Technical Report

LONG-TERM LAKE ICE DECLINE ON LAKE SCUGOG

Prepared for:
Scugog Lake Stewards Inc.
Port Perry, Ontario, Canada

Prepared by:
Dr. Jennifer Korosi, Dr. Joshua Thienpont, Aniko Gruber, Zahraa Jaafar, Minahill Malik, Marielle Manansala, Divyam Patel, Raha Pishrow, Altrisha Rodrigues, Katherine Tse
York University
Toronto, Ontario, Canada

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SUMMARY

York University undergraduate students in the Environmental Science program partnered with the Scugog Lake Stewards to investigate lake ice decline on Lake Scugog as part of their senior capstone experience. The Environmental Science Capstone course pairs students with a community partner to tackle a real-world socio-ecological challenge by applying environmental science knowledge and tools. Over the duration of the 12-week term, students researched lake ice decline and its links to climate change, including implications for lake ecosystem health and water quality. Students also analyzed the long-term ice-off record for Lake Scugog at Port Perry, which has been carefully monitored and recorded since 1872. The findings revealed that ice-off date has been declining (i.e. ice-off occurring earlier) for Lake Scugog since ~1970, consistent with trends observed across the northern hemisphere due to anthropogenic climate change. This year was the earliest ice-off date ever recorded for Lake Scugog (March 5), occurring 10 days earlier than the previous record (March 15, in 2012). Climate patterns like the El Niño Southern Oscillation do not explain the recent decline in ice-off dates. This trend of earlier ice-off dates and overall declines in lake ice cover duration and thickness is projected to continue. Shorter ice-covered seasons will have an impact on ecosystem conditions in the open-water season, but it is extremely challenging to predict exactly how different components of the ecosystem will be affected (e.g. primary productivity, nutrient cycling) because of a lack of paired summer-winter monitoring and the uncertain cumulative effects of multiple interacting stressors.

Experiential learning is an integral part of training the next generation of environmental scientists to work collaboratively to find solutions to environmental problems. We would like to take the opportunity to thank the Scugog Lake Stewards for partnering with this year's cohort of senior capstone students.

BACKGROUND ON LAKE ICE AND CLIMATE CHANGE

Widespread declines in the duration of the ice-covered season have been reported for lakes across the globe, with rising global air temperatures caused by anthropogenic greenhouse gas emissions strongly implicated as the primary cause of lake ice decline (Benson et al., 2012; Huang et al. 2022; Lopez et al. 2019; Sharma & Magnuson 2014; Sharma et al. 2019). This is because air temperature is the most important explanatory variable for ice phenology (i.e., ice ice-on and ice-off dates), moderated by lake morphometry (i.e., depth, surface area, orientation with respect to prevailing winds) and snowfall (Brown and Dugay 2010; Mishra et al. 2011; Sharma et al. 2020; Warne et al. 2020). Large-scale climate oscillations such as the El Niño–Southern Oscillation (ENSO) also explain a statistically significant amount of variation in ice phenology due to their influences on winter air temperatures and precipitation (Mishra et al. 2011; Sharma et al. 2020).

In 18 lakes in the Northern Hemisphere, ice-on occurred 11 days later per century, and ice-off occurred 9 days earlier, over the last ~150-200 years, with an accelerated rate of decline over the last quarter century (Imrit and Sharma 2021). Projections indicate that lake ice loss will continue to intensify with future climate warming (Huang et al. 2022; Sharma et al. 2019). If mean annual air temperatures exceed a critical threshold of 8.4°C (mean annual air temperature in Peterborough, ON is currently 6.9°C.), lake ice cover is predicted to become intermittent (i.e., freezes in some years and not in others), with permanent loss of ice cover predicted above a critical threshold of 10°C (Sharma et al. 2019). One hundred and seventy-nine lakes in the Northern Hemisphere are projected to experience a permanent loss of ice cover before the end of the decade, followed by an additional 5700 lakes by the end of this century if greenhouse gas emissions are not mitigated (Sharma et al. 2021).

In addition to ice cover duration, climate warming has also been implicated in declines in ice thickness, which determines the safety of winter recreational activities and transportation by ice roads (Imrit et al. 2022; Woolway et al. 2022). Ice thickness declined by an average of 1.2 cm per decade since 1962 in 27 lakes and rivers in North America, with 81% of the variability in ice thickness explained by a combination of warmer winter air temperatures, increased winter cloud cover, and increased snowfall[1] (Imrit et al. 2022). Model projections have indicated that ~0.23± 0.07 m of global mean maximum lake ice thickness will be lost over the next 80 years (Huang et al. 2022). The duration of safe ice (thicker than 10 cm) for recreational purposes is also projected to shorten by an average of 13 days with global warming of 1.5°C (2024–2038) relative to 1900-1929, and by 24 days with global warming of 3°C (2061–2075) (Woolway et al. 2022). Lakes located between 40°N and 45°N latitude are projected to experience a 66% loss in duration of safe lake ice under global warming of 3°C (Woolway et al. 2022). For reference, Lake Scugog is situated at a latitude of 44°N. Note that the "safe ice" threshold of 10 cm thickness refers to so-called black (i.e. clear) ice, but the proportion of opaque/white ice that is less stable is expected to increase under global warming due to warmer, wetter winters (Weyhenmeyer et al. 2022). This means that safe ice thresholds will need to be greater than 10 cm.

[1] Snow has low density and insulates the lake ice from cold air temperatures. A deeper snowpack is associated with thinner lake ice, especially when heavy snowfall occurs early in winter before sustained sub-zero temperatures.

A LONG-TERM RECORD OF "ICE-OFF" DATES FOR LAKE SCUGOG

Ice-off dates have been consistently monitored at Port Perry Bay since 1872 (first by Observer magazine, followed by Focus Magazine), with only minor changes to the definition of "ice-out" over that time. We analyzed the record using a generalized additive model (spline k=5, gamma distribution, REML method) to identify trends over time. The results of the generalized additive model revealed that ice-off date has been declining since 1971 (R-sq. Adj. = 0.174, deviance explained = 18.7%), and that ice-off now occurs approximately 2 weeks earlier, on average, compared to pre-1970 (Figure 1). This year broke a new record for earliest ice-off, occurring on March 5 compared to the previous record of March 15 in 2012. The trend of earlier ice-off dates fits with the global pattern of lake ice decline described above, due to climate warming.

This year's mild winter was also partially the result of an El Niño–Southern Oscillation (ENSO) event. ENSO is a recurring climate pattern that relates to ocean temperature anomalies in the central and eastern tropical Pacific Ocean. During an El Niño phase, the trade winds weaken or change direction, resulting in a buildup of warm water along the western coast of South America. This changes global atmospheric circulation patterns, influencing climate across the globe. El Niño phases are associated with warmer winters in southern Ontario. We qualitatively examined the potential influence of El Niño events on ice-off dates in Lake Scugog by identifying the 14 strongest El Niño event years specific to the winter months, using the Extended Multivariate ENSO Index calculated for 1895-2015 by the Physical Sciences Laboratory of the National Oceanic and Atmospheric Administration (NOAA). El Niño events correspond to average or below-average ice-off dates, and do not explain the consistent decline in ice-off dates since ~1970 (Figure 2). The previous ice-off record was not an El Niño year.

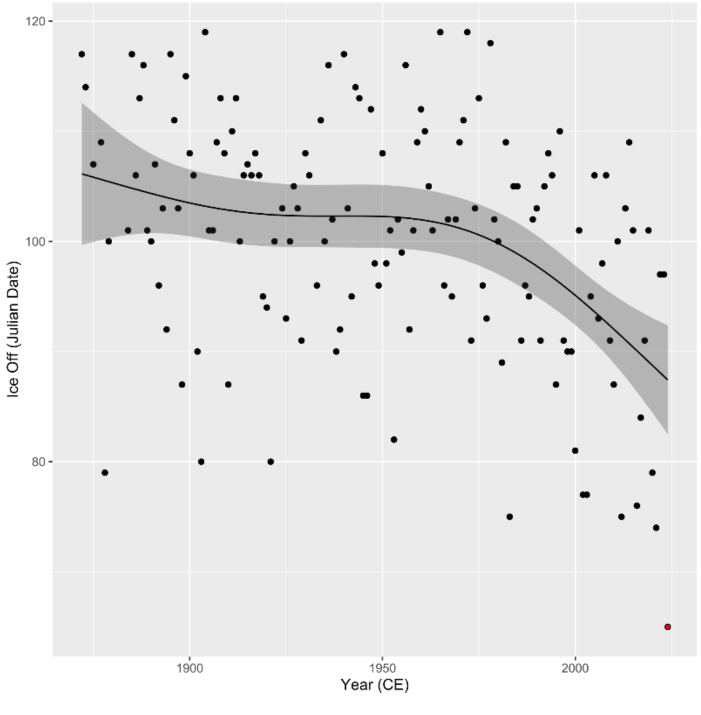

Figure 1 – A long-term record of ice-off dates (1872-2024) for Lake Scugog collected at Port Perry by the Port Perry Star and the earlier Observer newspaper. The black line shows the results of a fitted generalized additive model revealing trends in ice-off over time, and the grey shading is the 95% confidence intervals for the fitted model.

1872............April 26
1873............April 24
1875............April 17
1877............April 19
1878...........March 20
1884............April 10
1885............April 27
1886............April 16
1887............April 23
1888............April 25
1889............April 11
1890............April 10
1891............April 17
1892.............April 5
1893............April 13
1894.............April 2
1895............April 27
1896............April 20
1897............April 13
1898...........March 28
1899............April 25
1900............April 18
1901............April 16
1902...........March 31
1903...........March 21
1904............April 28
1905............April 11
1906............April 11
1907............April 19
1908............April 22
1909............April 18
1910...........March 28
1911............April 20
1912............April 22
1913............April 10
1914............April 16

1915............April 17
1916............April 15
1917............April 18
1918............April 16
1919.............April 5
1920.............April 3
1921...........March 21
1922............April 10
1924............April 12
1925.............April 3
1926............April 10
1927............April 15
1928............April 12
1929.............April 1
1930............April 18
1931............April 16
1933.............April 6
1934............April 21
1935............April 10
1936............April 25
1937............April 12
1938...........March 31
1939.............April 2
1940............April 26
1941............April 13
1942.............April 5
1943............April 24
1944............April 22
1945...........March 27
1946...........March 27
1947............April 22
1948.............April 7
1949.............April 6
1950............April 18
1951.............April 8
1952............April 10

1953...........March 23
1954............April 12
1955.............April 9
1956............April 25
1957.............April 2
1958............April 11
1959............April 19
1960............April 21
1961............April 20
1962............April 15
1963............April 11
1965*..........April 29
1966.............April 6
1967............April 12
1968.............April 4
1969............April 12
1970............April 19
1971............April 21
1972............April 28
1973.............April 1
1974............April 13
1975............April 23
1976.............April 5
1977.............April 3
1978............April 28
1979............April 12
1980.............April 9
1981...........March 30
1982............April 19
1983*.........March 16
1984............April 14
1985............April 15
1986.............April 1
1987.............April 6
1988.............April 4
1989............April 12

1990............April 13
1991.............April 1
1992............April 14
1993............April 18
1994............April 16
1995...........March 28
1996............April 19
1997.............April 1
1998...........March 31
1999...........March 31
2000...........March 21
2001...........April 11
2002...........March 18
2003...........March 18
2004.............April 4
2005............April 16
2006.............April 3
2007.............April 4
2008............April 15
2009.............April 1
2010...........March 27
2011............April 10
2012*.........March 15
2013............April 13
2014............April 19
2015............April 11
2016...........March 16
2017...........March 25
2018.............April 1
2019............April 15
2020...........March 29
2021...........March 25
2022.............April 7
2023.............April 7
Earliest: March 15, 2012
Latest: April 29, 1965

Figure 2 – A list of ice-off dates from 1872 to 2023. Highlighted years represent the 14 strongest El Niño event years specific to the winter months, using the Extended Multivariate ENSO Index calculated for 1895-2015 by the Physical Sciences Laboratory of the National Oceanic and Atmospheric Administration (NOAA).

IMPLICATIONS OF DECLINING LAKE ICE

Lake ice provides important cultural ecosystem services that are being measurably impacted by lake ice decline due to climate change, including the cancellation or shortening of outdoor skating rinks, ice fishing tournaments, and winter ice road operations (Brammer et al. 2015; Knoll et al. 2019). Identifying and quantifying the impacts of lake ice decline on lake ecology is considerably more challenging to interpret, due in part to the influence of lag effects, multiple interacting stressors, and a lack of long-term data. “Winter limnology” is an emerging area of research that is growing rapidly in response to widespread observations of lake ice decline and the recognition of the substantial knowledge gaps regarding its ecological implications (Powers & Hampton 2016).

Recent advances in winter limnology have revealed that aquatic primary and secondary production under the ice is much more abundant than previously recognized (Hampton et al. 2017). Light is a key limiting factor for under-ice primary production, with light transmission influenced by ice thickness, ice opacity (proportion of black ice versus white ice), and snowpack depth. Under-ice primary production is an important source of dissolved oxygen to fish and other aquatic organisms at times of the year when ice seals the underlying water off from atmospheric inputs of oxygen. A 30-year record of under-ice nitrogen dynamics in 5 north-temperate lakes also revealed that nitrate accumulates under the ice as the winter progresses, such that shorter ice-covered seasons will likely have an influence on lake nitrogen budgets (Powers et al. 2017).

Winter diatom (single-celled siliceous algae) blooms are becoming more frequent in Lake Erie and likely contribute to summer oxygen depletion (Reavie et al. 2016). Winter-spring diatom blooms have also been correlated with summer cyanobacteria dynamics in Lake Erie and elsewhere (Zepernick et al. 2024). Such inter-seasonal connections (i.e., winter influences summer which influences winter, etc.) are probably the norm rather than the exception (Hampton et al. 2017). Higher phytoplankton biomass has also been documented in summer following warm winters with short ice-cover duration or ice-free winters (Aidan et al. 2000; Weyhenmeyer et al. 2008). Conversely, higher winter primary productivity has also been associated with lower summer productivity, which was possibly due to winter algae depleting the available nutrient pool (North et al. 2014). This highlights the complexity inherent in disentangling inter-seasonal connections and demonstrates the pressing need to “close the loop” through long-term paired winter-summer lake monitoring (Hampton et al. 2017).

Winter ice cover was found to be strongly associated with summer warming trends in a global synthesis of lakes, whereby lakes that are seasonally ice covered warmed at a faster rate than air temperatures (O’Reilly et al. 2015; Dugan 2021). Declining ice cover leads to a longer open-water season, which can contribute to warmer summer water temperatures and less frequent mixing of lakes, acting synergistically with warming summer air temperatures (Woolway et al. 2022). The effect of ice cover duration on summer temperatures was shown to be strongest in the month immediately following ice break-up for Lake Peipsi in Russia/Estonia, where mild winters were also associated with higher nitrogen and silica concentrations and lower phosphorus concentrations (Blank et al. 2009). A longer open water season can also enhance global evaporation rates in lakes (Wang et al. 2018), contributing to declines in lake levels that have water security and water quantity implications.

Warmer winters are likely to reduce the success of coldwater-adapted winter specialist fish species whose behavioral and reproductive strategies are tied to winter conditions (Shuter et al. 2012). Lake Erie yellow perch (*Perca flavescens*) had failed recruitment events following mild winters based on field observations from 1973 to 2010, which was shown to be the result of warmer water temperatures at spawning time (Farmer et al. 2015).

CONCLUSIONS & RECOMMENDATIONS

Ice-off on Lake Scugog at Port Perry now occurs approximately two weeks earlier, on average, than it did prior to 1970. This is consistent with a global pattern of declining lake ice cover duration occurring in response to anthropogenic climate change. The trend towards earlier ice-off dates on Lake Scugog is likely indicative of a declining trend in overall ice cover duration and ice thickness, although these components have not been monitored. Climate projections strongly indicate that ice cover decline will continue, and even accelerate, into the future. Lake Scugog is at risk of transitioning from a seasonally ice-covered lake to one that experiences intermittent ice cover if mean annual air temperatures increase above 8.4ºC.

There is broad scientific consensus that declining lake ice will contribute to widespread changes across all lake ecosystem components and processes in both winter and summer, especially as lakes approach critical thresholds for intermittent or loss of ice cover. However, the broader ecosystem implications of lake ice decline are difficult to predict. Concerns that are particularly relevant for Lake Scugog include the potential for lake ice decline to amplify the rate of surface water warming in the summer, enhance evaporative water loss, and exacerbate existing challenges with aquatic plant growth and algal production. Warmer waters have implications for fish communities, especially those that rely on cool water temperatures at the time of spring spawning. Enhanced plant and algal productivity could lead to higher oxygen consumption in winter when dead plant and algal material are broken down, but a shorter ice-covered season could also counteract this by increasing the flux of oxygen from the atmosphere to the lake in winter.

To better understand the implications of declining ice cover on Lake Scugog, we need to link water quality monitoring efforts in summer to the monitoring of lake ice and under-ice conditions in winter. This is challenging because winter lake sampling is logistically difficult and has many safety implications. We recommend that the Scugog Lake Stewards continue to build on their strong record of bringing multiple partners together from communities, governments, and researchers to “close the loop” between summer and winter monitoring.

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