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A world without lake ice?

by Sapna Sharma[1] | Associate Professor; Simon R. Watson[1] | Research Associate; Catherine O'Reilly[2] | Associate Professor

[1]: Department of Biology, York University, Toronto, Ontario, Canada
[2]: Department of Geography, Geology, and the Environment, Illinois State University, Normal, IL, USA

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ABSTRACT

Lakes are rapidly losing ice cover around the Northern Hemisphere. Currently, 14,800 lakes are no longer freezing every winter. And even small increases in temperature could result in thousands of additional lakes losing ice cover. Lake ice provides essential ecosystem services that support human life. Its loss will impact hundreds of millions of people socioeconomically and culturally.

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Seasonal lake ice cover is rapidly disappearing, and with it, ecosystem services that support human life and culture. Lake ice provides natural resources such as freshwater, food, transportation, and renewable energy. But it also supports emotional wellbeing by connecting remote communities through ice roads and creating opportunities for recreation, including skating, ice fishing, and hockey. Ultimately, these qualities and services have underpinned human culture and identity, while generating a sense of place and belonging. Lake ice has informed an awareness of nature's intrinsic power, value, and beauty. Whether experienced in the resounding upheaval of ice breakup or the white glare of a snow-covered lake under the sun, seasonal lake ice has a profound and humbling effect on the human psyche. Our connection to lake ice has prompted generations of people to document the timing of ice breakup and freeze across hundreds of lakes long before meteorological stations were developed. These records serve as invaluable empirical evidence of climate change, revealing an alarming acceleration of lake ice loss and the need for present-day mitigation efforts.

The longest and most consistent lake ice record has been collected by fifteen generations of Shinto priests who have recorded freeze dates since 1443 in Lake Suwa, Japan. The Shintos believed that the male god would travel over the lake ice every winter with

his dragon to see the female god on the opposing shore. The appearance, direction, and size of the ridge (*omiwatari* - 御神渡り) left by the footsteps of the God were used by the priests to forecast rice harvest. Such meticulous long-term records of climatic variables are rare and point to the significance of lake ice for human communities. The Lake Suwa records themselves, in combination with records from hundreds of lakes around the Northern Hemisphere, reinforce findings that suggest strong trends towards shorter ice-cover duration, with earlier ice breakup and later ice onset, as temperatures rise.

In our recent study, we collected lake ice data for an additional 513 lakes around the Northern Hemisphere using historical records spanning 40 to 575 years. Twenty-nine of these lakes did not freeze every winter. Our objective was to understand which factors influenced whether a lake froze annually. Then, using this information, we were able to forecast which lakes around the Northern Hemisphere would become susceptible to ice cover loss with climate warming.

We found that air temperature was the most important factor predicting ice cover, with lakes in warmer regions more vulnerable to ice loss. However, we also found that individual lake characteristics such as depth, elevation, and shoreline complexity interacted with temperature to influence the sensitivity of lakes to ice cover loss. Presently, we estimate that 14,800 lakes have some winters without ice cover. However, even small increases in air temperature could result in thousands of additional lakes losing ice cover. For example, if air temperatures rise by 2°C, we predict 35,300 lakes will lose winter ice cover. In the worst-case scenario, with a rise of 8°C, that number increases to 215,000. These projections are alarming because lakes may begin to lose ice cover within the next generation. For example, one of the most well-studied lakes in the world, Lake Mendota in Madison, Wisconsin, with an ecological record beginning in the 1850s, may stop freezing annually within the next decade.

Ice cover loss in even a single winter can have wide-ranging ecological consequences, including reduced water quantity owing to increased evaporation, and degraded water quality as water temperatures increase, dissolved oxygen concentrations decrease, and algal blooms proliferate. But ice cover loss also has broad cultural and socioeconomic implications for communities where winter activities are a key component of the social fabric. For example, Rochester, Minnesota, organizes a series of winter events that include activities on lake ice. In 2018, they raised $350,000 USD for local non-profit organizations. And in rural China, hundreds of thousands of people attend one of the last remaining traditional ice-fishing events, where the first fish caught is believed to bring good luck and can sell for tens of thousands of dollars. Ultimately, our projections demonstrate that lake ice loss could affect anywhere from 394 to 656 million people who depend on lakes for water, food, transportation, recreation, and cultural traditions.