Summary of Knowledge on Alpine River Systems in *Tongait KakKasuangita SilakKijapvinga* (Torngat Mountains National Park), Nunatsiavut, Labrador

Katryna Barone | Dr. Andrew Trant | Dr. Robert Way

A State of Knowledge Report

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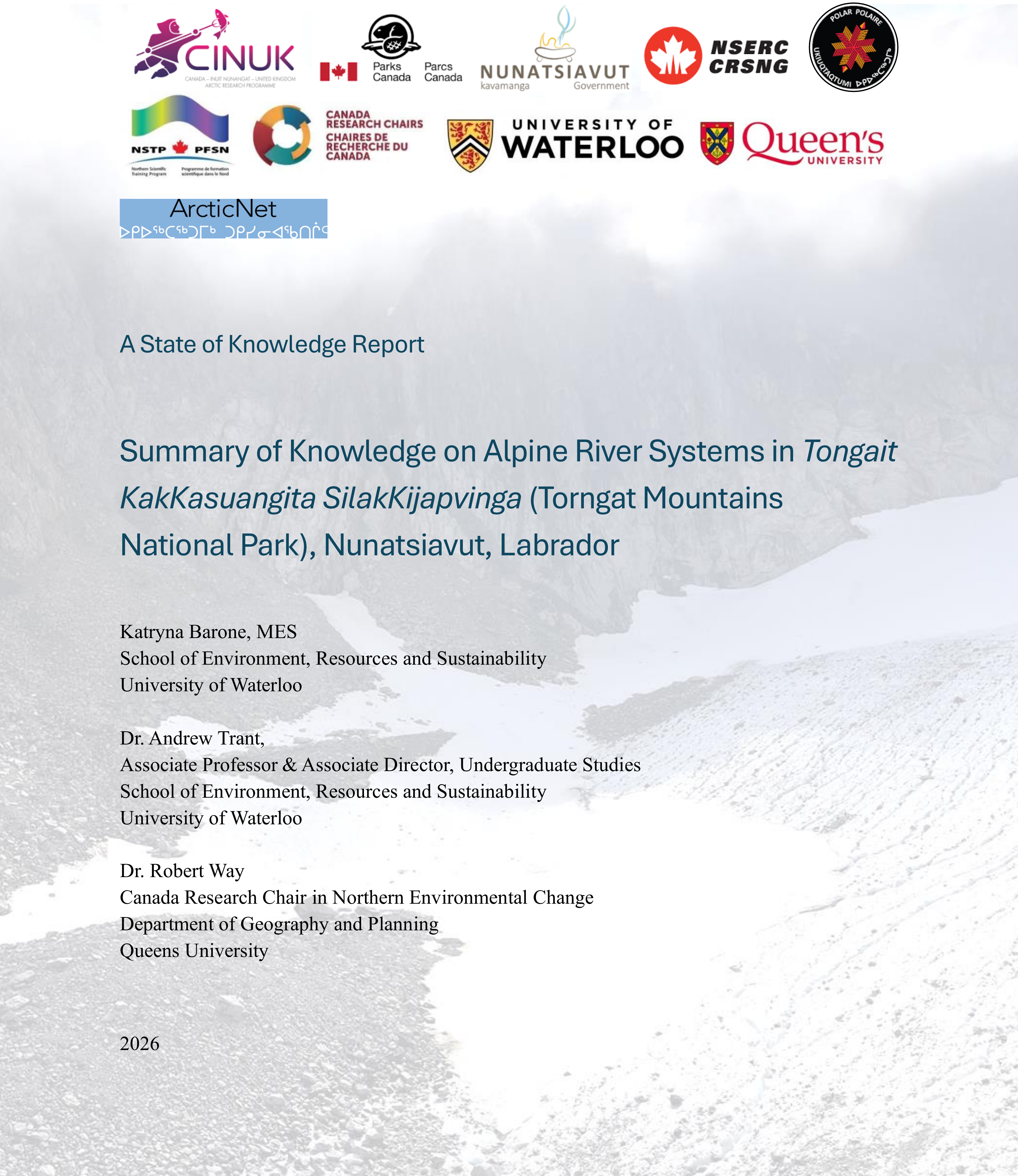

A State of Knowledge Report

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Table of Contents

List of Figures

1: Introduction

The effects of climate change are impacting the Arctic more rapidly than anywhere else on the globe, transforming the land and placing northern communities at the forefront of new environmental challenges and uncertainty (Harris et al., 2020; Malik & Ford, 2025). Remote alpine river systems in the Arctic are among the few pristine features left in the world but will face lasting and severe changes in the coming decades (Slemmons et al., 2013). This is largely the consequence of altered water resources caused by global-scale glacier retreat, decreased snow accumulation, and the development of post-glacial ecosystems (St. Pierre et al., 2019). Expected changes for stream morphology include a reduction in sediment load, increased streamflow variability, warmer water temperatures, increased channel stability, and changes in nutrient content (Bourquin et al., 2025). For freshwater biotic communities, this may constrict the distribution of cold-specialized species, shift the composition of local flora and fauna, and introduce invasive species (Bosson et al., 2023).

Ongoing changes to alpine river systems are likely occurring in *Tongait KakKasuangita SilakKijapvinga* (Torngat Mountains National Park [TMNP]) which is located at the southern limit of the eastern Canadian Arctic in Arctic Labrador and hosts the only remaining glaciers in continental northeastern North America (Way et al., 2014; Barrand et al., 2017). The remote location of TMNP has kept this region's ecosystems largely intact and minimally influenced by anthropogenic change, making it particularly useful for understanding how climate change can impact Arctic ecosystems. However, Hanly et al. (2023) highlights that the remoteness of TMNP has also contributed to a knowledge gap on the current state of the region's alpine river systems and potential risks their downstream environments face as climate change transforms the cryosphere and hydrosphere.

2: Torngat Mountains National Park

2.1 History and Establishment

Human occupation of northern Labrador dates back nearly seven thousand years with archaeological evidence such as tent rings, stone caribou fences, food caches, and burial sites present throughout the region (Brice-Bennett, 1977). The ancestors of Nunatsiavut and Nunavik

Inuit have continuously used this region for hunting, gathering, fishing, and the collection of raw materials for tools, oil lamps, and jewelry and carvings (Government of Canada, 2023). This region is a place of deep spiritual connection for Labrador Inuit with the name "*Torngat*" hailing from Inuttitut meaning "*place of spirits*" (Brice-Bennett et al., 2023). This word is derived from "*Torngarsoak*", a master spirit from Inuit mythology who controls the life of sea animals and takes the form of a huge polar bear believed to reside in the Torngat Mountains (Brice-Bennett, 1977). For over 500 years, the Torngat Mountains were continuously inhabited by Nunatsiavut and Nunavik Inuit, also known as *Avanimiut* or "people of the North". However, between 1956 and 1959, *Avanimiut* were forcibly relocated south from the Okak Bay (Nutak) and Hebron regions by the provincial government to what the government considered to be more "established and centralized" communities (Figure 1). This permanent displacement resulted in monumental social and cultural harm for *Avanimuit*, disrupting their way of life, traditional practices, and depriving them of their ancestral homeland (Brice-Bennett et al., 2023).

Research to identify a possible national park for northern Labrador began in 1969 and a prospective spot in the Torngat Mountains was quickly found. In the 1970s, before park development could be pursued further, the recently formed Labrador Inuit Association (LIA), the political representation for Inuit in Labrador, indicated their intent to file a land claim with the Government of Canada and suggested any negotiations about a national park be included in those negotiations (Brice-Bennett et al., 2023). The land claim was filed to the federal government in 1977 and accepted for negotiation the following year but would take several decades to finalize. Initially, the land claim involved plans to reconstruct a community in the North; however, due to pressure from the federal and provincial governments this idea was abandoned and instead compensation and a formal apology from the provincial government were given to displaced families (Brice-Bennett et al., 2023). In 2005, the Nunatsiavut Government and Torngat Mountains National Park Reserve were established under the Labrador Inuit Land Claim Agreement. On July 10th, 2008, Torngat Mountains National Park officially became Canada's 42nd National Park when the Nunavik Inuit Land Claims Agreement came into full legal effect (Brice-Bennett et al., 2023).

The management of TMNP follows an integrated management structure between Parks Canada and an all-Inuit Cooperative Management Board in recognition of the connection Nunatsiavut and Nunavik Inuit have to this land (Brice-Bennett et al., 2023). The CMB advises the federal Minister of Environment and Climate Change Canada (ECCC) on all TMNP related matters and ensures Inuit traditional knowledge is incorporated in all decisions. The CMB is made up of seven members: two members from the Nunatsiavut Government, two members from the Makivik Corporation who represent Nunavik's Inuit, two members from Parks Canada, and an independent Chairperson. The CMB also provides advice to the Torngat Wildlife and Plant Cooperative Management Board, the Torngat Joint Fisheries Board, the Nunatsiavut Government, and other agencies operating in the area on all matters related to management and conservation (Lemelin et al., 2015). *Tongait KakKasuangita SilakKijapvinga* serves as an important symbol of Inuit legacy and identity in Labrador and protects a land rich in culture and beauty (Brice-Bennett et al., 2023).

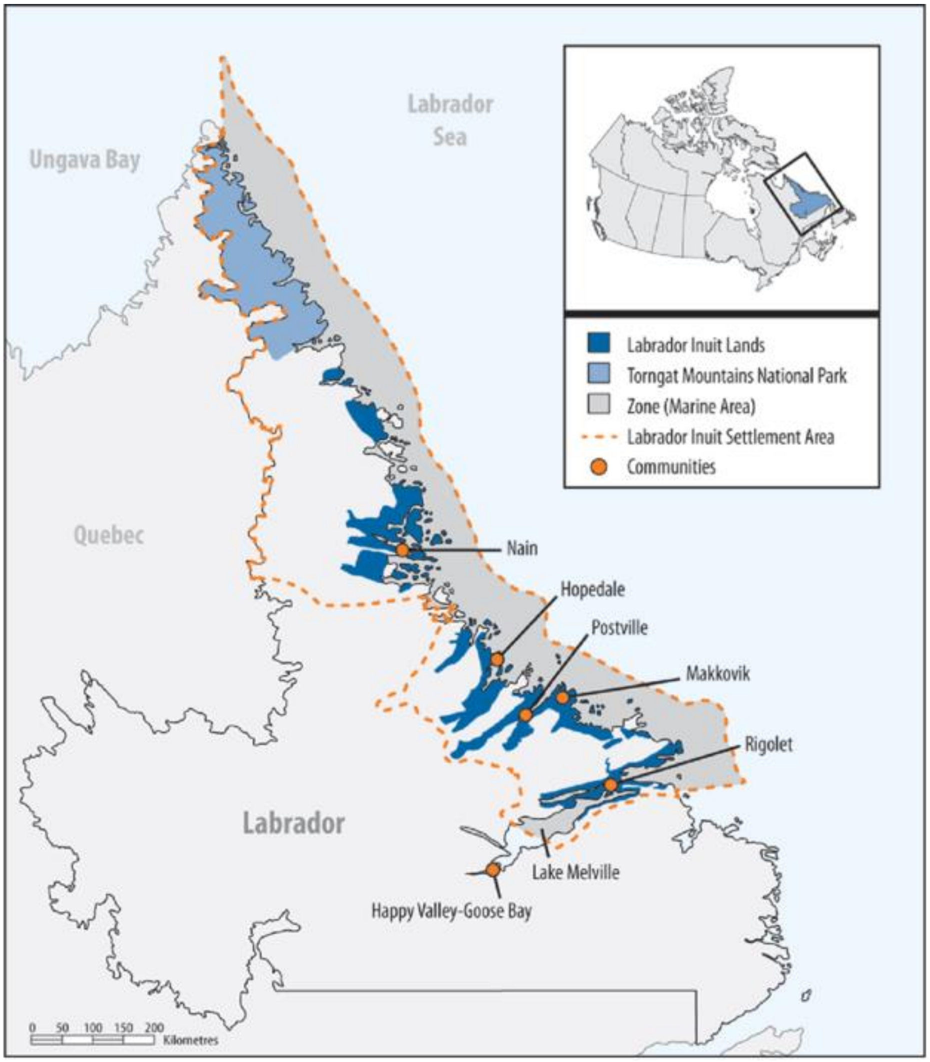

Figure 1: Map of Nunatsiavut and Labrador Inuit Settlement Area showing Nunatsiavut communities and Torngat Mountains National Park. Map retrieved from Ortenzi et al. (2024).

2.2 Geology and Climate

Spanning over 9,700 km^2, TMNP encompasses the northernmost tip of Labrador and the southernmost limit of the Arctic Cordillera ecozone, which extends from northern Labrador to Ellesmere Island. This region is bracketed to the east by the Labrador Sea and to the west by the Quebec-Labrador watershed divide. The Torngat Mountains range includes the tallest mountains in mainland Canada east of the Rocky Mountains and possess the only remaining glaciers in continental northeast North America (Way et al., 2014). The underlying geology of this region is amongst the oldest on Earth with formations such as the Nanok gneiss in Saglek Bay dating back 3.9 billion years. Bedrock is mainly composed of orthogneiss and granite near the coast, undifferentiated gneiss further inland, and sections of sedimentary rocks in the south and igneous intrusions present in the north (Way et al., 2014). The physical landscape of TMNP is composed of two distinct landscapes, the George Plateau and Torngat Mountains. The George Plateau is characterized by sweeping bedrock plains cut deep by massive U-shaped river valleys that run west to east through the Torngat Mountains (Figure 2). The Torngat Mountains are steep and rugged, rising from the ocean and reaching over 1000 meters in prominence, with the highest peak being Mount Caubvick at 1652 m a.s.l., and forming towering cliffs along the coastline. This whole region is littered by evidence of past glaciation, such as deep fjords, drumlin fields, kame terraces, erratics, eskers, and cirques (Riley et al., 2013).

Figure 2: Towering cliffs and U-shaped valleys of Torngat Mountains National Park (photographed by author, 2023).

TMNP is classified as polar tundra and is heavily influenced by the Labrador Current, which keeps summers mild and winters cold and dry (Way et al., 2014). The region's proximity to a coastal moisture source and its steep topography have allowed for the preservation of over one-hundred small mountain glaciers scattered throughout the mountain's cirque basins (Way et al., 2014). Seasonal air temperature models for 2000-2014 for the Labrador-Ungava region show a mean summer air temperature of 7°C, a mean winter air temperature of -17°C, and a mean annual precipitation of 400-700 mm for TMNP (Way et al., 2017). In recent decades, statistically significant warming trends have been observed in Nunatsiavut across all seasons with annual air temperatures warming by 2.4°C since 1940 (Way, 2024).

2.3 Flora and Fauna

Despite the extensive history of human use, TMNP is a relatively pristine wilderness area rich in biodiversity. Much of the vegetation in the northern extent of TMNP is sparse tundra, but in the south a variety of boreal, coastal, alpine, and Arctic plant and animal species can be found (Trant et al., 2022). Foraging animals here survive off of lichen, grasses, low-lying berry plants, and palatable shrubs. These mountains are also home to many iconic Canadian species, such as *nanuq* (polar bear; *Ursus maritimus*), *adlak* (black bear; *Ursus americanus*), *tuttuk* (caribou; *Rangifer tarandus*), *pamiuligak* (minke whale/grumpus; *Balaenoptera acutorostrata*), *kaiguliatsuk* (ringed-seal; *Pusa hispida*), and *ikKaluk*, along with a multitude of bird species, including species-at-risk such as *kotsiutik* (harlequin duck; *Histrionicus histrionicus*), peregrine falcons (*Falco peregrinus*), barrows golden-eye (*Bucephala islandica*), and short-eared owls (*Asio flammeus*) (Government of Canada, 2023).

The Arctic Cordillera is above the latitudinal limit for trees, so dominant woody vegetation is composed of deciduous shrub species which respond quickly to improved growing conditions (McDowell et al., 2023). The most notable ecological change for this landscape has come from the rapid expansion of shrubs, especially in valleys and along river corridors, in a phenomenon coined as "shrubification" (Myers-Smith et al., 2011; Davis et al., 2021). A recent time series of Normalized Difference Vegetation Index (NDVI) in the Nakvak Brook watershed, located in the southern portion of TMNP, shows a significant greening trend over the past four decades. Land cover hindcasts record a 235% increase in shrubs and a 105% increase in wet vegetation cover over the past three decades while forecasts expect an additional 51% increase in shrubs by 2039/43 (Figure 3) (Davis et al., 2021). Enhanced shrub trapping of snow has been implicated in observations of permafrost thaw and carbon release across the circumpolar north (Davis et al., 2021). Shrub expansion can also encroach on other low-lying plants such as berry plants, an important food resource for people and animals, and lichens, which is a primary food source for *tuttuk*, whose numbers appear to be in decline across Canada (Johnson et al., 2025). Shrubification also offers a new complexity to the relationship *tuttuk* have with forage availability as *tuttuk* may eat the palatable shrubs, such as birch and willow, keeping their expansion under control but leave non-palatable shrub species to flourish (Johnson et al., 2025). Another primary concern is that taller and denser shrubs make it more difficult for Inuit and visitors to travel through the land and harder to spot *nanuq* and *adlak*, raising human-wildlife safety concerns (Davis et al., 2021).

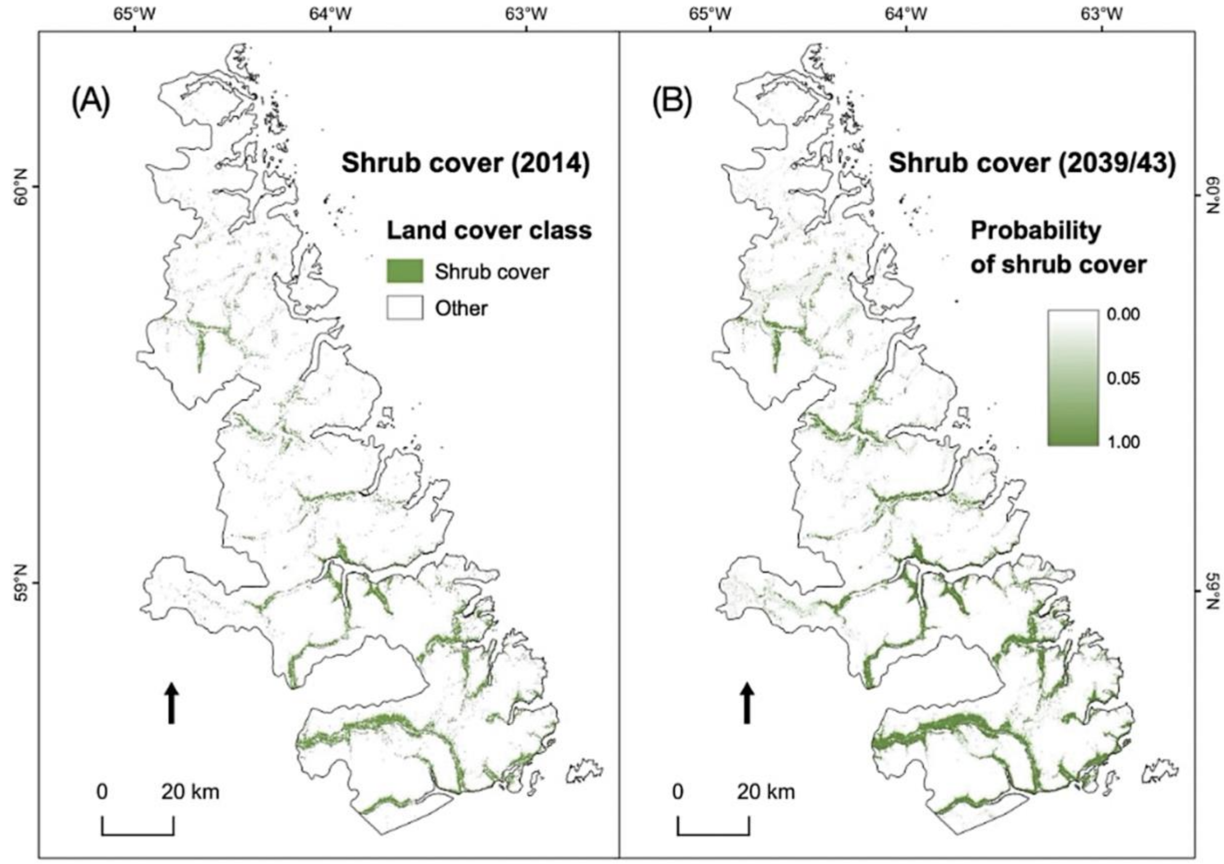

Figure 3: Map of Torngat Mountains National Park and the distribution of shrubs in 2014 (A) and projected shrub expansion in 2039/43 (B). Retrieved from Trant et al. (2022).

2.4 The Cryosphere and Hydrosphere

Ecosystem change in TMNP is expected to be modified by changes in the cryosphere as glaciers and snowpacks shrink leading to major shifts in source water (Brown et al., 2007) (Figure 4). Modelling by Way and Lewkowicz (2016) suggests that the southern portion of TMNP falls within the extensive discontinuous permafrost zone with the northern portion of TMNP residing in the continuous permafrost zone. Thawing permafrost in this region could affect regional hydrology and vegetation cover through the release of stored water, carbon, and nutrients (Giesler et al., 2014). However, little work has been done to understand the extent and changes of permafrost in this area, though current research efforts aim to fill in these knowledge gaps (CINUK, 2023).

Figure 4: Meltwater collecting in a pool at the toe of an Unnamed Glacier in the Blow Me Down Mountains (58.8°N, 62.9°W) (photographed by author, 2025).

While the impacts of permafrost thaw in TMNP are largely understudied, there is at least some knowledge about the region's glaciers. TMNP is home to 105 small alpine glaciers which all occur within 50 kilometres of the coastline and span just over 1° of latitude from 58.6°N to 59.9°N (Figure 4) (Way et al., 2014). Observed changes reveal that these are in steady decline with a regional glacier loss of 27% recorded from 1950 to 2005 and a 52.5% reduction in ice extent since the Little Ice Age (LIA) maxima (Way et al., 2015; Barrand et al., 2017). These studies have linked glacial decline to trends of decreasing winter precipitation and increasing summer and autumn atmospheric warming since the early 1990s. Ongoing changes to the region's glaciers likely have downstream effects on the region's freshwater ecosystems which are an integral part of the cultural landscape for Nunatsiavut and Nunavik Inuit (Barrand, et al., 2017).

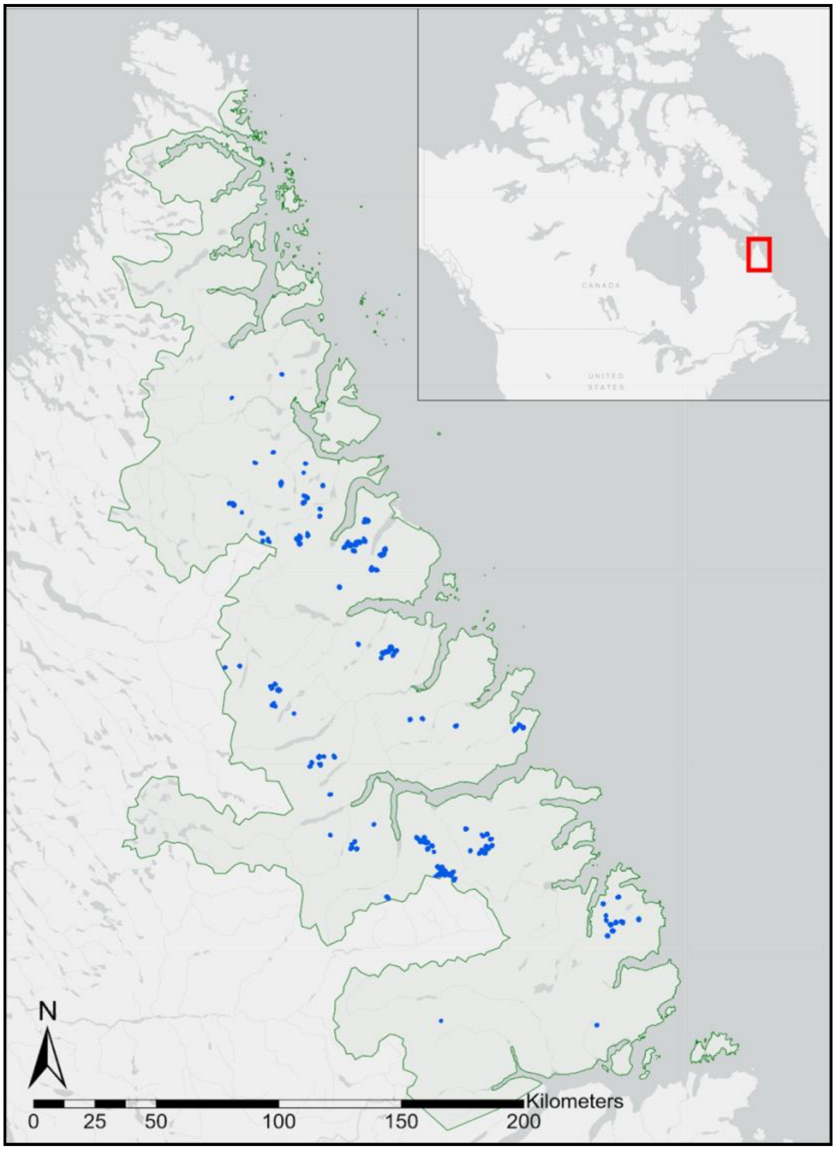

Figure 5: Map of glaciers in Torngat Mountains National Park with glaciers represented in blue and the park boundary outlined in green (basemap imagery from ESRI Canada and Parks Canada's open database, created by the author in 2025).

3: Alpine River Systems and the Cryosphere

3.1 The Role of Glacial Meltwater

Glaciers are important water reservoirs for alpine systems and critical for maintaining streamflow throughout the year especially during the drier, warmer months late in the melt season (Sepúlveda et al., 2022). Globally, alpine glaciers have been responding strongly to climate change and are expected to experience significant mass loss throughout this century (Huss & Hock, 2018).

The general consensus is that as glaciers recede, stream flow will decrease, becoming warmer, slower, and less turbid (Sudlow et al., 2023). These effects will be greatest once the “peak water” threshold is crossed. This refers to the point at which glacier shrinkage results in a surface area too small for the glacier to sustain its previously increasing meltwater contributions from warming conditions (Figure 5). Following “peak water” rivers begin to experience a steady decline in water supply as annual runoff decreases and eventually ceases altogether once the glacier becomes functionally extinct (Clarke et al., 2015). Current projections suggest larger glaciers may reach peak water closer to the end of the century while many small alpine glaciers (< 5km^2) may have already passed their peak water threshold or will reach it in the next few years (Huss & Hock, 2018). Reduced glacier meltwater contributions to streamflow will be most obvious in late summer, when contributions of snow and rainwater are also low (Bliss et al., 2014). Ecosystem shifts also occur following glacier loss as previously glacier fed systems transition to perennial and seasonal snowpatch fed systems, and then much later potentially more barren rain and groundwater fed systems (Sudlow et al., 2023). However, prior to reaching “peak water” glacier discharge will increase resulting in an influx of water and material to downstream environments (Milner et al., 2009). Resulting shifts in source water contribution before and after “peak water” will have a number of dynamic effects for alpine river systems, including modified streamflow, sediment and nutrient transport, thermal regimes, and freshwater biodiversity (Milner et al., 2009; Huss & Hock, 2018; Michelutti et al., 2020).

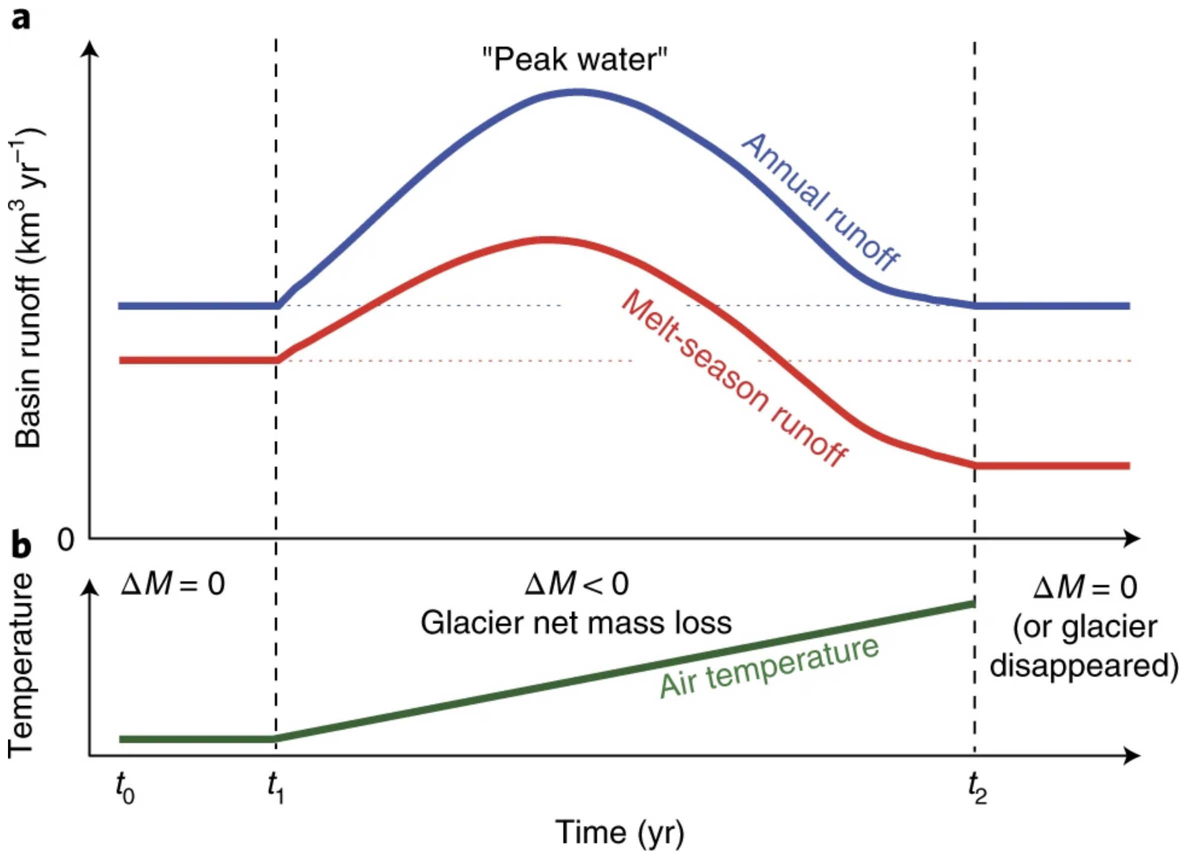

Figure 6: Schematic illustration of changes in annual and melt-season runoff for a glacier fed watershed in response to increasing atmospheric temperatures and glacier net mass loss. Retrieved from Huss & Hock (2018).

3.2 The Role of Snowmelt

Alongside glacier retreat, climate change is also impacting snow deposition and snow melt processes in alpine areas due to rising air temperatures and larger proportions of atmospheric precipitation occurring as rain rather than snow, affecting the magnitude and timing of water availability (Immerzeel et al., 2019). Satellite imagery has shown a multidecadal decrease in snow cover duration and snow depth across portions of Canada's Subarctic and low-Arctic (McDowell et al., 2023). Further, future climate projections show snowlines retreating higher in altitude throughout many major alpine catchments along with earlier and faster seasonal snowmelt (Bavay et al., 2013). This is a major concern for alpine river systems as spring snowmelt is often the largest hydrological event of the year, determining the start of the growing season, recharging depleted groundwater stores, and mobilizing nutrients (Perdrial et al., 2014; Rixen et al., 2022; Hille et al., 2024). Changing patterns in snow cover may lead to more variable hydrological regimes and weaken the relationship between snowmelt and streamflow as spring discharge rates decline (Dyer, 2008).

4: Seasonal Shifts and Expanding River Networks

4.1 Seasonal Discharge

Seasonal variations in streamflow are common for alpine rivers and often coincide with regional climatic patterns of temperature and precipitation (Gibson et al., 2020). Alpine rivers traditionally experience low flows in the winter when a majority of precipitation falls as snow and peak flows in late spring or early summer with the onset of snowmelt, followed by a return to low flow conditions in the summer once the snowpacks have been depleted (Hille et al., 2024). However, glacier fed watersheds can maintain more consistent stream levels throughout the dry season and even have a greater base flow in the winter in comparison to snow fed and rain fed systems as their flow is sustained by glacier melt (Slemmons et al., 2013; Ohlanders et al., 2013). Meltwater from alpine glaciers is also vital for maintaining river flow in years of low flow or drought, buffering flow variability from extreme rainfall events, and recharging groundwater storage (Milner et al., 2009; Huss & Hock, 2018). With glacier retreat and shifting climate patterns resulting in earlier melt, seasonal discharge is likely to eventually evolve towards earlier spring peaks and lower summer flows (Milner et al., 2009).

Shifting precipitation patterns are further changing flow patterns due to an increased frequency of large rainfall events. This will lead rain fed systems, whose streamflow’s peak and ebb throughout the dry season echoing rainfall events, to become further dominated by rain (Déry et al., 2009). In addition, higher volumes of rainfall will lead to thinner snowpacks, increased slumping events, and shallower frozen upper soil layers, allowing for higher soil moisture contents and the mobilization of solutes within the active layer (Wang et al., 2024). Between increasing rainfall and ongoing cryospheric change, alpine river systems are moving towards a more intensified hydrological cycle affecting the volume, timing, and pathways water will take through a watershed (Wrona et al., 2016).

4.2 Development of Proglacial Zones

The environment situated directly in front of a glacier is known as the proglacial zone. Ecological succession of newly established proglacial zones is currently one of the fastest ongoing ecosystem shifts taking place around the globe with around 78% of areas emerging from glacier retreat expected to be terrestrial (Bosson et al., 2023). As glaciers continue to retreat, more proglacial zones will be revealed, and river networks are expected to expand into these newly emerged higher elevation zones at a rate of 1% per decade (Wilkes et al., 2023). This may result in reorganization of river routes and sediment transport in the upper catchments of watersheds with the growth of proglacial zones and shrinkage of glacial headwaters (Shugar et al., 2017). The expansion of proglacial ecosystems and different stages of ecological succession between them can diversify local habitat conditions, increase ecological connectivity, and help generalist species adapt (Bosson et al., 2023). However, how and at what rate proglacial zones will develop depends on relative contributions of ice and snow, proximity to glacier sources, and local climatic conditions (Slemmons et al., 2013).

4.3 Sediment Transport

The presence of unconsolidated sediment and glacial till in emerging proglacial zones allows for a greater length of active channel braiding and high sediment loads in streams (Slemmons et al., 2013). The hydraulic intensification of watersheds leading to more frequent flooding events and increased weathering processes can further contribute to higher sediment loads (St. Pierre et al., 2019). This can reduce stream stability, light penetration, and oxygen content, making downstream conditions difficult for some aquatic organisms by impacting photosynthesis, primary production, and visibility (Slemmons et al., 2013).

The effects of increasing sediment transport are expected to be greatest prior to "peak water". Following "peak water" lower streamflow will reduce turbidity and weathering processes, decreasing sediment transport and allowing for stream bed stabilization (Sudlow et al., 2023). Reductions in suspended sediments will then allow for greater light penetration and better stream clarity, leading to increased biotic activity in freshwater environments and the greening of stream channels (Bourquin et al., 2025). Enhanced greening of proglacial zones is predicted to further alter hydrological, nutrient, and carbon cycles by elevating evapotranspiration rates, increasing the uptake of water and nutrients for plant growth, and stabilizing stream channels (Hou et al., 2022; Milner et al., 2009).

5: Alpine River Systems and the Carbon Cycle

5.1 The Role of Rivers in the Global Carbon Budget

River systems have been historically overlooked when investigating global carbon budgets due to the small portion (<1%) of the Earth's surface they cover and the difficulty in determining their carbon contributions as seasonal changes in streamflow make carbon balances highly variable (Schrope et al., 2000; Isaak & Rieman, 2013; Perdrial et al., 2014). However, recent studies have shown that rivers play an important role in regional and global carbon cycles due to their unique influence as both net sources and sinks of dissolved carbon (Schrope et al., 2000; Zhang et al., 2024). Carbon input to river systems can occur in various ways such as flushing through decomposing organic matter in soils from surrounding terrestrial landscapes, erosion from carbon-containing rock, soil respiration beneath waterways, and biological functioning of freshwater habitats such as aquatic plant respiration (Slemmons et al., 2013). The abiotic and biotic processes occurring in alpine rivers mean they typically become supersaturated with carbon dioxide (CO^2) (St. Pierre et al., 2019). While some CO^2 remains in streams, or is stored in the ocean, a large fraction of it enters back into the atmosphere through degassing (Schrope, 2000). Hou et al. (2022) estimate that rivers release ~40% of their CO^2 into the atmosphere through outgassing, store ~20% through sediment burial, and deliver the remaining ~40% to marine environments. Further work by Kerins et al. (2024) suggests that though alpine rivers tend to be small, they are so abundant that they may contribute to a third of global stream CO^2 contributions through degassing, an amount equivalent to 16% of the annual global land carbon sink. This contribution is predicted to increase in the future as warmer water temperatures allow for less CO^2 storage (Schrope, 2000).

5.2 Dissolved Organic and Inorganic Carbon

Rivers transport both organic and inorganic forms of carbon. Organic carbon occurs as carbon compounds found in living organisms and contributes to primary production and respiration in rivers. Inorganic carbon occurs as carbon dioxide (CO^2), carbonic acid (H^2CO^3), bicarbonate (HCO^{3-}), and carbonate (CO^{3-2}) and regulates the acidity and buffering capacity of rivers and is needed for photosynthesis (Cole & Prairie, 2014). The two most investigated forms of carbon in streams are dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC), which are defined as the fraction of organic and inorganic carbon able to pass through a 0.45 µm filter (Kerins et al., 2024). Both DOC and DIC are important for aquatic food webs and ecological functioning in riverine habitats as they provide the basis for primary production, regulate pH balance, and influence the overall biogeochemistry of streams (Zhang et al., 2024). The main sources of DOC come from the degradation of terrestrial vegetation releasing organic matter into soils and root exudates while the main sources of DIC are physical and chemical weathering, biotic respiration processes, and the oxidation of DOC into CO^2 (Kerins et al., 2024; Zhang et al., 2024). Proportions of DOC and DIC in a river are governed by climatic factors such as air temperature and precipitation, biological factors such as vegetation growth stage, type, decomposition, and proportion of wetland cover, and physical characteristics such as watershed area, sediment depth, underlying geology, and rates of stream discharge (Hou et al., 2022). For alpine rivers, glaciers can be an important source of DOC and DIC concentrations (Liu et al., 2023).

Glacial catchments typically have low amounts of DOC due to sparse vegetation cover and poorly developed soils (Slemmons et al., 2013). However, water stored in glaciers can hold a large amount of DOC due to years of biologic carbon sequestration, accumulation of soil and plant matter blown onto glacial surfaces, and the biological activity of supraglacial microbial communities on glaciers (Figure 6) (Milner et al., 2017; Liu et al., 2023). As glaciers retreat and stream flow increases, DOC concentrations in alpine river systems are predicted to increase as stored DOC is free to enter into river systems and increased streamflow will lead to greater flushing of DOC from surrounding ecosystems (Slemmons et al., 2023; Kerins et al., 2024). While DOC may increase under an intensified hydrological cycle, DIC is predicted to decrease due to dilution (Giesler et al., 2014). This is due to DOC being produced in younger, shallow soils which are more easily flushed out during high flows. Meanwhile, DIC is more abundant in older, deeper groundwater stores that take longer for water to penetrate and seep back out of (Battin et al., 2023; Kerins et al., 2024).

Figure 7: Photos of moss (left) and leaves (right) found on the surface of an Unnamed Glacier in the Blow Me Down Mountains (58.8°N, 62.9°W).

Changes to the carbon cycle in alpine systems are also expected from regional warming. For example, the decomposition of alpine litter mainly occurs in winter, which is then covered by snow and ice and will not enter streams until the snowmelt season (Hou et al., 2022). As snowmelt advances earlier in the year due to warming winter temperatures, this will lead to an earlier influx of DOC with potential impacts on the timing of biological activity downstream (Ejarque et al., 2021). Heavier runoff from increased precipitation events can also increase riverbank scouring and weathering, raising both DOC and DIC concentrations (Hou et al., 2022). Regional warming will also increase active layer thicknesses where permafrost is present, leading to more pronounced subsurface flow and transport of carbon stored in soil (Zhang et al., 2024). Cumulatively, these changes will likely shift the ratio of DOC and DIC in alpine river systems, though the timing and outcomes of this are still largely unknown. This presents a challenge in predicting how regional and global carbon balances will be affected and how future conditions for riverine habitats may adapt (Hou et al., 2022).

6: Alpine River Biodiversity and Habitat Change

6.1 Changes in Community Composition

The strongest determinant of biodiversity and community composition in alpine regions is the ability of a species to tolerate extreme physical and chemical conditions in an unstable environment (Ritcey & Culp, 2008). However, being highly specialized for these conditions can also restrict many of these species to specific areas, making it hard for them to adapt to changing climate conditions (McDowell et al., 2023). For freshwater species, branching networks of river systems create additional challenges as rivers can be easily fragmented leading to the isolation of populations, separation from resources and habitats, and potential to be trapped by warm temperatures and upstream limits of watersheds (Brown et al., 2007; Isaak & Rieman, 2013). Currently, the greatest threat to alpine river biodiversity is expected to come from the loss of suitable habitat space for cold-water species and the range expansion of warm-water species that may outcompete cold-water species (Culp et al., 2019; Wrona et al., 2016).

The predicted upward expansion of warm-water species in alpine river systems is attributed to declining influences of cryospheric processes. Rivers fed by glaciers have unique characteristics compared to snow and rain fed streams due to colder temperatures, channel instability, large sediment loads, seasonal ice cover, and highly turbid flows (Brown et al., 2007; Kosek & Ruman, 2021; Wilkes et al., 2023). Climate change projections suggest alpine river systems will experience an increase in average stream water temperature and electrical conductivity, and a decrease in turbidity and pH levels, allowing for more favourable conditions for generalist species to emerge (Bourquin et al., 2025). Furthermore, longer growing seasons are likely to enhance plant growth and biological productivity (Milner et al., 2009; Griffiths et al., 2017). Longer growing seasons and earlier meltwater peaks will also allow stream channels to stabilize earlier in the year leading to fewer disturbance events and more opportunities for plant biomass to accumulate (Sudlow et al., 2023). As a result, it is likely that shifts in biodiversity patterns of freshwater ecosystems will occur, including an increase in species richness and species turnover, as cold-water species are outcompeted (Culp et al., 2019). The arrival of certain species from the south may further alter regional hydrological regimes. For example, species such as dam-forming beavers, nitrogen fixing alder, algae, and mat-forming cyanobacteria can alter streamflow levels, evaporation and runoff processes, and nutrient cycling. For people living in northern communities, ecosystem changes following the arrival of southern species raise concerns about water quality and drinking water safety, and alterations to ecologically and culturally important habitats (Wrona et al., 2016).

6.2 Threats to Cold-Water Species

Water temperature in streams is strongly correlated to air temperature, and it is expected that climate change will lead to a rise in both water temperature and air temperature. A decline in the contribution of cold glacier and snow meltwater, and reduced streamflow limiting the thermal capacity of rivers to buffer against heating will also contribute to increased water temperatures (Milner et al., 2017). Warmer conditions would then be expected to favour more warm-water species over cold-water species who may have a more difficult time adjusting to changing temperature regimes. This is a special concern for people living in northern communities as it may impact economically and culturally important species, such as fish (Milner et al., 2009).

Salmonid species such as *ikKaluk* (Arctic char; *Salvelinus alpinus*) can be found throughout the Canadian Arctic but in northern parts of Quebec and Labrador they are endemic to alpine rivers due to specific thermal tolerance levels (Figure 7) (Brown et al., 2012; McDowell et al., 2023). This species requires moderate water temperatures between 5°C and 9°C, with overwintering temperatures between 0-2°C, and optimal spawning temperatures estimated to be at 7°C (Harris et al., 2020). A recent study centered on rivers in Nunatsiavut, Labrador, demonstrated that during warm water events, habitat for *ikKaluk* is constricted and results in behavioural changes. These changes include reduced or ceased feeding and growth, less territorial behaviour during spawning season, and movement to cooler river sections to escape thermal stress. In some rivers premature mortality of *ikKaluk* has been reported following warm water events along with delays in upstream migration and altered habitat use due to low water levels (Geissinger et al., 2024). However, it is possible that *ikKaluk* and other cold-water species may adapt to changing conditions and find refuge in colder upstream catchments where glaciers and perennial snow patches persist (MacMillan-Kenny et al., 2025).

Figure 8: *ikKaluk* (Arctic char; Salvelinus alpinus) jumping upstream in the Komaktorvik River (59.12°N, 64.05°W) (photographed by author in August 2025).

Predicting where and how long suitable habitats may persist proves a challenge as it is unclear how ecological communities will adapt and how transportation corridors may be affected by changing streamflow levels and thermal regimes. Wilkes et al (2023) suggest that riverine habitats will change dynamically in the future rather than linearly due to the unique geographical characteristics of individual catchments and the size of resident glaciers leading to non-uniform ecosystem development. Due to this, a better understanding of how resilient these environments are to warming conditions and shifts in source water contributions is needed to understand how change will occur in order to protect at-risk species (Michelutti et al., 2020; Wilkes et al., 2023).

6.3 Pollutants and Contaminants

There are concerns surrounding whether glaciers and perennial snowpacks can act as repositories for pollutants and contaminants due to their long-term storage capabilities (McDowell et al., 2023). Glaciers can harbour bacteria, fungi, viruses, and chemicals transported by long-range atmospheric processes, such as perfluorinated chemicals (PFCs), mercury, and persistent organic pollutants (POPs), the release of which can impact the integrity of downstream ecosystems and alter freshwater chemistry (Slemmons et al., 2013; Wrona et al., 2016). In addition, changes in the hydrosphere in alpine areas may mobilize contaminants from terrestrial ecosystems and distribute them throughout watersheds (Wrona et al., 2016). River sediments and aquatic organisms can act as sinks for pollutants and contaminants, allowing for these to accumulate in alpine environments and food webs over time (Kosek & Ruman, 2021). This poses risks to the health of alpine river systems and even in some cases northern communities (Wrona et al., 2016). Community observations of microplastics in fish and increased precipitation of contaminants affecting air and water quality in Nunatsiavut confirm that pollution is already occurring, raising concerns about food and water security (Nunatsiavut Government, 2024).

7: Alpine River Systems in the Torngat Mountains

7.1 Projected Changes to Alpine River Systems

Similar to other alpine areas the hydrological regimes in TMNP can be categorized as glacier-dominated, snow-dominated, rain-dominated, groundwater-dominated or a hybrid of these systems (Figure 8) (McDowell et al., 2023). Changes in glacier extent, source water contribution, and the quantity and quality of riparian vegetation are likely to have the greatest influence on stream function and structure in this area (Ritcey & Culp, 2008). Future warming is expected to make stream flow warmer, slower, and less turbid, with glacier loss altering downstream environments to resemble those of more barren non-glacial systems in the future (Sudlow et al., 2023). Prior to reaching “peak water” a wetter climate is anticipated to become a major impact of increased glacier melt due to higher rates of discharge impacting downstream ecology (Slemmons et al., 2013). Future changes to TMNP’s alpine river systems and their habitats are anticipated which raises environmental and cultural conservation concerns.

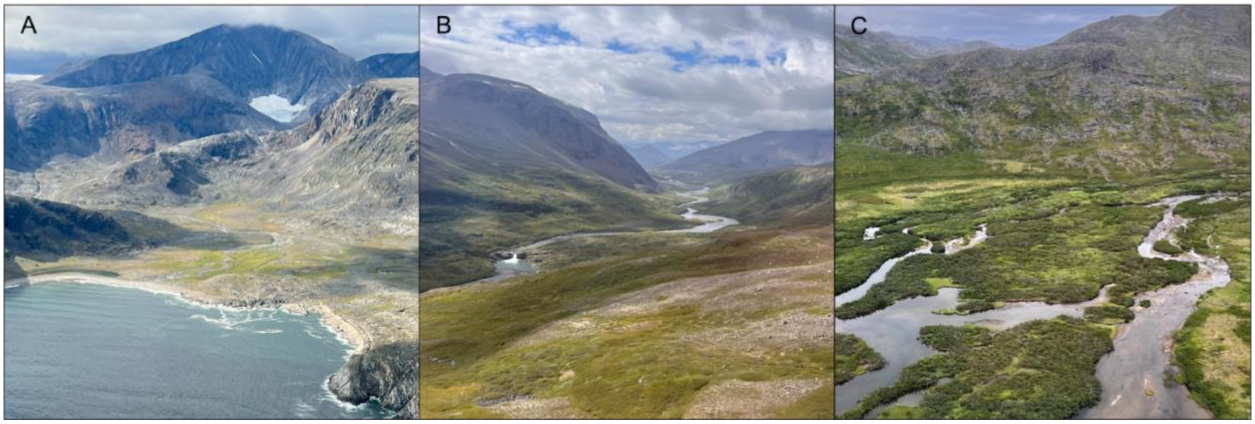

Figure 9: Photography of three valleys in TMNP fed by different source waters. (A) Glacially-fed Blow Me Down Mountains (58.8°N, 62.9°W). (B) Snow-fed Nakvak Brook (58.6°N, 63.3°W). (C) Rain and groundwater-fed Torr Bay Brook (58.4°N, 62.8°W) (photographs by Andrew Trant in August 2022, and the author in August 2024).

7.2 Implications for Ecosystems and Livelihoods

TMNP supports a diversity of plants, animals, and waters, and fosters a sense of place and culture. The protection of TMNP ensures the protection of diverse and remarkable landscapes and sustainability for Inuit homelands (Brice-Bennett et al., 2023). Though protected areas can guard against habitat and species loss, they are still at the mercy of climate change and associated environmental transformations (Holsinger et al., 2019). Continued warming will continue to change freshwater systems in the region, altering local climate and weather patterns, snow accumulation, species distribution, nutrient cycles and carbon balance, and posing a threat to northern ecosystems and communities (Thorne et al., 2024).

The effects of climate change have already begun to impact the way of life for the people of Nunatsiavut. The *Silavut Asianguvalliajuk Nunatsiavut Climate Change Workshop* hosted in Nain in 2024 included extensive discussion of the ways in which Inuit have seen the land change and how it has impacted their way of life, identity, and ability to use and connect to the land (Nunatsiavut Government, 2024). Examples of ongoing changes included shifts in migration patterns for birds and locations of edible berry patches, unpredictable seasonal sea ice formation making winter travel more dangerous, increases in polar bear encounters as sea ice declines, more intense storm and weather events, and previously unseen southern wildlife species being spotted. One consistent theme throughout the workshop was that despite these challenges, Nunatsiavummiut are resilient and ready to take on the uncertainty climate change presents (Nunatsiavut Government, 2024). Today, there is both a need and a will for more standardized and consistent environmental monitoring in TMNP in order to produce meaningful research and help communities design effective conservation and adaptation strategies (Isaak & Rieman, 2013).

7.3 Hydrological Monitoring and Knowledge Gaps

Alpine river systems are ideally suited for studying the hydrological effects of climate change due to minimal direct human influence and their sensitivity to temperature change (Slemmons et al., 2013). The management and conservation of alpine river systems requires knowledge on how water moves and changes through a watershed. Unfortunately, due to limited resources there are few long-term hydroclimatological monitoring stations across northern Canada (Gibson et al., 2020). This is a fundamental challenge for stream hydrology research as it is difficult to explain and predict how water will flow through a landscape without long-term records. Each watershed also has its own unique characteristics, making it impossible to generalize river processes (McMillan et al., 2025). Still, developing a solid understanding on the current state of alpine river systems will help future monitoring and conservation efforts (Wrona et al., 2016).

Past hydrological monitoring in TMNP has been limited but this area has been identified as a priority by the CMB to better understand how changes in stream temperature and flow may affect local fish populations, biodiversity, and ecological functioning of aquatic and riparian ecosystems (Nunatsiavut Government, 2025). To begin to address this challenge, the IMAGINE team, an interdisciplinary research project investigating changes in the cryosphere and hydrosphere and their impacts on northern ecosystems and livelihoods, began collecting stream water samples in TMNP in August of 2024. Water samples were collected for the purposes of stable isotope tracing and aqueous carbon measurement and analyses. Stable isotopic tracers add value to hydrological monitoring and the prediction of future conditions in TMNP as they can track streamflow mixing and sources, estimate evaporation and water residence times, and gain knowledge of local water cycle variability (Gibson et al., 2020). Regular isotopic sampling can help detect early evidence of climate change impacts to alpine river systems, allowing us to better protect freshwater resources and habitats (Gibson et al., 2020). Monitoring of aqueous carbon in alpine rivers also provides a wealth of knowledge on the ecological functioning and material transport processes of alpine watersheds (Milner et al., 2017).

Figure 10: Photograph of water sampling team including the author and Inuit Youth Research Technician (IYRT) team (Ella, Melissa, and Jessica) collecting water samples and field observations in Nakvak Brook (58.6°N, 63.3°W) (photographed by Robert Way in August 2024).

The IMAGINE Team has also installed three hydrological monitoring stations in the southern portion of TMNP since 2023. The goal of these stations is to monitor changes in stream height throughout the year, building on an existing network of similar hydrological monitoring stations run by Parks Canada (Government of Canada, 2023). Consistent and long-term monitoring of stream level is needed to better understand existing hydrological trends and track future in response to shifting atmospheric patterns. In addition, stream level monitoring is a useful and non-invasive tool to monitor seasonal changes in stream flow, including the onset of snowmelt, precipitation events, and drought and flooding conditions, and can help establish reliable baseline hydrological data for TMNP (Depetris, 2021; Immerzeel et al., 2019). Building on the legacy of the IMAGINE Project, a new ArcticNet project (FORGE-TMNP) will continue this research to guide management decisions and safeguard alpine ecosystems and resources. As we embark towards a warmer world, it is important to consider what the future holds for alpine river systems as the sources that feed them disappear, and how we can best inform stewardship of these landscapes for generations to come.

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