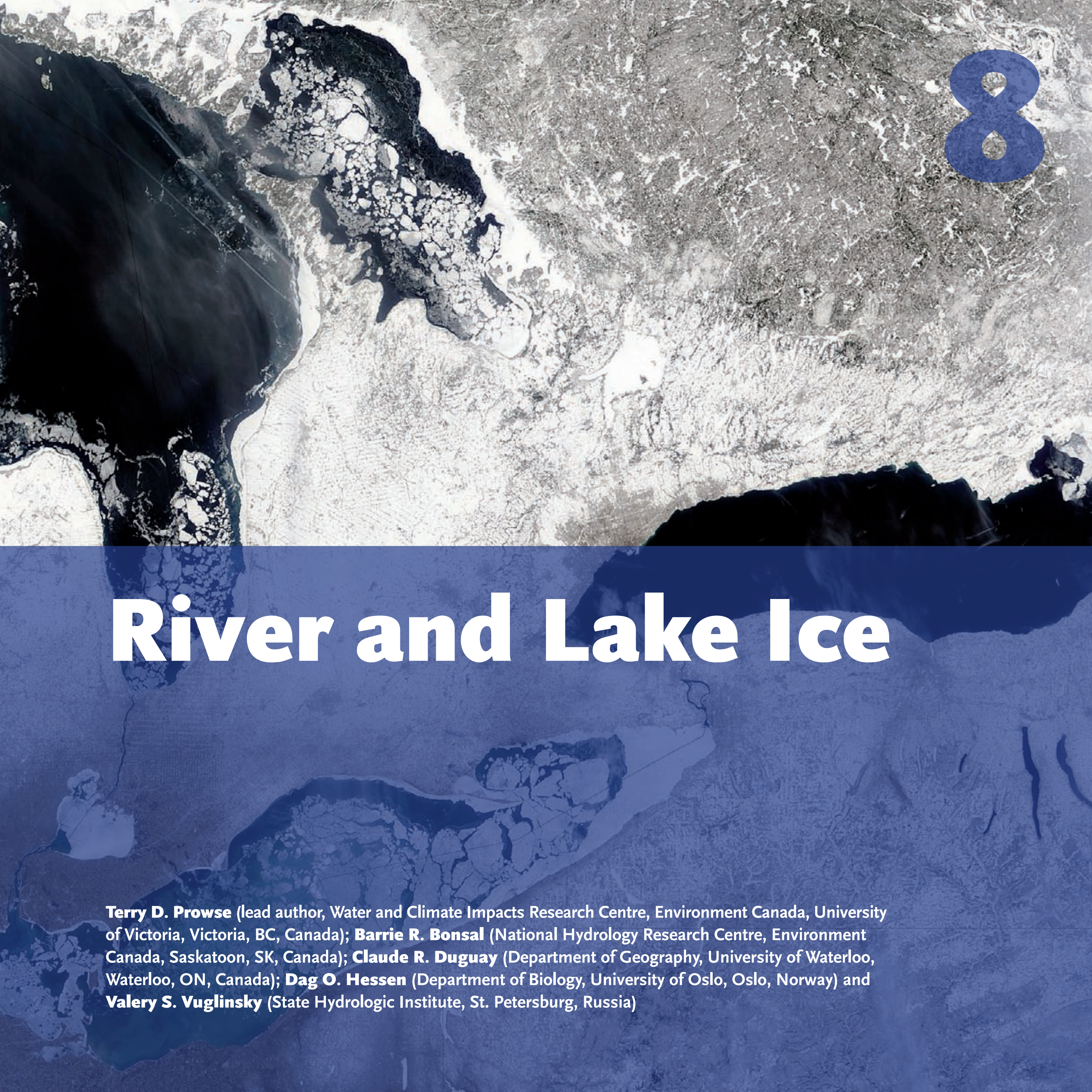

8

River and Lake Ice

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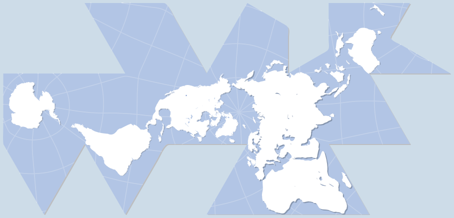
River and Lake Ice

Summary

Floating freshwater ice is a key component of cold-regions river and lake systems. Ice creates and controls unique aquatic habitats and related biological productivity and diversity. It also poses major challenges (for example, flood threats) and opportunities (for example, transportation) for communities. Changes in freshwater-ice cover have largely mirrored trends in air temperature, with large regions of the Northern Hemisphere experiencing reductions in ice-cover duration characterized by earlier spring break ups and, to a lesser degree, later autumn freeze ups, particularly over the last 50 years. Although more dramatic changes in the timing and duration of the ice season are projected for the future, our understanding of how climate has affected or will alter the more important freshwater-ice processes (such as ice-cover composition, thickness and break-up dynamic,) remains poor. Improving our knowledge of these climate-ice relationships is the key to being able to properly adapt to, or even mitigate, future environmental change.



River and lake ice: floating ice formed in rivers and lakes.
Distribution: high latitude and mountain regions mainly in the Northern Hemisphere.

Introduction to river and lake ice

Freshwater ice is a major component of the terrestrial cryosphere. It affects an extensive portion of the global hydrologic system, including the rivers and lakes found throughout high-latitude and alpine areas, mainly in the Northern Hemisphere. Seasonal ice cover can develop as far south as 33°N in North America and 26°N in Eurasia producing effects on 7 of the world's 15 largest rivers[1], and 11 of the 15 largest lakes.

River and lake ice are important modifiers of numerous biological, chemical and hydrologic processes[1–3], key sources of winter transportation and, in the case of rivers, capable of causing extensive and costly damage to human infrastructure[4]. Because the various forms and processes of freshwater ice are directly controlled by atmospheric conditions (temperature and precipitation), their spatial and temporal trends can be used as indicators of climate variability and change. Given the broad ecological and economic significance of river and lake ice, scientific concern has been expressed regarding how future changes in climate might affect ice-covered hydrologic and aquatic systems[5–7].

Trends and outlook

Limited by the availability of detailed observations, most historical evaluations of changes in freshwater ice have focused on relatively simple characteristics, such as the timing of autumn freeze up and spring break up, and maximum ice-cover thickness. Based on 27 long-term (about 150-year) records from around the Northern Hemisphere, Magnuson and others[8] (Figure 8.1) discovered that freeze up has been delayed by approximately six days per hundred years and break up advanced by a

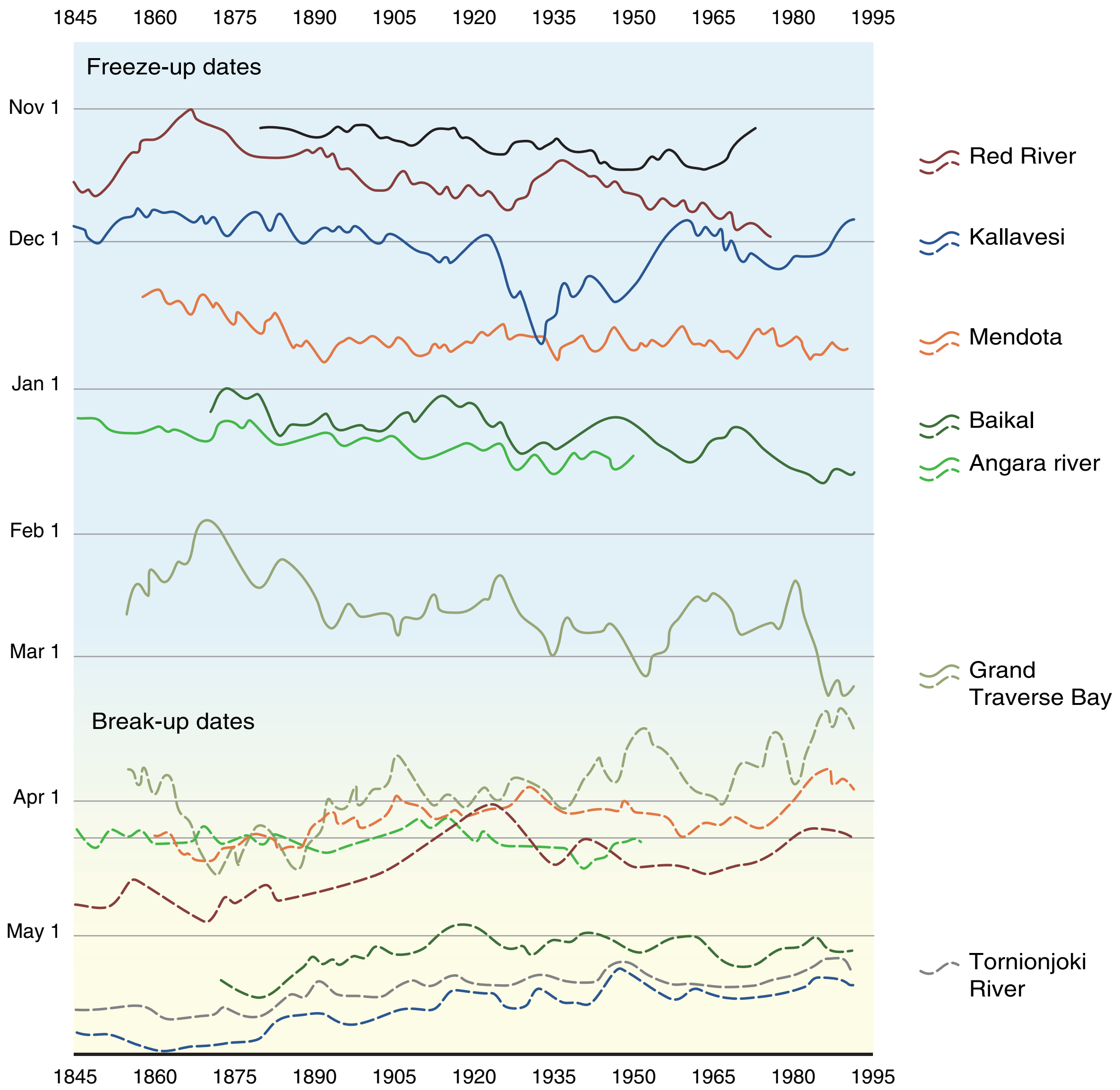


Figure 8.1: Time series of freeze-up and break-up dates from selected Northern Hemisphere lakes and rivers (1846–1995). Data were smoothed with a 10-year moving average.

Source: Based on Magnuson and others 2000[8] similar rate, resulting in an almost two-week per century reduction in the ice-covered season. Numerous other regional and continental studies have been conducted using the more spatially-detailed sets of observations available for the latter half of the 20th-century. Results reveal strong contrasts in freeze-up and break-up timing between decades and between regions[9–13] (see box on spring temperatures and ice break up) largely paralleling trends in major atmospheric patterns that have produced regional climatic warming or cooling[14,15].

Overall, the data for river ice indicate that long-term increases of 2–3°C in autumn and spring air temperatures have produced an approximate 10 to 15 day delay

Spring temperatures and ice break up

Although ice-cover duration on rivers and lakes of the Northern Hemisphere has significantly decreased in response to increasingly warmer climate conditions during the 20th century, the response has been shown to vary regionally and to be strongly related to the variability and regime shifts in large-scale atmospheric and oceanic oscillations.

In Canada, recent evidence indicates a shortening of the freshwater-ice season over much of the country with the reduction being mainly attributable to earlier break ups. These trends match those in surface air temperature during the last 50 years (Figure 8.2). For example, similar spatial and temporal patterns have been found between trends (1966 to 1995) in autumn and spring 0°C isotherms[14] (lines on a map showing location of 0°C air temperatures) and lake freeze-up and break-up dates, with generally significant trends toward earlier springs and earlier break-up dates over most of western Canada and little change in the onset of cooler temperatures and in freeze-up dates over the majority of the country in autumn[9].

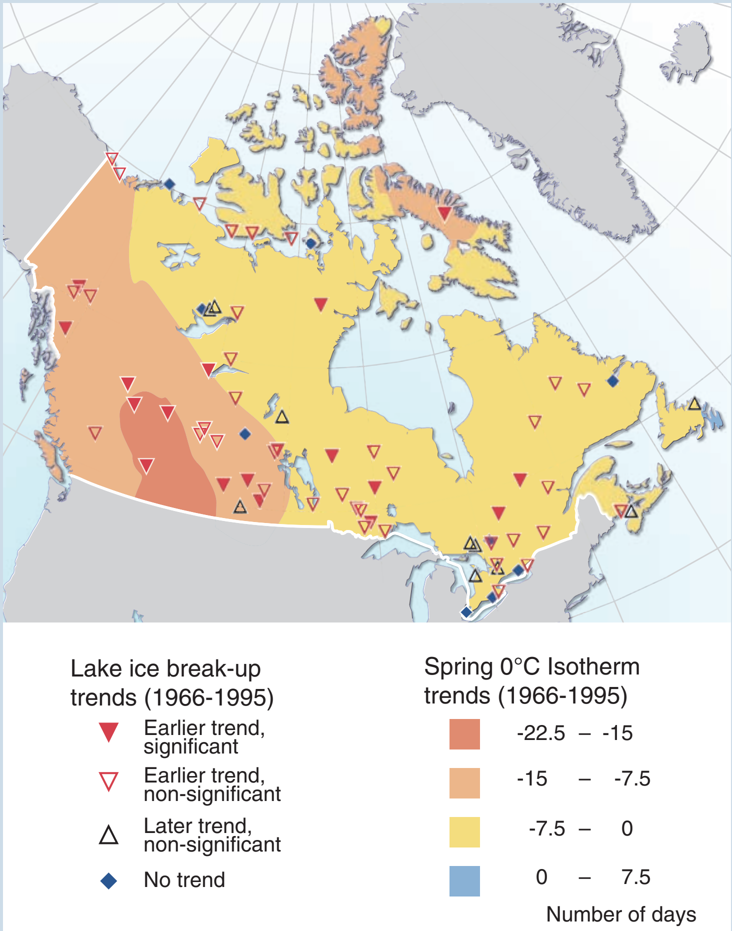


Figure 8.2: Trends in spring temperatures and in ice break-up dates in Canada.

Source: Based on Duguay and others 2006[9] in freeze up and a similar advance in break up[16]. These mirror the longer term response rates found by Magnuson and others[8] but caution is required in relying on such simple temperature-based relationships because they can change over time[6,17].

Large-scale, comprehensive records of river and lake-ice thickness are relatively rare. One data set compiled for Canada over the last 50 years[18] does not reveal any obvious trends over the latter part of the 20th century[19], although smaller-scale regional trends in Northern Europe and Asia have shown a tendency to thinner ice over the same period[20].

Due to the complex relationship between climate and freshwater ice conditions[6,21], future projections of river and lake ice have largely relied on the temperature-based relationships described above. Projections generally indicate further delays in freeze up and further advances in break up, with the amount of change depending on the degree of warming that is forecast[10,22]. For accurate prediction of many ice characteristics, such as composition, thickness, strength and even duration, however, the complicating effects of snow cover need to be considered[2,23–26].

River flows, break up and flooding

River-ice break up on cold-region rivers is often the most dramatic hydrologic event of the year and capable of producing flood-level conditions exceeding those possible under higher flows during the open-water period[1] (Figure 8.3). In temperate climates, river ice can go through a series of freeze-up/break-up cycles, whereas in colder climates break up is typically a spring event. In either case, break up starts when the driving forces – primarily the flood wave from snowmelt, sometimes augmented by rainfall – exceed the resisting forces operating to keep the ice cover intact (ice thickness and strength). The mildest break ups occur when both forces are reduced to a minimum and the ice cover simply melts away, similar to the way lake ice melts. By contrast, the largest floods are produced when the two opposing forces are greatest – a large flood wave colliding with a strong, intact ice cover[4].

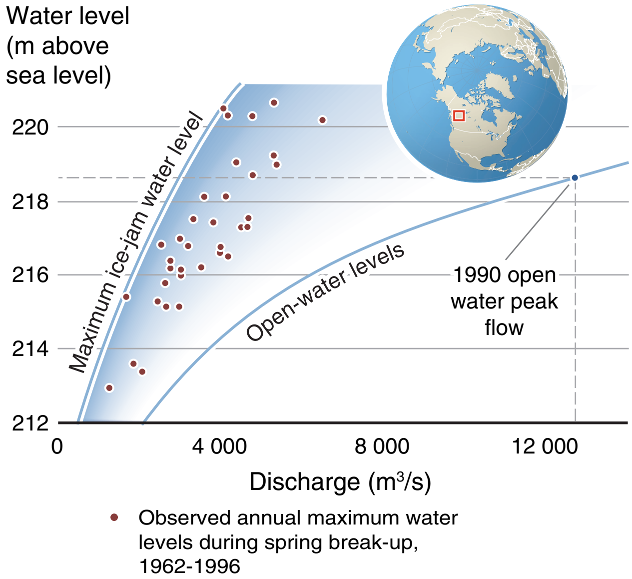


Figure 8.3: Example of enhanced water levels produced from river ice, Liard River (Canada). The lower curve shows the correspondence between river flow and water levels under open-water conditions. The much greater maximum water levels possible under ice-jam conditions are illustrated by the upper curve. The transition in break-up severity from dynamic to thermal break-up effects (see text) is depicted by the gradually shaded area between the two curves. Dots are observed annual maximum water levels during the spring break up. The 1990 dashed line shows the maximum recorded flow for the Liard River – but note that the water level corresponding to this peak flow is lower than for many break-up events with much lower flows. Effects of climate on snowmelt runoff and ice characteristics will lead to regional changes in break-up severity and associated frequency and magnitude of ice-induced flooding.

Source: Based on Prowse and others 2002a[27]

River temperature gradients and floods

Generally the most severe spring floods in Northern Hemisphere cold-region north-flowing rivers are the result of a strong temperature gradient between the headwaters in the south and the downstream river reaches in the north. In these cases, the spring flood wave produced by snowmelt must "push" downstream into colder conditions, and hence towards a relatively intact ice cover that has experienced little melting. Changes in this north to south temperature gradient would alter the severity of break up and the associated flooding.

In the future, cold season (October to May) temperatures are projected to warm more at higher latitudes as compared to lower latitudes (Figure 8.4). The largest north to south differences are evident in East Greenland, Scandinavia and northwest Russia (region d) and Chukotka, Alaska and the western Canadian Arctic (region b), and become particularly magnified in the 2080s. This warming pattern would lead to a reduced temperature gradient along the course of some major Arctic rivers. If such reductions prevail during particular parts of the cold season, they are likely to have major implications for hydrologic events such as the spring snowmelt period and ice break up. High-latitude temperature increases are likely to lead to less severe ice break ups and flooding as the spring flood wave pushes northward.

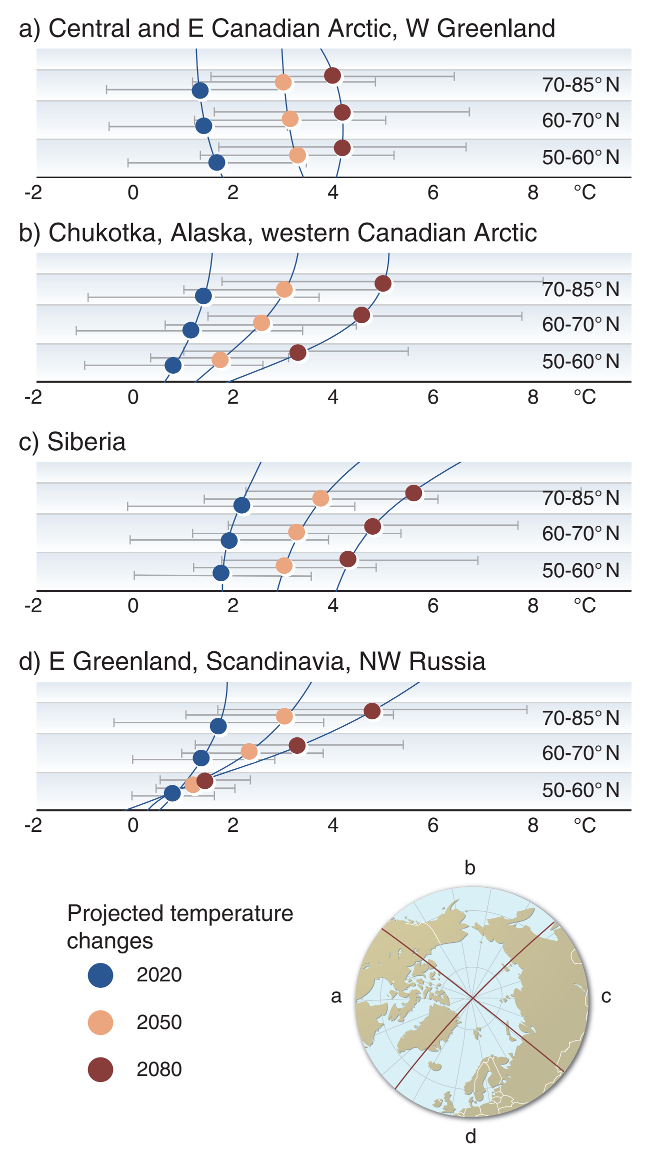


Figure 8.4: Average projected changes in cold-season mean temperatures over Arctic land regions. The changes are broken into three latitudinal bands for each region, as shown on the small map (which has an outer rim of 50° N). Error bars represent standard deviation from the mean. Where greater warming is projected at higher latitudes than at lower latitudes, temperature gradients will be reduced along large north-flowing rivers and this will likely reduce break-up severity. The reverse is true for regions where warming is most pronounced in the southern latitudes.

Source: Based on Prowse and others 2006[29]

As noted earlier, historical trends indicate that the timing of break up has advanced with warming but few attempts have been made to consider changes in the severity of break up[11,28]. Concern has been raised, however, about how large-scale patterns of warming might affect thermal gradients along large northward-flowing rivers – changes in these gradients can be expected to affect the incidence and magnitude of ice-induced flooding[29] (see box on river temperature gradients and floods). A related concern involves the increased potential for mid-winter break ups, which are more unpredictable than spring events but can be just as severe[27,30].

Impacts on human economies and well-being

The greatest impacts of freshwater ice on humans are associated with the dramatic ice and flooding that accompany dynamic freeze-up and break-up events. For many cold regions, it is ice-induced flood events that regularly outweigh costs associated with open-water floods[31]. The economic costs of river ice jams in North America average almost US$250 million per year[32,33] (converted to 2006 values), although this could be a conservative value considering that the cost of a single 2001 break-up season in Eastern Russia in 2001 exceeded US$100 million[34]. They also pose significant risk to human life, particularly because they are less predictable and occur more rapidly than open-water events.

Many northern settlements were established at the confluence of rivers or where rivers enter lakes and these sites are known to be highly susceptible to ice-jam formation[4] (Figure 8.5). Damage by ice action and flood waters to such settlements by infrequent but severe ice jams can be costly. Freeze up, break up and changes in ice thickness and production also cause regular problems for in-channel operations such as hydropower generation, bridges and pipelines, and transportation[32]. All such freeze-up, break-up and ice-thickness related impacts will vary under changing climates.

Figure 8.5: Ice-jam flooding, Ounasjoki River, Finland.
Photo: Esko Kuusisto

Figure 8.6: Loss of ice coverage reducing ice transportation access to northern communities, Liard River, Canada.
Photo: T.D. Prowse

Even the general loss of ice cover through shrinkage of the ice season has been identified as a major economic concern for some northern regions where winter river-ice and lake-ice road networks currently provide essential and relatively inexpensive access to communities and industrial developments[35,36]. Loss of ice-based transportation (Figure 8.6) and ice-related effects on aquatic systems that influence fish and small mammal productivity will be especially important for small indigenous communities, particularly in the Arctic[7,36]. Many indigenous people depend on frozen lakes and rivers for access to traditional hunting, fishing (Figure 8.7), reindeer herding or trapping areas, and for some isolated communities winter travel on frozen rivers is the principle access to larger centres.

Impacts on biological productivity

Freshwater-ice covers control most major interactions between the atmosphere and the underlying aquatic systems (for example solar radiation, thermal regimes and oxygen levels), and hence biological productivity. Reductions in lake-ice covers under future climates will produce changes in temperature and light levels, water circulation patterns and aquatic UV radiation exposure, all of which are important to biological productivity and diversity[37,38]. Of particular concern are variations and change in light and nutrient availability, water circulation patterns, and layering of warm and cold water during the ice-off period. In general, the life cycles of most aquatic organisms are linked with ice cover and temperature, and future changes in these will result in unpredictable responses (see box on alpine lakes).

Figure 8.7: Lake ice fishing, Nunavut, Canada.
Photo: Shari Gearheard

Alpine lakes, snow cover and fish production

Climate warming means that lowland lakes typically are experiencing longer ice-free periods, promoting greater biological productivity. However, despite this warming trend, biological productivity may be reduced, at least temporarily, in alpine areas with increased winter precipitation.

During years with high winter precipitation in alpine areas of western Norway, in spite of higher temperatures, fish growth and recruitment were lower than in low-snowfall years (Figure 8.8). Annual fish growth rates were negatively correlated with spring snow depth – the greater the snow depth, the less the fish grew[23]. During the years 1992 to 1995, a period with mean spring snow depth of 275 cm, fish growth was reduced by 50% compared to years with much less spring snow accumulation (1991 and 1996). A further increase in winter snowfall in these regions, as projected by climatic scenarios, would be expected to result in further reductions in biological production.

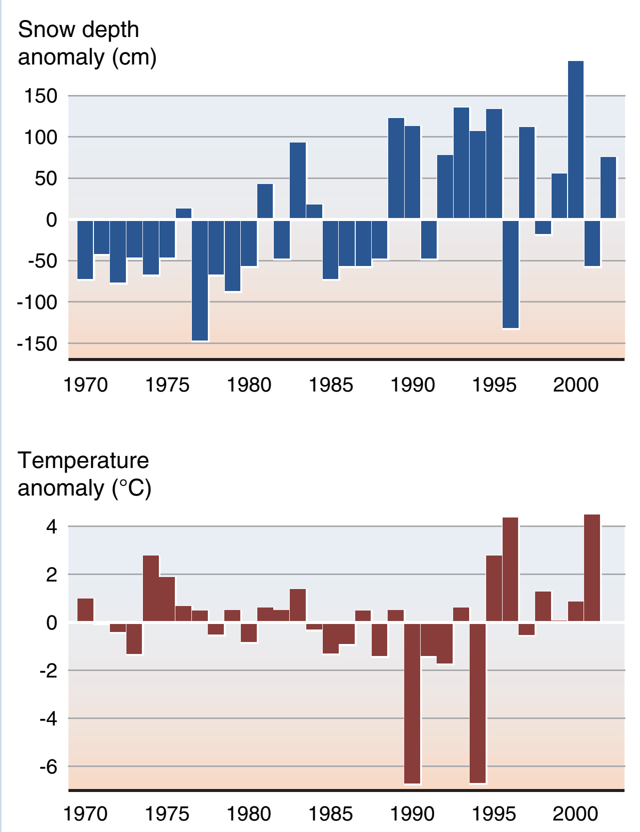
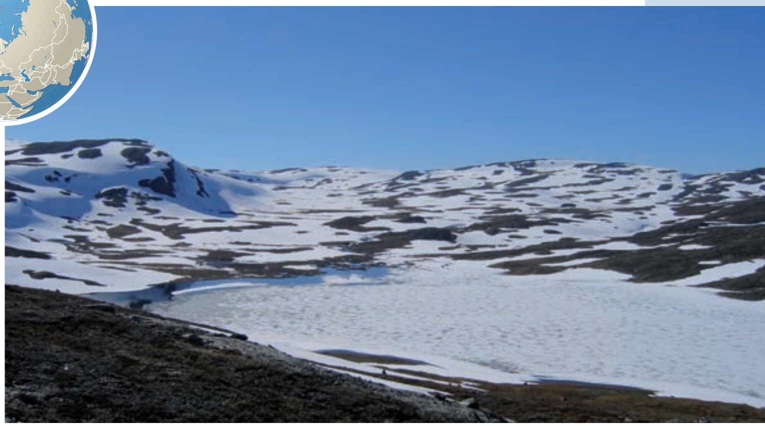


Figure 8.8: Strong interannual changes in snow depth and ice cover may occur in some mountain areas due to increased winter precipitation (as snow). Photos show an alpine lake at the Hardangervidda plateau, western Norway, in early July, for years of high and low winter precipitation. High snowfall years are associated with a strong North Atlantic Oscillation. The charts show that snow cover is not related to temperature.

Source: Based on Borgström and Museth 2005[39]
Photos: R. Borgström



The ice scour and flooding produced by river ice are known to be major reasons for the high biological productivity and diversity found in northern rivers, particularly along their margins and in deltas where break-up events are also the key suppliers of water and nutrients[40,41]. Decreases in the frequency and/or severity of break-up flooding that may arise under future climates could threaten the ecosystem health of such river systems[29,42] (see box on maintaining delta pond ecosystems).

Maintaining delta pond ecosystems

The physical development and ecosystem health of river deltas in cold regions are strongly controlled by ice processes and thus are highly susceptible to the effects of climate change. As an example, the photograph shows a typical lake/pond and river network in the Peace-Athabasca Delta (Canada), one of the largest freshwater deltas in the world. The water budget and sediment-nutrient supply for the multitude of lakes and ponds that dot the riparian zones of such deltas depend strongly on the supply of floodwaters produced by river-ice jams during the spring. These spring floods usually exceed those from open-water flow events, as illustrated in Figure 8.9(a). Studies of future climate conditions for the Peace-Athabasca Delta indicate that a combination of thinner river ice and reduced spring runoff, due to smaller winter snowpack, will lead to decreased ice-jam flooding[42]. This, combined with greater summer evaporation from warmer temperatures, will cause a decline in delta-pond water levels[43].

An adaptation strategy that has been successfully used to counteract the effects of climatic drying of delta ponds involves the use of flow enhancement through water releases from reservoirs. This increases the probability of ice-jam formation and related flooding of the delta ponds (Figure 8.9(b)).

Peace-Athabasca Delta.
Photo: Dörte Köster

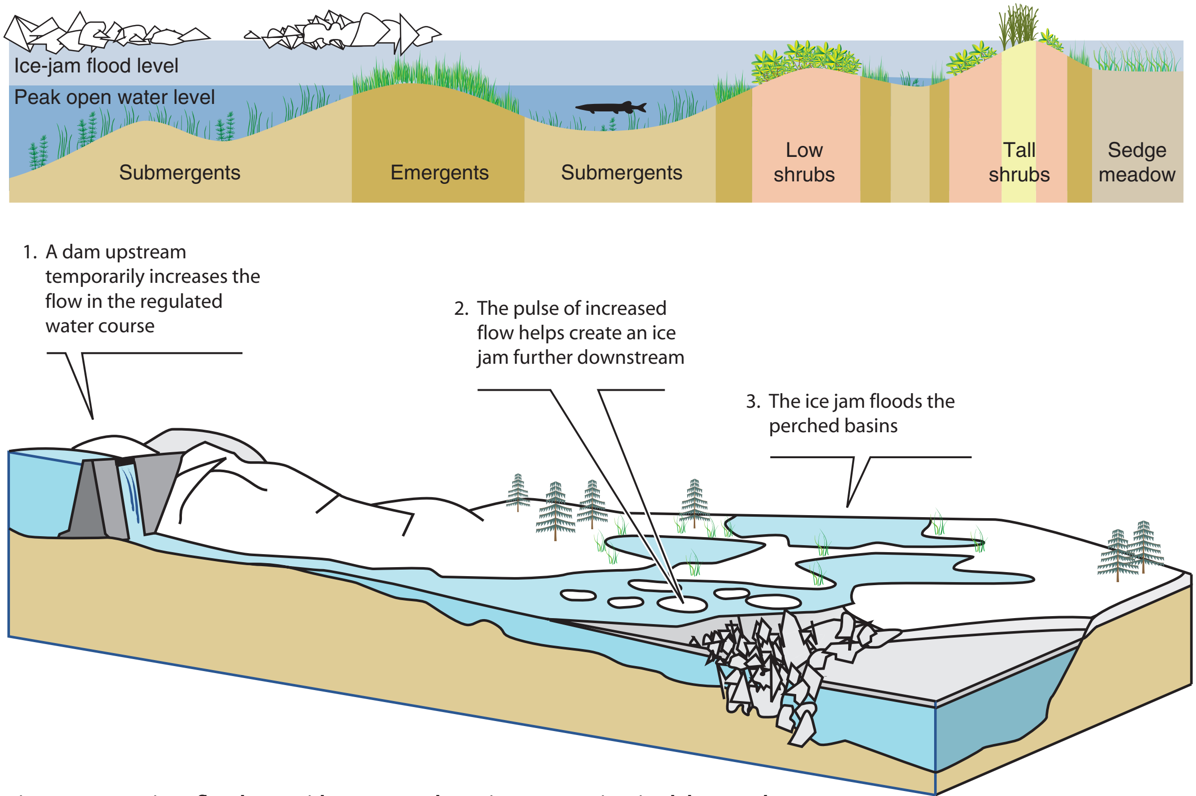


Figure 8.9: Ice-jam floods provide water and nutrients to maintain delta ponds.
(a) Higher flooding levels in spring break up reach the perched basins.
(b) An adaptation strategy: water released from the reservoir on the left increases the probability of ice jams and flooding of the ponds.

Source: Based on Prowse and others 2002b[44]

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