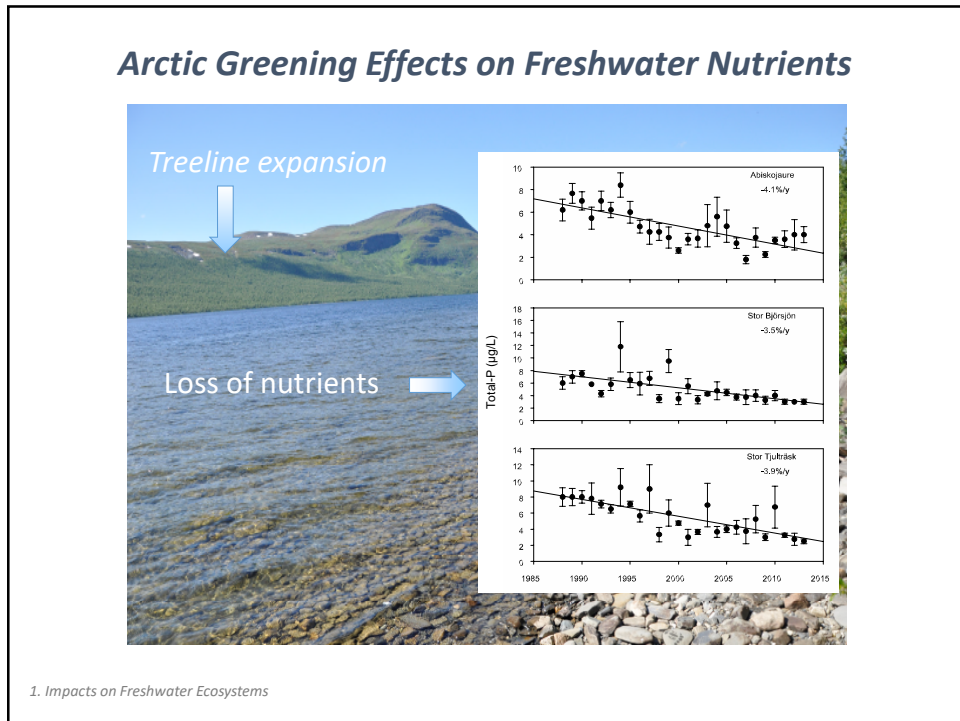
- Ice-on 10 days later and ice-off 10 days earlier since the early 1900s
- Since early 1990s:
 - River: extra **20 days** with open water!
 - Lake: extra **40 days** with open water!
- Thermal trends have huge implications for biodiversity via changes in phenology, growth, light availability, wind action, etc....)

1. Impacts on Freshwater Ecosystems

8



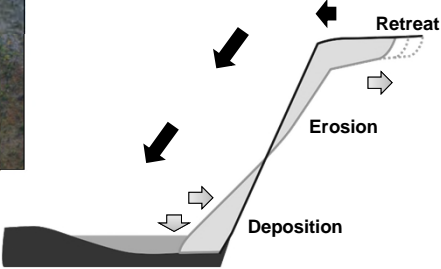


9



10

Permafrost Thaw:

- Mudflows into Stream Valleys**

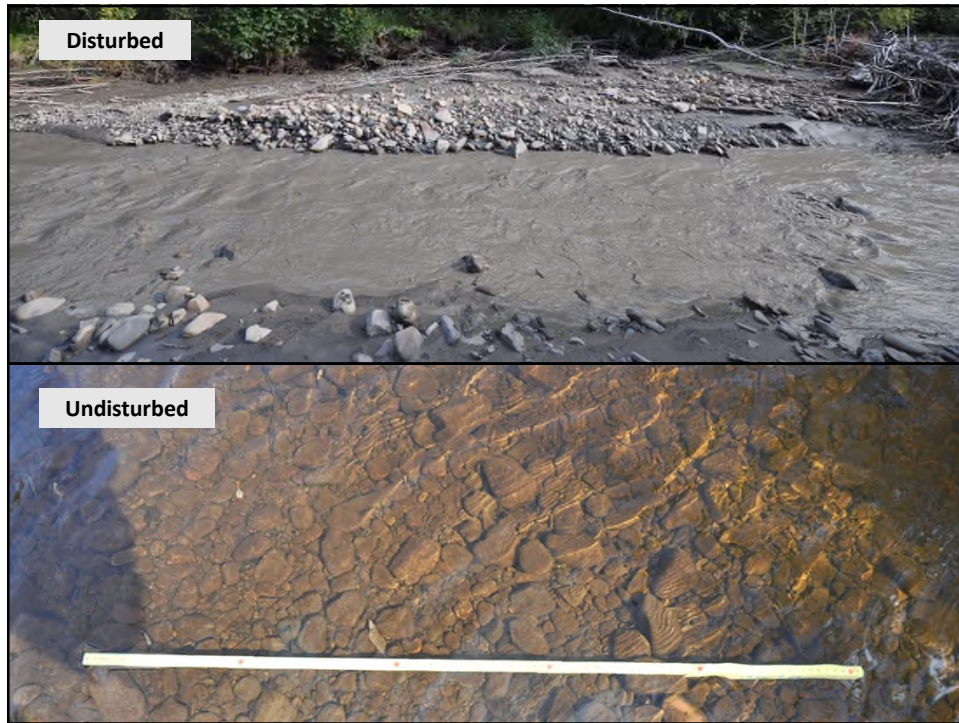


1. Impacts on Freshwater Ecosystems

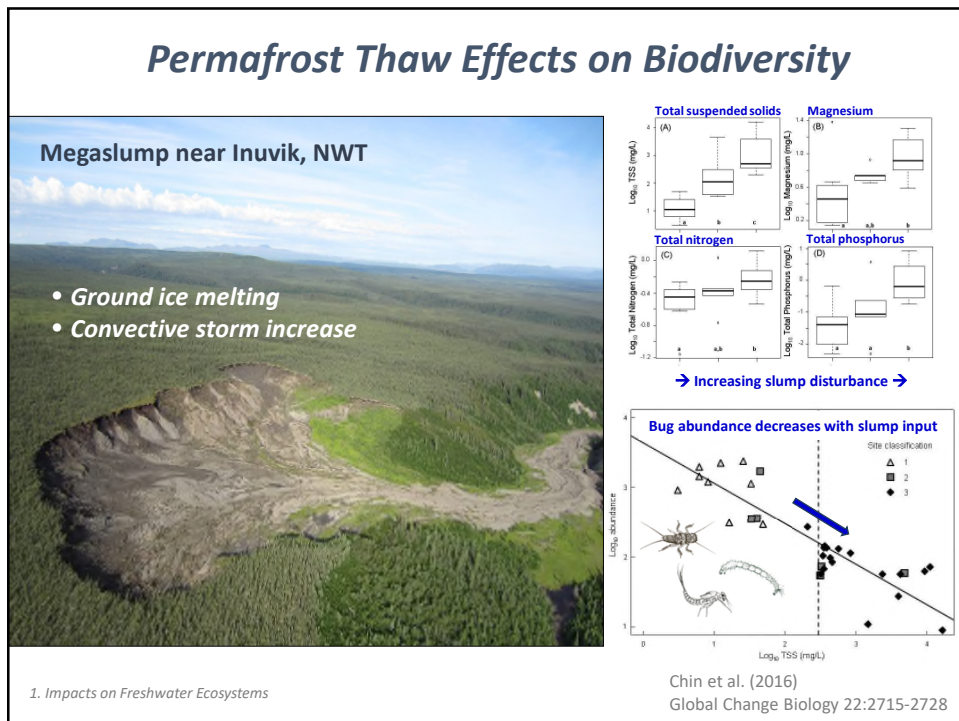
11




12



13



14



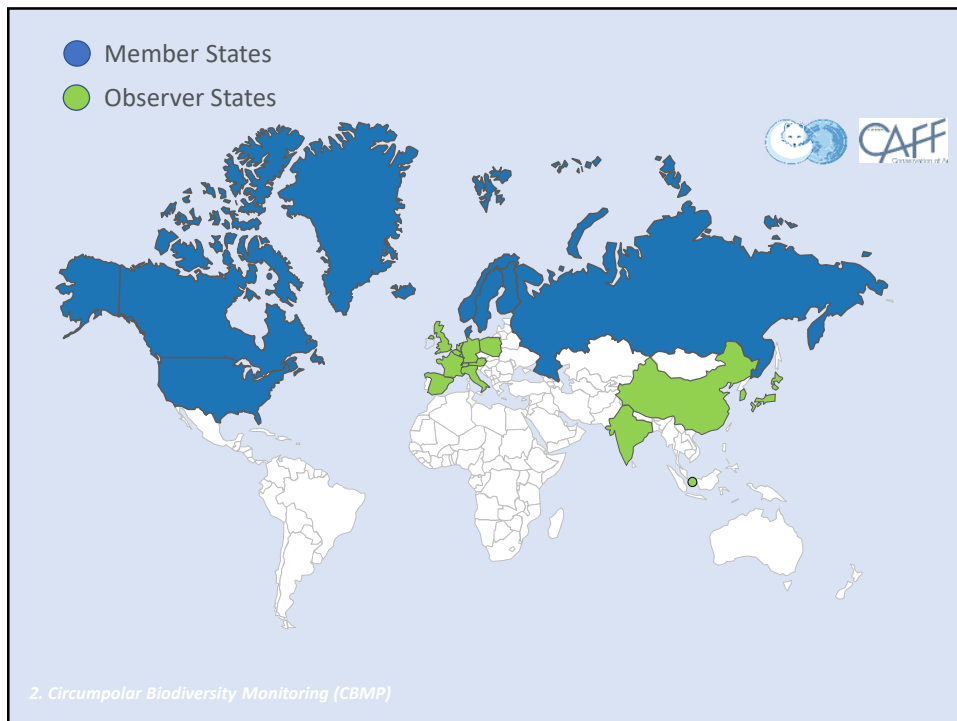
The Arctic Council logo is a circular emblem. At the center is a white arctic fox facing left, with a globe behind it. The text "ARCTIC COUNCIL" is written below the fox. Surrounding the center are 15 stylized human figures in blue and green, arranged in a circle. The text "8 MEMBER STATES" is at the top, "6 WORKING GROUPS" is on the right, "6 INDIGENOUS PERMANENT PARTICIPANT ORGANIZATIONS" is on the left, and "OBSERVER STATES AND ORGANIZATIONS" is at the bottom.

Arctic Council

- Intergovernmental forum
- Sustainable development
- Environmental protection

2. Circumpolar Biodiversity Monitoring (CBMP) 15

15



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CAFF-CBMP: International Approach to Circumpolar Monitoring



- Network of scientists, governments, Indigenous organizations that **harmonize monitoring and assessment of Arctic biodiversity**
- **Facilitate detection and response to the biodiversity related trends and pressures**
- **Capacity building, communication and outreach**
- **Coordinate circumpolar assessments of status and trends in biodiversity**
- **Co-production of knowledge with Indigenous Peoples**



2. Circumpolar Biodiversity Monitoring (CBMP)

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Western Science Perspective

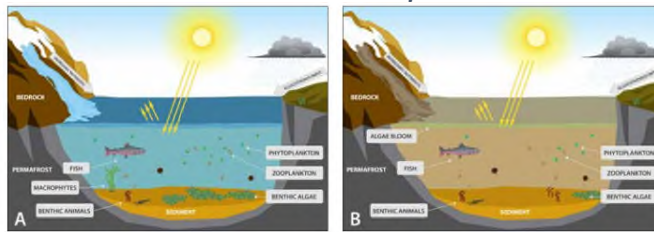


Figure 4-2 (a) Typical Arctic lake food web, including primary and secondary consumers, and indicating vertical placement of food web components in the water column, and (b) Arctic lake food web following climate-change induced inputs of sediments and nutrients, indicating resulting food web shifts with declines in water transparency.

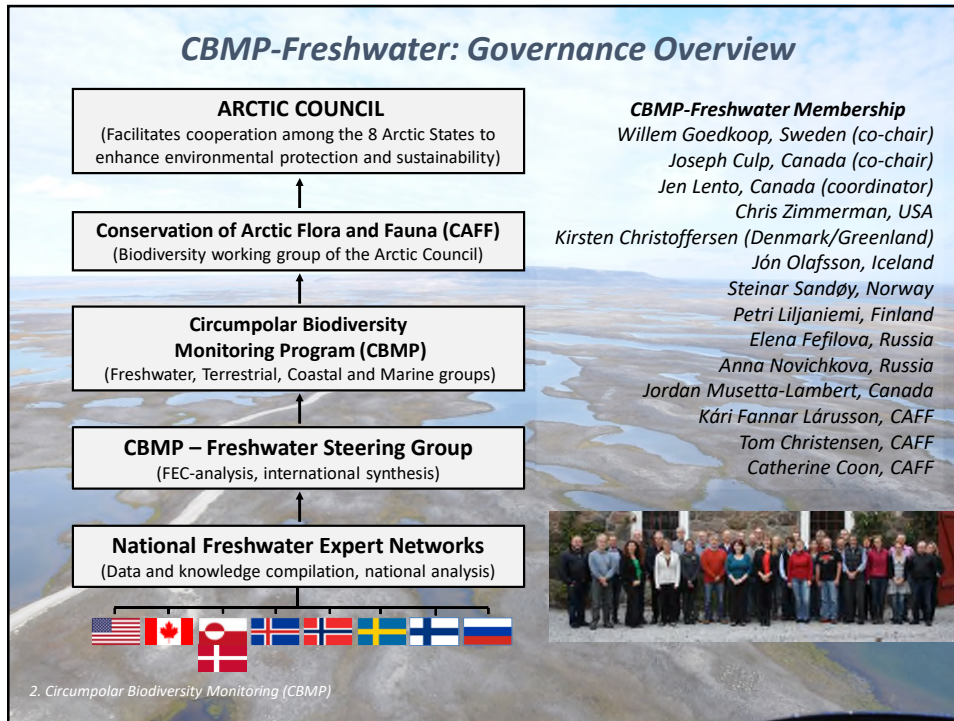
Indigenous Knowledge Perspective



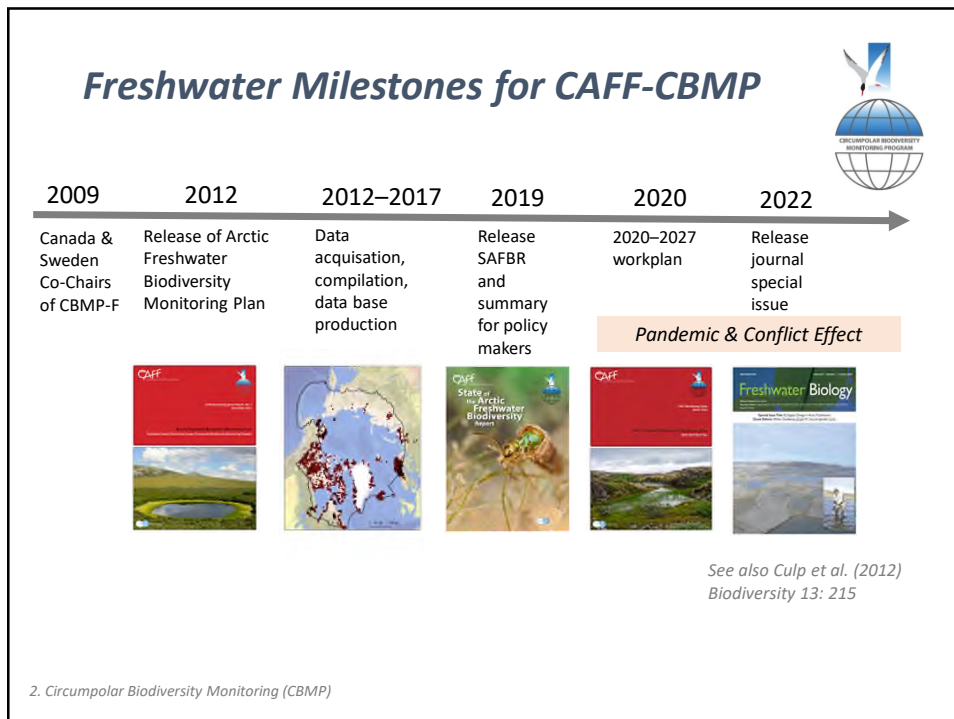
Knowledge Co-Production Requires Trust, Respect and “Two-Eyed Seeing” of Different World Views

2. Circumpolar Biodiversity Monitoring (CBMP)

18



19



20

Freshwater Circumpolar Biodiversity Monitoring Plan (CBMP-Freshwater)

- Assess change in biodiversity of lake and river ecosystems
- Need identified in Arctic Climate Impact Assessment (ACIA-2005) and Arctic Biodiversity Assessment (2013)
- Arctic biological monitoring largely uncoordinated (8 different countries)
- Arctic's size makes detection of change difficult
- Ecosystem-based approach to identify state, trends and causal relationships (*time frame ≥ 10 y*)



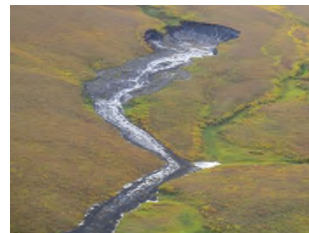
CAFF/ABA Boundaries

2. Circumpolar Biodiversity Monitoring (CBMP)

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Broad Questions for Assessments

1. **What is the current status of Arctic freshwater biodiversity?**
2. **Can biodiversity status be measured through simple variables and indicators; if so, what suite of these should we apply?**
3. Is biodiversity changing; if so, are species increasing, declining, moving or disappearing?
4. **What are the primary environmental and anthropogenic drivers causing this change?**
5. Are boundaries of Arctic/sub-Arctic ecosystems shifting?



3. Biodiversity Pattern & Synthesis

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Focal Ecosystem Components

Focal Ecosystem Component (FEC): *Biotic elements judged to be ecologically pivotal, charismatic or particularly sensitive to environmental change*

State of Arctic Freshwater Biodiversity Report: Focus on biotic FECs with most data and supporting abiotic variables:

Biotic FECs

Consumers

- Fish (Lakes, Rivers)
- Zooplankton (Lakes)
- Benthic invertebrates (Lakes, Rivers)

Producers

- Phytoplankton (Lakes)
- Benthic algae (Lakes, Rivers)
- Macrophytes (Lakes)
- Microbiota



3. Biodiversity Pattern & Synthesis

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Impact Hypotheses / Predictions Developed

- Response relationships of FECs to key drivers
- Statements for “environmental” and “human” stressors
- ~15 impact hypotheses identified for lakes and rivers

Stressor	Lake Impact Hypothesis Example
Shift in nutrient regime from permafrost thaw	Nutrient enrichment → increased nutrient availability → 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

Stressor	River Impact Hypothesis Example
Shift in ice regime	Changes in ice on/ice off → shift between dynamic and thermodynamic breakup → change in frequency of bed disturbance → altered habitat through change in median particle size → shift in community composition and functional diversity, change in productivity

3. Biodiversity Pattern & Synthesis

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Creation of Circumpolar Database

- Collection of new data impractical
- Freshwater biomonitoring tradition (> 100 y):
 - abundance and composition
 - standard methods (inter-calibration)
 - government, industry, academia
- Data collected by each country for each FEC:
 - Largely contemporary information (1950 – present)
 - Some historical data (1800 – 1950)
 - Paleolimnological data for diatoms (lake cores)
 - Multi-year effort with extensive QA/QC
 - National databases (Sweden) vs data islands (Canada)
- Metadata @ CAFF's Arctic Biodiversity Data Service

3. Biodiversity Pattern & Synthesis

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Assessment Data:

- > 9000 stations
 - Abiotic data more extensive
- Extensive spatial coverage
- But few long-term data sets
- Geospatial variables extracted for hydrobasins
- Nomenclature harmonized across circumpolar region
- Organized by station, hydrobasin and ecoregion
- Rarefaction to correct for sample size bias

3. Biodiversity Pattern & Synthesis

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CBMP-Freshwater Assessment (SAFBR)

- SAFBR published online:
Lento et al. (2019)
<https://www.caff.is/freshwater>
- SAFBR-Summary for Policy Makers
<https://www.caff.is/freshwater>
- Freshwater data base archived in Arctic Biodiversity Data Service (ABDS)
- Special issue (*Freshwater Biology* 2022)
- Extensive information on biodiversity trends



3. Biodiversity Pattern & Synthesis

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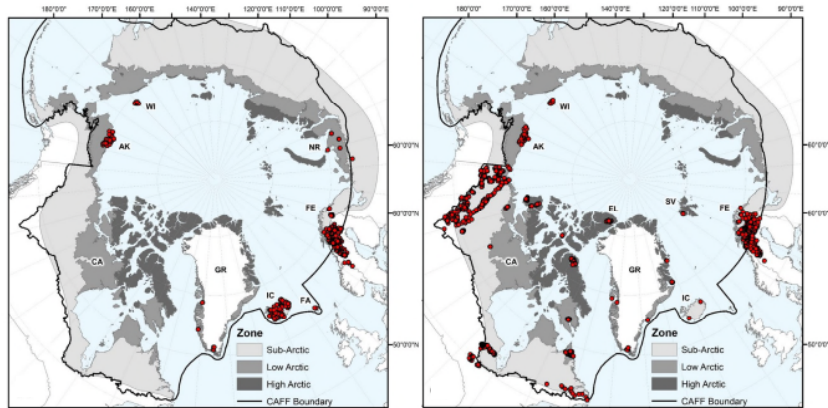
Objectives of Macroinvertebrate (Bug) Assessment

- Focus on lake and river biodiversity of macroinvertebrates
- Assess **spatial patterns** in alpha and beta diversity across the circumpolar Arctic to identify diversity baselines;
- Compare and contrast the roles of **temperature and spatial connectivity** as large-scale drivers of taxonomic composition;
- **Identify environmental correlates** of macroinvertebrate community composition that affect responses to climate change;
- Identify **locations with high biodiversity** and geographic locations for inclusion in future circumpolar assessments of freshwater biodiversity.

3. Biodiversity Pattern & Synthesis

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Benthic Macroinvertebrate (Bug) Sample Locations



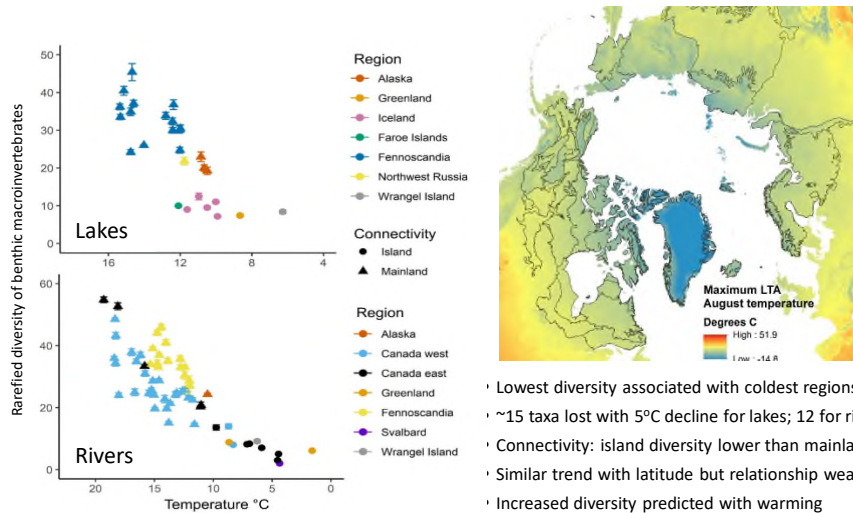
Lakes (n=372)

Rivers (n=1164)

3. Biodiversity Pattern & Synthesis

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Temperature Is Overriding Driver of Freshwater Biodiversity



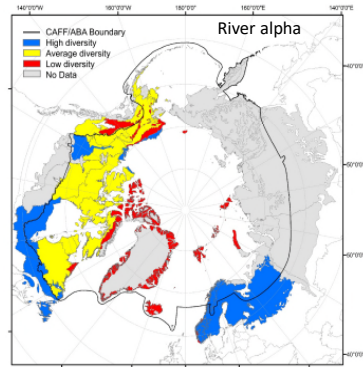
- Lowest diversity associated with coldest regions
- ~15 taxa lost with 5°C decline for lakes; 12 for rivers
- Connectivity: island diversity lower than mainland
- Similar trend with latitude but relationship weaker
- Increased diversity predicted with warming
- Loss of unique cold-adapted species

3. Biodiversity Pattern & Synthesis

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Synthesis of Diversity Across All Organism Groups (Algae to Fish)

- Average standardized diversity for ecoregions
 - FEC rarefied diversity standardized (adjusts for trophic effect)
 - Z scores classified as low (< -0.5), average ($-0.5 < Z < 0.5$) or high (> 0.5)
- Low diversity at high latitudes, high elevations and on islands
 - Associated with low temperature and reduced connectivity
 - High diversity at lower latitudes and Fennoscandia which benefits from Gulf Stream warming
 - Similar pattern in lakes and rivers
- Low diversity regions best represent unique Arctic biota
 - Cold stenotherm taxa gradually risk extinction as southern species arrive
 - Example: charr replaced by brown trout in Fennoscandia
- Irreversible loss of unique Arctic freshwater biodiversity (Heino et al. 2020.)



3. Biodiversity Pattern & Synthesis

Heino et al. (2020)
J. Applied Ecology 57:1192-1198

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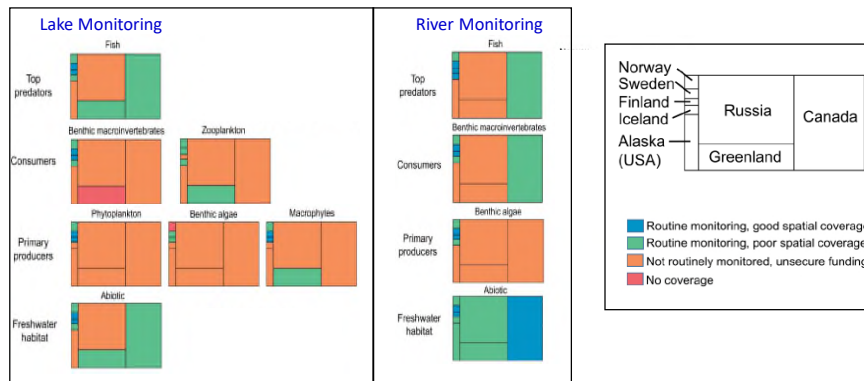
State of Circumpolar Monitoring: Lakes & Rivers

Assessment

- Experts identified monitoring efforts based on **funding, frequency and spatial coverage**
- Water chemistry and quantity monitored more than biota
- Most biotic monitoring occurs in Norway, Sweden, Finland, Iceland
- Canada focuses on fish and BMI (poor spatial/temporal coverage)
- Ability to detect change broadly limited due to lack of time series data

Future need

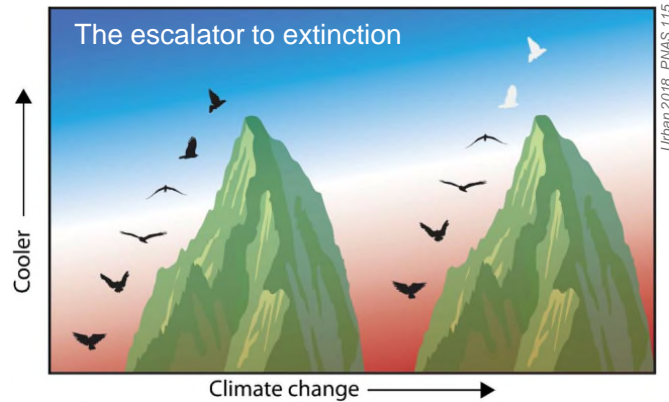
- 2.0 monitoring programs: integrated remote sensing and biomonitoring (hub & spoke design)
- Harmonized monitoring among Arctic countries with required reporting of system state
- Co-production of knowledge with Indigenous Peoples of the Arctic is essential



3. Biodiversity Pattern & Synthesis

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Organism Range Expansion Upon Warming...



4. Summary & Conclusions

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'Escalator to extinction...'

- Southern species migrate northwards and gain competitive advantage over cold-stenotherms
- Cold-stenotherms "at risk" (e.g. char, fairy shrimps, stoneflies)

**"Conveyor Belt to Extinction"
... is an irreversible process**



4. Summary & Conclusions

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Key Messages

What we know?

- Arctic freshwaters are changing rapidly due to multiple stressor effects
- Climate warming effects include shrubification and permafrost thaw that effect freshwater biodiversity
- Existing data useful to establish circumpolar pattern of alpha and beta diversity for FECs
- Large spatial gaps in monitoring coverage and few long-term data series for Arctic freshwaters

What is required?

- Arctic Council as a vehicle for international cooperation in monitoring of freshwater biodiversity
- Coordinated monitoring of freshwaters, standardized methods and data sharing/archiving
- Network of monitoring sites to implement spatial and temporal monitoring
- CBMP database requires regular updating if status and trends are to be assessed

Who needs to be involved?

- Increased interaction among scientists, policymakers, stakeholder groups and the public
- Indigenous Peoples must be included in monitoring and assessment activities of Arctic freshwaters (leadership, planning, execution)

4. Summary & Conclusions

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Funding & Support Teams

The collage features the following logos and images:

- Logos:** LAURIER UNIVERSITY, CAFF, ARCTIC COUNCIL, CANADIAN RIVERS INSTITUTE, UNB, SLU (Svenska lantbruksuniversitetet), Environment Canada, NSERC CRSNG, NORTHWEST TERRITORIES, NWT CIMP, PARKS CANADA, USGS (science for a changing world), Ympäristöministeriö / Miljöministeriet / Ministry of the Environment, and NORWEGIAN ENVIRONMENT AGENCY.
- Photos:** Two men sitting on stone steps; a group of people in outdoor gear around a table; a polar bear in a snowy landscape; a group of people in a meeting; and several group photos of team members.

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***Thank you from
CBMP-Freshwater***

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Further Readings:

Barry et al. 2023. Development of a multi-scale monitoring programme: approaches for the Arctic and lessons learnt from the Circumpolar Biodiversity Monitoring Programme (CBMP) 2002-2022. *Frontiers in Conservation Science* 4:1326672. DOI [10.3389/fcosc.2023.1220521](https://doi.org/10.3389/fcosc.2023.1220521)

Chin et al. 2016. Thermokarst destabilization of ice-rich permafrost terrain drives shifts in stream ecosystems. *Global Change Biology* 22: 2715-2728.

Culp et al. 2012. Developing a circumpolar monitoring framework for Arctic freshwater biodiversity. *Biodiversity* 13:215-227.

Culp et al. 2022. Establishing biodiversity baselines and trends and evaluating drivers of ecological change in circum-Arctic lakes and rivers. *Freshwater Biology* 67: 1-13
<http://doi.org/10.1111/fwb.13831>

Lento et al. 2019. *State of the Arctic Freshwater Biodiversity*. Conservation of Arctic Flora and Fauna International Secretariat, Akureyri, Iceland. ISBN 978-9935-431-77-6.
<https://www.caff.is/freshwater>

Lento et al. 2021. Temperature and spatial connectivity drive patterns in freshwater macroinvertebrate diversity across the Arctic. *Freshwater Biology* 67: 159-175.

[Goedkoop](#) et al. 2022. Improving the framework for assessment of ecological change in the Arctic: A circumpolar synthesis of freshwater biodiversity. *Freshwater Biology* 67: 210-223.

Heino et al. 2020. Abruptly and irreversibly changing Arctic freshwaters urgently require standardized monitoring. *J. Applied Ecology* 57:1192-1198. <https://doi.org/10.1111/1365-2664.13645>

State of Arctic Freshwater Biodiversity Report. 2019. Summary for Policy Makers.
<https://www.caff.is/freshwater>

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