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Environmental change observed from two urban Arctic lakes in Iqaluit, Nunavut†

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Arctic ecosystems are considered to be especially vulnerable to the effects of environmental change, but the combined influence of a warming Arctic and expanding urban development is less clear. While temperature-driven change has long been the principal focus of studies on Arctic lakes, increasing local human populations, inadequate municipal infrastructure, and expansion of the resource extraction industry may now have a larger influence. Here, we present a chironomid-based paleolimnological assessment of two lakes within the urban boundary of Iqaluit, Nunavut, to determine responses to changes in climate over the Anthropocene. Iqaluit is one of the largest urban centers in the Canadian Arctic with a population that has been increasing for decades and a history of pollution that has affected nearby freshwater systems. We observed warming in both lakes, inferred by a reduction of cold-water stenotherms, such as *Heterotrissocladius* and *Corynocera oliveri*-type, concurrent with increases in generalist taxa, including *Psectrocladius* and those of the tribe Tanytarsini. We note that the two lakes had differences in their assemblages related to the specific habitats associated with each; IQ04 is a large kettle lake with a pronounced profundal zone, whereas IQ01 is oblong with a larger shallow littoral reach. We found that both lakes were responsive to climate, both indicating a warming trend that began ~1985–1990, regardless of the proximity to human activities, and note that it is important that these ecosystems be monitored given continued environmental stress expected with future warming and further urban development.

Environmental significance

Few studies examine Arctic lakes that are in urban contexts. Here, we examine two lakes that are in the Capital City of Canada's most northern territory, Nunavut. We sampled biological indicators (*e.g.*, Chironomids; Diptera: Chironomidae) through the sedimentary record of each system using paleolimnological assessment. We found that regardless of the lakes being different in their landscape position and amount of urban influence, both systems tracked recent climate warming. The proximity to an urban population was either not sufficient to have a noticeable effect on the two local lakes, or the influence of climate overshadowed these effects. We deduce that the overarching influence of a warming climate impacted both systems, albeit with different species responses through time.

1 Introduction

The influence of urban development on freshwater ecosystems is multifaceted, with a number of interacting threats that may influence biodiversity, including climate change. While Arctic ecosystems have long been considered to be some of the least impacted by humans in the world,[1] near-surface temperatures in the Arctic have increased by more than twice that of the global average since the 1970s.[2] The effects of climate change are more pronounced at higher latitudes due to positive feedbacks associated with reduced albedo from decreased ice and snow.[3,4] Climate change is also considered to be a threat multiplier that has the potential to make the effects of other environmental stressors worse.[5] As such, Arctic freshwater lakes and ponds are under an especially great degree of environmental stress[6] as temperature has been shown to play a critical role in mediating their chemical and biological processes.[7]

While the influence of warming on the ecology of Arctic lakes has been previously observed,[8–11] there are a limited number of studies on lakes in proximity to local human populations. Atmospheric transport of pollutants to Arctic lakes has been well documented,[12–15] but a direct influence of urban centers on Arctic freshwater ecology has not yet been described. Northern regions are quickly developing;[16] the northern territories of

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Nunavut and the Yukon had the highest per capita population increases in Canada in 2020–21.[17] The growing influence of both global (*e.g.*, atmospheric transport of pollution) and local sources of pollution can have a significant impact on the environment. For example, the inefficiency of generating electricity from diesel fuel combustion results in northern communities generating considerably higher emissions per capita than many of those in the rest of Canada.[18] Indeed, local air pollution in the Arctic can be considered severe,[19] especially when gravel roads are constructed on or near contaminated soils.[20]

Regional development can also significantly impact nearby ecosystems that may be used by local populations for cultural and subsistence purposes. Thienpont *et al.*[21] found that pollutants from oil drilling activities in the Mackenzie delta region of the western Canadian Arctic were leeching into nearby shallow lakes, which in turn increased conductivity levels, reduced water quality, and led to diversity shifts in several aquatic species. Climate change is likely to amplify human impacts, as ecological thresholds are crossed allowing for increased production in ecosystems once limited by temperature.[22,23] For example, Antoniades *et al.*[24] showed how nutrient inputs from a leaking sewage system near the hamlet of Resolute, Nunavut, caused a rapid shift towards benthic production following regional warming. Indeed, Viehberg *et al.*[25] found that the influence of human activity on the ecology of Arctic lakes can persist for a century after the initial anthropogenic stressors occurred.

The examination of the depositional history of freshwater ecosystems, using paleolimnological approaches, has allowed for the context of human influence to be compared to predisturbance conditions.[5,26,27] The comparison of physical, chemical, and/or biological indicators preserved in the sediment history of lakes can be used to determine influences on their abundance and diversity over time. Chironomids (Diptera: Chironomidae), also known as non-biting midges, are a commonly used bioindicator species that have an aquatic larval stage that leave behind chitinous head capsules that preserve well in sediment.[28] Chironomids are commonly used to infer temperature,[29–32] but are also known to be effective indicators for aquatic production,[9] water depth,[33] habitat availability,[34] and even heavy metal deposition.[35] Changes in chironomid species assemblages in a downcore stratigraphic record can be used to infer how past environments have changed over time.[29,30]

Here, we analyze the lacustrine sediment history of two urban lakes and infer influences of environmental change from subfossil chironomid assemblages in Iqaluit, Nunavut, Arctic Canada. Designated the capital of the territory in 1999, Iqaluit has had a relatively long history of local human influence for the Canadian Arctic. Iqaluit was founded in the 1940s, originally named Frobisher Bay, and designated by the United States airbase as "Crystal Two". Iqaluit was also a Distant Early Warning Line (DEW Line) station following WWII, up until about 1963.[36] Over time this base transitioned into a major settlement, emerging as one of Canada's most rapidly growing municipalities.[37] Urban development over the last 60 years has been well documented,[38,39] including significant impairment of local water quality, and biodiversity in freshwater systems.[40–43]

The influence of global processes, including global atmospheric pollution, has been readily observed in the sediment history of remote Arctic lakes.[15,44,45] Likewise, the influence of local anthropogenic stressors has also been examined in the context of the concurrent response of lakes to climate.[46,47] Whether chironomids can be used to infer past climate in systems that have competing, or collinear, stressors is not well understood.[48] Since biodiversity in Arctic ecosystems is often seen as having a bottom-up control due to the harsh climate limiting abundances, small-scale influences from pollution may have a larger effect on species that already exist at thresholds of tolerance. For example, Medeiros *et al.*[41] noted that species that are explicitly known as pollution-tolerant in southern ecosystems were the first to disappear in impaired streams in Iqaluit due to severe climate-related stresses on fecundity. As such, we aim to assess the long-term effects of climate change on urban Arctic lakes, as well as determine whether increased urban development over the Anthropocene (since 1950) has superseded climate as the primary driver of ecological change. As populations in Arctic communities continue to grow, it is important to understand how direct anthropogenic activities impact the trajectory of climate-stressed ecosystems.

2 Methods

2.1 Site description

Iqaluit is located in Frobisher Bay, Baffin Island (Fig. 1), and has grown in population from 6700 in 2011 to 7429 in 2021.[17] Iqaluit has an average July temperature (climate normal 1970–2010) of 7.7 °C and annual total precipitation averaging 404 mm (Station 2402590, Environment Canada). We examined two lakes within a short distance (2–3 km) of the urban residential core of Iqaluit; IQ01 and IQ04 (Fig. 1). These lakes were selected due to the proximity to the urban center as well as being a sufficient size and depth for sample collection. The surficial geology of both lake catchments is Precambrian bedrock overlain by glacial deposits.[49] There is little vegetation around the catchment area of either of the lakes, with a predominance of Arctic grasses, sedges, and a few species of moss. The catchment of IQ01 has experienced larger longer-term disturbances due to its location 150 m from the former American military site known as 'upper base', which connected the site by road since the 1950s. Peramaki and Decker[50] found elevated concentrations of bioavailable lead directly adjacent to lake IQ01, which was sampled due to concerns over transport of contaminants across the Lake Geraldine watershed (Iqaluit's water supply) as described by Poland *et al.*[51] An additional road was built across its catchment in 2000 to connect the site to trails used for hunting purposes, which was then widened in 2004. The use of the road for transportation purposes has greatly increased since 2006, resulting in the impoundment of the lake by the road and perched culverts. We note that a large amount of construction debris, including several hazardous material bags containing asbestos, were found in the shallow reaches of the lake in 2006 (personal observation). Several housing developments have also

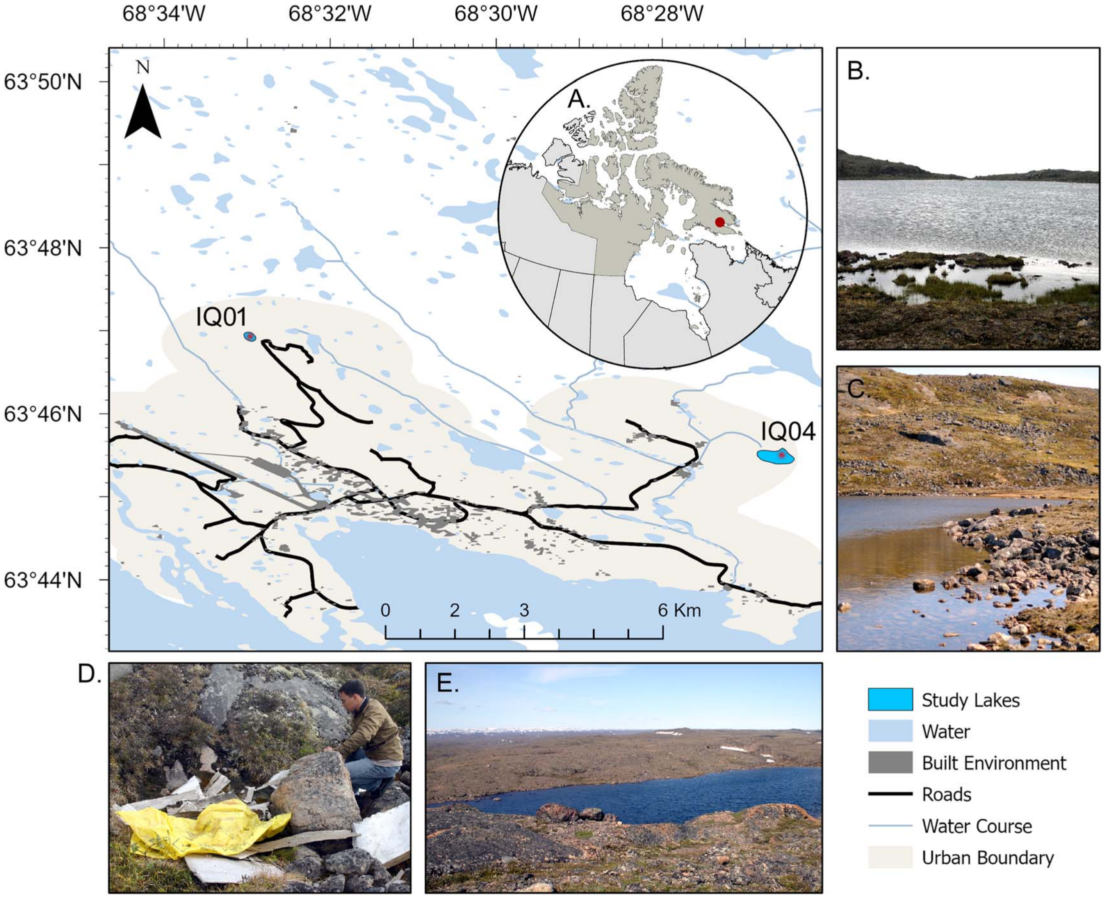

Fig. 1 Map of Iqaluit, Nunavut, Canada, with study lakes indicated. The location of Iqaluit with respect to Canada is outlined in panel A, with images of IQ04 in panel B, C, and industrial waste adjacent to lake IQ01 in panel D and an image of the lake in panel E. Images were taken by A. S. M. at the time of sampling.

been built since, which has expanded the direct urban influence on the lake, visibly increasing urban debris found in the lake and its catchment. IQ04 has historically been further from direct and legacy impacts; however, the site has been used for recreation for several decades due to its close proximity to residential areas. Lake IQ04 is also within 500 meters of a local roadway.

2.2 Field sampling

Field observations were recorded for both lakes. IQ04 is a round kettle lake with a surface area of 8.8 ha situated on a plateau with a pronounced profundal zone; measurements collected with a depth sounder deployed from a boat showed the lake deepened quickly from the shoreline. Lake IQ01 is a smaller lake (1.8 ha surface area) that is oblong in shape with a larger shallow littoral reach. Sediment cores were collected from the boat at the mid-basin of both lakes, August of 2007, with the use of an Uwitec gravity corer (8.4 cm diameter). Cores were extruded at 0.5 cm intervals for the entire core lengths collected; 25 cm from IQ01, and 19 cm from IQ04. Each subsample was placed in labelled Whirl-Pak® bags, transported in a cooler, and stored at 4 °C at Dalhousie University in Nova Scotia, Canada, for processing and analysis.

At the same time as core collection environmental parameters (temperature, oxygen reduction potential, conductivity, and pH) were measured with the use of a YSI multi-parameter probe (Table 1). Water samples for analysis of chlorophyll-*a*, major ions, nutrients, and dissolved and particulate organic carbon were also collected, described, and reported in Medeiros *et al.*[52] Samples were analysed by the Canada Center for Inland Waters (CCIW), Burlington. A thermal profile of each lake was collected with the use of a chain of HOBO Tidbit v2 water temperature data loggers deployed a subsequent visit to the lakes during July of 2015.

2.3 Laboratory analysis

A dating chronology was established for each core determined using a Constant Rate of Supply (CRS) model.[53] Sediment intervals for IQ01 were measured for ^{210}Po isotopes in 2008 by alpha-spectrometry, and for ^{137}Cs in 2010 by gamma-spectrometry at CCIW. As ^{210}Pb and ^{210}Po are assumed to be in equilibrium, supported ^{210}Pb was estimated by using the deepest value of ^{210}Po measured, and unsupported ^{210}Pb for each interval above this was determined by subtracting this ^{210}Po value from the measured ^{210}Po.

Table 1 Water chemistry of surface samples from IQ01 and IQ04 collected from Iqaluit, Nunavut, Canada[a]

		IQ01			IQ04				
		Date			Date				
Variable	Units	7/3/2006	9/9/2007	8/6/2010	7/11/2006	9/21/2007	7/19/2008	8/8/2010	8/13/2014
Lat	DD°	63.782			63.758				
Long	DD°	−68.549			−68.445				
Area	Ha	1.8			8.8				
Elev.	m.asl.	175			158				
Depth	m	7.2			8.8				
pH		7.97	—	7.90	7.85	8.05	—	7.60	7.60
COND	μS cm^{-1}	19	—	27	41	43	—	34	34
ORP	Mv	123.0	—	178.9	132.2	165.3	—	—	—
TN	μg L^{-1}	121	149	118	161	138	175	116	207
TP	μg L^{-1}	2.6	1.9	3.2	2.4	3	2.9	2	5.5
CHLA	μg L^{-1}	1.0	0.9	0.4	0.6	0.9	0.1	0.2	—
SIO$_2$	mg L^{-1}	0.86	1.83	3.25	0.86	3.85	2.60	3.35	1.18
DOC	mg L^{-1}	1.5	2.1	2.6	1.3	2.9	4.5	1.3	1.9
DIC	mg L^{-1}	1.6	3.6	4.2	3.7	10.3	5.2	5.1	4.5
POC	mg L^{-1}	0.364	0.213	—	0.184	0.210	0.208	—	—
PON	mg L^{-1}	0.030	0.036	—	0.049	0.025	0.023	—	—
Cl	mg L^{-1}	0.89	0.82	0.70	0.86	1.08	1.08	0.61	1.07
SO$_4$	mg L^{-1}	1.10	2.57	1.71	1.91	7.76	4.77	6.90	2.35
Ca	mg L^{-1}	2.45	4.41	5.17	5.44	11.90	9.58	8.39	5.09
Mg	mg L^{-1}	0.55	0.98	0.71	0.61	1.24	1.00	1.16	1.11
K	mg L^{-1}	0.16	0.14	0.09	0.19	0.13	0.16	0.16	0.16
Na	mg L^{-1}	0.61	0.76	0.69	0.65	2.64	0.77	0.70	0.75

[a] Lat = latitude, long = longitude, area = lake surface area, elev. = lake surface elevation, depth = mid-basin coring depth, COND = conductivity at 25 °C, CHLA = chlorophyll-*a*, ORP = oxidation–reduction potential, — = missing value.

Sediment cores were analyzed for subfossil chironomids at Dalhousie University following standard methods,[29] where each sample was treated with potassium hydroxide (KOH) and heated at 75 °C for 30 minutes, with stirring for 15 minutes to deflocculate the sediment so that the head capsules could be more easily extracted. The treated sediment was then poured through nested sieves of 212 and 106 μm and rinsed with 95% ethanol. Residues were then rinsed with distilled water and backwashed into Bogorov counting chambers and then sifted by hand using a dissecting microscope and specimens extracted with fine-tipped forceps. Specimens from each subsample were mounted on glass slides using Entellan® mounting medium and identified using a compound microscope to the most specific taxonomic resolution possible following Brooks *et al.*[34] and Medeiros and Quinlan.[54] A minimum of 50 head capsules were enumerated from each sediment core interval;[55] sediment intervals with fewer than 50 enumerated head capsules in the initial sediment subsample were resampled for more sediment until the minimum head capsule count was reached.

2.4 Statistical analysis and climate reconstructions

Data analysis was completed using R statistical software v.4.1.2.[56] For each core, taxa were represented by their relative abundances, calculated as the percentage of identifiable chironomids in each sample for each interval, and plotted stratigraphically over depth and chronological time. Zonation was established using constrained cluster analysis (CONISS) and compared against the broken stick model to check the significance of each zone. The Shannon index (H') was calculated for each interval to indicate diversity. A detrended correspondence analysis (DCA) was used to represent turnover (beta diversity over time) between adjacent intervals in each core.[57] To aid in interpretation of dominant trends, rare taxa, *i.e.*, those whose relative abundance never exceeded 2% of the total identifiable chironomids in any interval, were removed from the stratigraphic diagrams.

A chironomid-based paleotemperature inference model[58] was applied to the relative abundances of chironomid taxa from each interval of both cores to estimate mean-July air temperature. A 2-component weighted-averaging partial-least squares (WA-PLS) transfer function was applied to the abundances of chironomid assemblages, Hellinger transformed, of each core interval using taxa-environmental relationships from a training set of 403 lakes from across northern North America.[58] Estimates are presented based on leave-one-out cross-validation. A loess smoothing line was applied to the output using the ‘loess’ function of the package ‘stats’ in R with default parameters of a 2-degree polynomial, span (α) of 0.75, and default fitting based on weighted least squares. The squared chord distance to the closest modern analogues in the Fortin *et al.*[58] training set was also analyzed for each downcore interval (ESM1), as well as the goodness-of-fit of each core's reconstruction (ESM2) using the “palaeoSig” package v.2.0-3.[59] The core trajectories of both lakes were passively plotted across an ordination based on the training set (ESM3) using the “analogue” package.[60]

3 Results

3.1 Core chronologies

The ^{210}Pb record for IQ01 had an initial value of 30.7 Bq kg^{-1} at 0.5 cm and 6.0 Bq kg^{-1} at 6.0 cm where ^{210}Pb background was estimated as 1880 CE using the constant rate of supply model (Fig. 2a). The ^{137}Cs peak of 15.8 Bq kg^{-1} occurred at 3.0 cm, which corresponded to 1964 CE based on the ^{210}Pb profile. The ^{137}Cs peak is expected in lacustrine sediment in the northern hemisphere ∼1963 CE as this is the date of maximum fallout deposition that occurred because of nuclear weapon testing.[53] Interval ages below 6.0 cm depth were estimated through linear extrapolation with the basal interval of 25.0 cm being estimated to 1560 CE. The ^{210}Pb record for IQ04 had an initial value of 72.0 Bq kg^{-1} at 0.5 cm and 0.0 Bq kg^{-1} at 3 cm where ^{210}Pb background was estimated as 1900 CE using a constant rate of supply model (Fig. 2b). The model was also supported by the ^{137}Cs peak of 139.5 Bq kg^{-1} at 2.0 cm, corresponding to 1964 CE based on the ^{210}Pb profile. Interval ages below 4.0 cm depth were estimated through linear extrapolation of the dry weight accumulation, such that the basal interval of 19.0 cm is estimated to 1320 CE. Extrapolated dates prior to 1885 CE should be interpreted with caution.

3.2 Chironomid analysis

A total of 1269 chironomid head capsules, representing 59 different taxa, were extracted from the IQ01 sediment core (Fig. 3a). Based on the compositional similarity of samples, 2 significant zones were identified, indicating a shift in

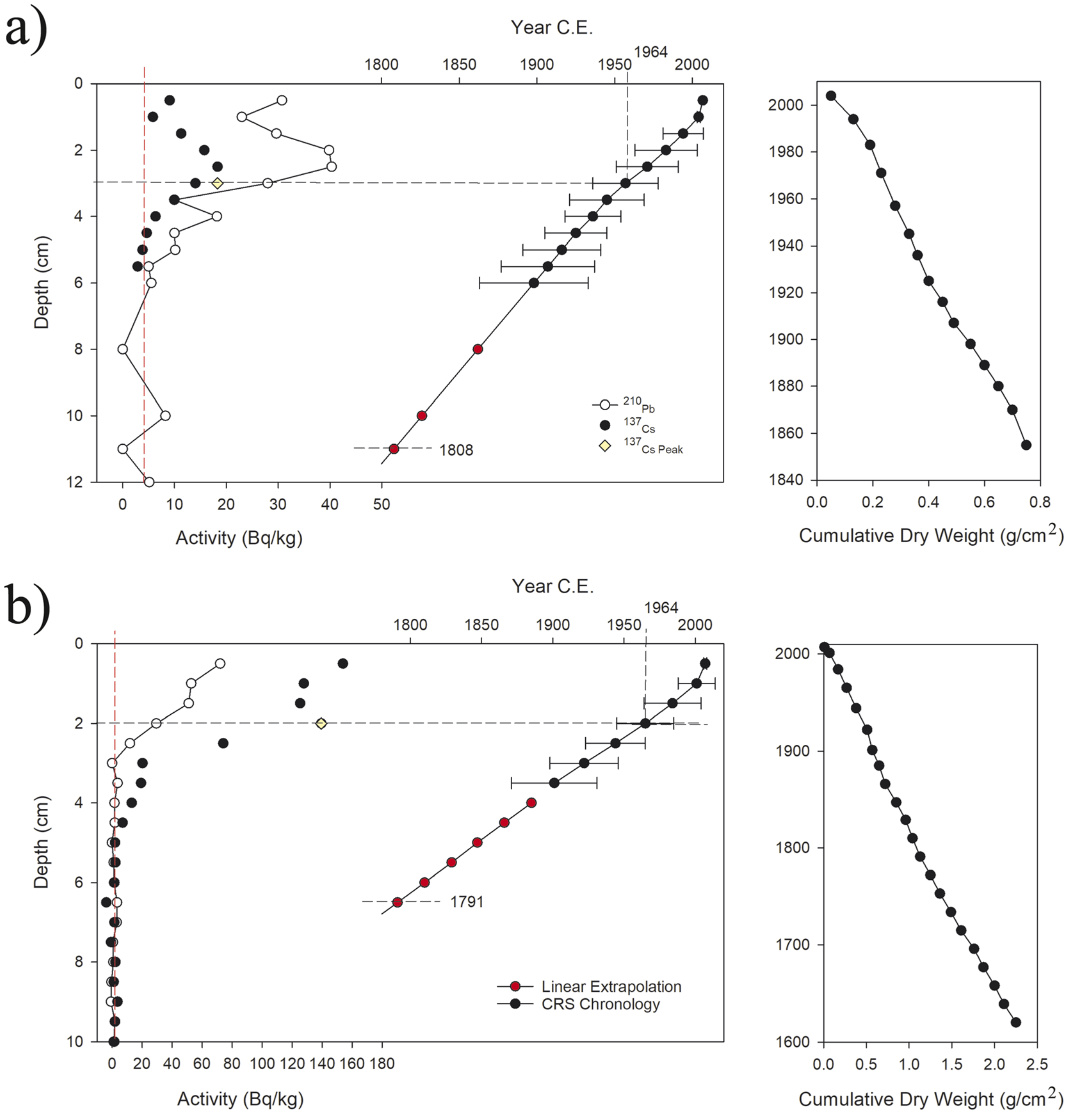

Fig. 2 Sediment core chronologies based on the CRS ^{210}Pb model and ^{137}Cs peak for (a) lake IQ01, and (b) lake IQ04. Linear extrapolation of chronology is indicated by red dots. Error bars represent the standard deviation of calculated sediment core interval age based on a CRS model chronology. The black dashed line horizontally across the upper portion of each sediment core chronology represents the core depth of the ^{137}Cs peak, and the red dashed line vertically represents the estimated supported ^{210}Pb in each core. Cumulative dry weight (g cm^{-2}) of sediments are plotted by estimated dates using the CRS model (CE).

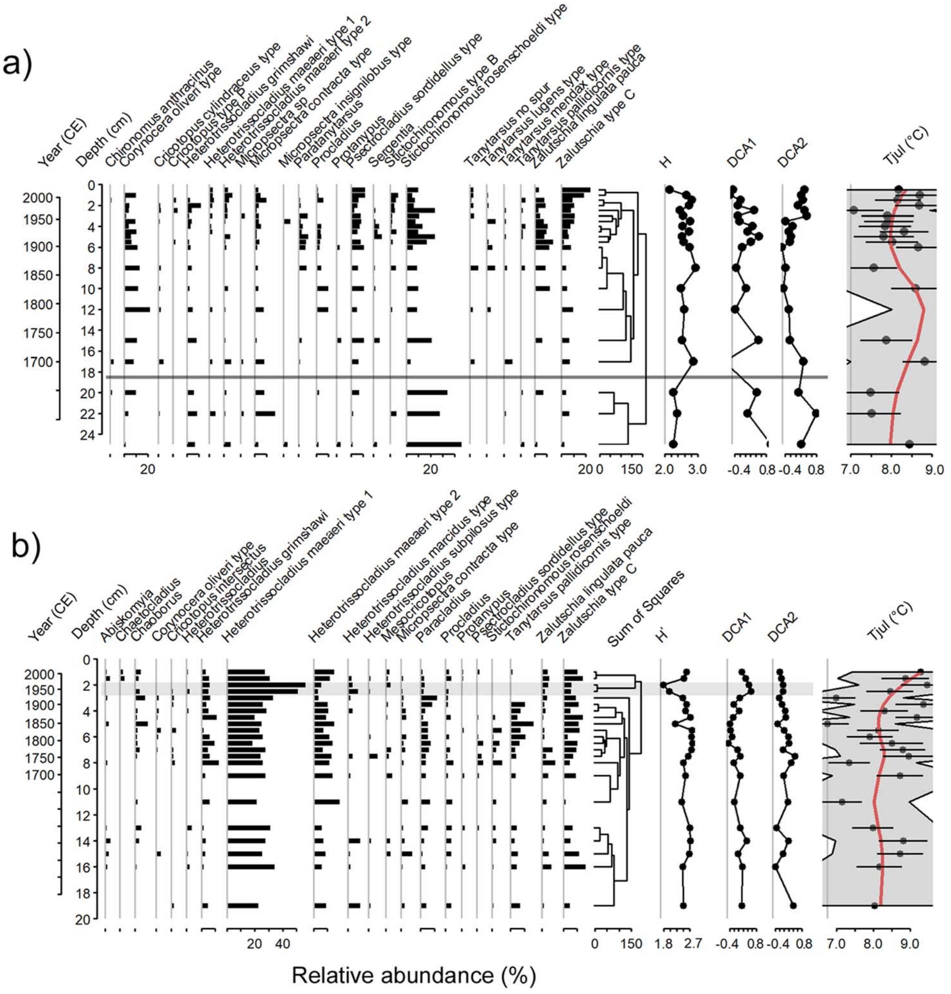

Fig. 3 Stratigraphy of chironomid assemblage, Shannon diversity (H'), DCA scores, and mean-July reconstructed air temperature (T_{jul} °C) for (a) lake IQ01, and (b) lake IQ04. Only identified taxa representing a minimum of 2% in 2 intervals are shown. A horizontal shaded line denotes a period of significant assemblage change, as based on a constrained cluster analysis (sum of squares) using a broken stick model. Reconstructed temperature reflects the output of the Fortin *et al.*[58] modern training set and the WA-PLS2 transfer function using a loess smoothing line. Error bars indicate the error component based on bootstrap estimates for each sample and the estimated standard error of prediction of the model is indicated in the shaded gray area.

assemblages from the base of the core (25 cm) to 17.0 cm (1700 CE). We note a 'noteworthy' difference in assemblages at ~1995 (from 1.5 to 0 cm, 1995–2007 CE), which we describe as Subzone 2b.

Zone 1 (22–17.0 cm; prior to 1700 CE) was represented by only three intervals in the core, comprised of high abundances of *Stictochironomus rosenschoeldi*-type, *Micropsectra contracta*-type, *Heterotrissocladius grimshawi*-type, and *Corynocera oliveri*-type. *Stictochironomus rosenschoeldi*-type had the highest abundances of the core in this zone, exceeding 30% in each interval. The abundance of *Corynocera oliveri*-type and *Micropsectra contracta*-type both increased from <2 to 10% during this period. Similarly, *Psectrocladius sordidellus*-type increased from <2 to 8%. Diversity in Zone 1 was low, with a mean of 2.3 (H'). Reconstructed mean-July air temperatures were also among the lowest of the record, with a mean temperature of 7.9 °C.

Zone 2a (17–1.5 cm; 1700–1995 CE) featured high abundances of *Zalutschia lingulata pauca*-type, *Corynocera oliveri*-type, *Zalutschia*-type C, and *Psectrocladius sordidellus*-type. The average abundance of *Stictochironomus rosenschoedi*-type declined from >30 to ~10% during this zone. The average abundance of *Corynocera oliveri*-type and *Psectrocladius sordidellus* increased to 15 and 10%, respectively. Several taxa that were <1% in Zone 1 also showed increasedabundances to >5%, including *Procladius*, *Paratanytarsus*, and *Zalutschia lingulata pauca*-type. Overall diversity increased to an average of 2.6 (H'), and reconstructed mean-July temperatures increased from 8 to a peak of ~9 °C at 1790 CE, and then declined to an average of 8 °C by 1950 CE.

Subzone 2b (1.5–0 cm; 1995–2007 CE) was only characterized by the two top intervals of the core, but we note the decline in *Zalutschia lingulata pauca*-type (from >10 to 5%), and *Heterotrissocladius grimshawi*-type, *Parytanytarsus*, *Sergentia*, and *Tanytarsus lugens*-type (5 to <1%). These taxa were replaced by a large increase in *Zalutschia* type C (8 to 20%) during this period. Diversity in Zone 2b was lower (2.1) in the very top interval. Reconstructed air temperatures increased from <8.0 °C prior to 1970 CE to >8.0 °C at the top of the core.

A total of 1564 subfossil chironomid head capsules were extracted from the IQ04 sediment core comprised of 64 taxa. Based on the compositional similarity of samples 3 zones were identified; however, as 2 of the zones identified are only 2 samples each, we show this transition as a shaded gray period from 1930 to 1970 CE (Fig. 3b). Zone 1 (prior to 1700–1935 CE) was mostly dominated by *Heterotrissocladius*, especially *Heterotrissocladius maeaeri*-type 1, which had an average abundance of ∼25%. The second-most abundant taxon was *Heterotrissocladius maeaeri*-type 2, with an average of ∼20% until 3.5 cm (1900 CE) when it declined to 5%. Other notable taxa include *Zalutschia*-type C (average of ∼10%), *Tanytarsus pallidicornis*-type (∼8–10%), *Paracladius* (5–8%), and *Heterotrissocladius grimshawi*-type (5–8%). Average diversity (H') during this period was 2.5 and chironomid-inferred mean-July temperatures were 8–8.5 °C.

The transition in the chironomid assemblage between Zone 1 and Zone 2 (3–2 cm; 1930–1965 CE) was mainly due to large shifts in the abundance of *Heterotrissocladius*. *Heterotrissocladius maeaeri*-type 1, increased in abundance by 20% during this period, while *Zalutschia* type C declined from 10 to 5% and *Paracladius* declined from 8 to 3%. *Heterotrissocladius maeaeri*-type 2 declined 5% and *Heterotrissocladius marcidus*-type increased by 3% during this time. *Tanytarsus pallidicornis*-type, *Stictochironomus*, *Corynocera oliveri*-type were not present in this zone, all of which were present in small abundances prior to 1900 CE. This transition period was marked by a reduction in the Shannon diversity of the core to a low of 1.8. Chironomid-inferred temperatures increased from 8.5 to 9 °C. From 1970 CE to the top of the core (2007 CE), abundances of *Heterotrissocladius maeaeri*-type 1, *Heterotrissocladius maeaeri*-type 2, and *Zalutschia* type C all returned to the same average abundances as prior to 1930 CE. The diversity of the upper intervals also increased back to 2.6, the same amount as Zone 1. However, *Paracladius*, *Tanytarsus pallidicornis*-type, *Corynocera oliveri*-type, and *Stictochironomus* all remained either at low abundances or absent. Abundances of *Chaetocladius*, *Abiskomyia*, and *Mesocricotopus* all increased during this period by small amounts. Chironomid-inferred temperatures were projected at their highest during the upper intervals, reaching >9.0 °C.

4 Discussion

While temperature is known to have a strong influence on the trajectory of Arctic freshwater ecosystems, less is known about how local human activities may influence our ability to infer a temperature signal using paleolimnological methods. For temperate lakes, anthropogenic stressors can influence both water quality as well as aquatic trophic systems.[61,62] However, climate change has also been shown to amplify the effects of other ecosystem stressors.[5] Here, we assessed whether two lakes within proximity to urban activities in the city of Iqaluit are able to be used to infer a regional climate signal using paleolimnological methods.

4.1 Temperature driven change

Chironomid taxa are known to have specific temperature optima, therefore shifts in chironomid assemblages tend to be indicative of changes in temperature, especially in the Arctic.[34,63] Zone 1 of IQ01 (Prior to 1700 CE) was dominated in its early stages by *Stictochironomus rosenschoedi*-type and *Micropsecta contracta*-type, both of which are cold stenotherms.[34] Following 1700 CE, both decreased in abundance and were replaced by generalist taxa of the tribe Tanytarsini, *Psectrocladius sordidellus*-type, and *Zalutschia lingulata pauca*-type, all of which have higher thermal optima.[34,63] However, *Corynocera oliveri*-type also increased during this period, which is also a cold stenothermic morphotype commonly found in Arctic lakes.[54]

Lake IQ04 contrasted with lake IQ01 in that it had higher abundances of *Heterotrissocladius* and lower abundances of *Stictochironomus rosenschoedi*-type, which is consistent with the fact that IQ04 is a kettle lake with a limited littoral zone. Prior to 1935 CE, IQ04 had the highest taxonomic richness of its record, dominated by *Heterotrissocladius maeaeri*-type 1 and *Heterotrissocladius maeaeri*-type 2, cold stenothermic taxa.[34] The earliest part of the record of IQ04 had reconstructed mean-July air temperatures that were low, and similar to those of IQ01 regardless of the difference in taxa between the lakes. A small rise in reconstructed temperatures was also similar in both records following 1700 CE, which was reflected by an increase in *Zalutschia* type C, *Tanytarsus pallidicornis*-type, and *Zalutschia lingulata pauca*-type. *Zalutschia* type C is typically found in the high Arctic region, and *Zalutschia lingulata pauca*-type can be an indicator for dystrophic lakes with high humic content.[34,64] Porinchu *et al.*[8] note a warming trend following 1700 until 1830 CE in the Arctic Archipelago. The increase in reconstructed temperatures in our lakes following 1700 CE was more prominent in IQ01 than IQ04, reflecting the reduction of *Stictochironomus* and *Micropsectra contracta*-type, which have colder temperature optima.[63] The smaller trend in IQ01, in which the reconstructed warming trend did not exceed the error the model, is likely a reflection of an increase in taxa with warmer optima (*e.g.*, *Tanytarsus pallidicornis*-type) without any noteworthy reduction of cold-water adapted taxa.

Following 1950 CE, reconstructed temperatures increased in both records. The beginning of the 20th century has been inferred by other paleolimnological studies as a time when much of the eastern Canadian Arctic experienced a substantial shift in climate caused by anthropogenic warming.[65–68] IQ01 responded to that warming in a similar way to IQ04 (ESM4), with increases in taxa with higher temperature optima occurring >1950 CE. Kaufman *et al.*[67] note that the early 20th century is regarded as a period when Arctic temperatures started to climb in response to anthropogenic warming, but the mid 20th century (∼1950 CE) is when temperatures spiked to, at the time, the highest in over 2000 years. However, the shift in chironomid assemblages observed for both IQ01 and IQ04 were more pronounced following 1990, which is reflected by further reductions in cold-water taxa. Similar increased temperatures following 1950 have also been observed in locations across the eastern Arctic, including Baffin Island,[69] central Nunavut,[68] and Greenland.[70]

4.2 Local differences

Despite being located in relatively close proximity to each other, IQ04 and IQ01 had notably different chironomid assemblages; however, these differences can be mostly attributed to differences in habitat associated with lake morphology. While chironomids are known to primarily respond to temperature,[58] it is important to note that habitat also has a strong influence.[33,48]

IQ04 is a relatively round kettle lake with a pronounced profundal zone, and the chironomid assemblages of IQ04 are consistent with that type of lake morphometry. A thermal profile collected July of 2015 showed a colder thermal profile for lake IQ04 compared to lake IQ01 (ESM5). The assemblages for IQ04 were heavily dominated by *Heterotrissocladius*, which has been shown to be commonly found in deeper Arctic and subarctic lakes.[71] IQ04 also has higher abundances of *Paracladius* and *Abiskomyia* than lake IQ01, especially in recent intervals, which is also consistent with IQ04 being a deeper and colder lake as these taxa are often more abundant in large, cold, Arctic lakes.[33,72] The notable decline in *Paracladius*, a taxa commonly found in profundal environments,[73] and increase in *Zalutschia lingulata pauca*-type, commonly associated with vegetated littoral habitats,[54] may be due to the expansion of littoral habitat. When sampling lake IQ04 we noticed flooded grassy margins; whether this was from increased precipitation in the form of rain, *versus* snowfall, in a warmer climate,[74] or subsidence of lake shoreline margins due to permafrost degradation, we cannot definitely distinguish between, or a combination of both scenarios could have taken place. Nonetheless, given that the vegetation of the inundated shoreline margins was grass suggests that this is a recent phenomenon, and the littoral extent of the lake has increased. In contrast, the chironomid assemblages of IQ01 were consistently indicative of a shallower lake with a more pronounced littoral zone.

The most notable difference between IQ01 and IQ04 is that IQ01 has much lower abundances of *Heterotrissocladius*, likely due to IQ01 being smaller, shallow, and warmer than the optima for this taxon.[33] Instead, the assemblages of IQ01 were primarily comprised of several generalist taxa, and those associated with cold littoral habitat, such as *Stictochironomus rosenschoeldi*-type, several taxa of the tribe Tanytarsini, *Psectrocladius sordidellus*-type, *Corynocera oliveri*-type, and *Zalutschia*.[34] IQ01 could have also been more productive than IQ04, as IQ01 had higher abundances of *Corynocera oliveri*-type, which, aside from being a cold stenotherm, is also often found in lakes with higher dissolved organic content and higher chlorophyll-*a*.[54] While both lakes in recent years have flooded grassy areas adjacent to the lakes, the differences in the surface area of the lake basins are notable. The catchment of IQ04 is limited, as the lake is perched on an elevated plateau. In contrast, IQ01 is located in a valley below an elevated cliff, has a catchment that is primarily comprised of lush grasses on two sides, and has extensive areas of flooded marsh. This difference could result in a larger catchment-mediated inputs to IQ01, which could explain the taxonomic differences between the two lakes.

4.3 Influences of urbanization

In cases where local human activities have become a primary driver of environmental change in lakes, increased anthropogenic input would normally increase the abundance of certain pollution tolerant taxa, such as *Chironomus*[75] (Al-Shami *et al.* 2010), *Cryptochironomus*,[76] as well as some taxa from sub-family Orthocladiinae, including *Cricotopus bicinctus*-type and *Hydrobaenus*.[41] The influence of pollution would also be expected to lower species richness.[35,41] For IQ04 and IQ01, we found that regardless of their proximity to urban influences, both lakes reconstructed climate in a similar fashion. Taxa we would assume to be associated with pollution were low in abundance in both lakes, and the primary shifts in assemblages were mainly fluctuations in cold stenothermic taxa. That being said, we did not specifically measure for indicators of pollutants within the sediments of either lake.

The assemblages of IQ01 and IQ04 are similar to lakes in non-urban regions around Baffin Island. However, this is not to say that these lakes and other freshwater systems around Iqaluit are not being affected by their urban setting. Lake IQ04 showed shifts in the assemblage ∼1930 and 1970 CE, the period in which Iqaluit was initially settled and urbanized. This period was reflected by a large increase in *Heterotrissocladius maeaeri* type-1, and associated decreases in *Heterotrissocladius maeaeri* type-2, *Paracladius*, *Tanytarsus pallidicornis*-type and *Zalutschia* type C. *Heterotrissocladius maeaeri* type-2 and *Zalutschia* type C have lower temperature optima than the other taxa,[63] but *Paracladius* and *Tanytarsus pallidicornis*-type are both littoral taxa, suggesting that the shift in assemblages during this time may be due to an increase in the size of the littoral reach. Whether this was due to human activity in the area is unknown.

While we did not observe a shift in chironomid assemblages in lake IQ01, which is the closest lake to the former military base, in response to the development of Iqaluit, there is still likely an urban influence on the lake. Medeiros *et al.*[41] found that the urbanization of Iqaluit has had a noticeable effect on the chironomid assemblages of nearby freshwater streams; pollutants have been found in the tissues of fish in lakes near Iqaluit,[40] and hazardous waste disposal bags labelled to contain asbestos have been found in the lake and catchment of IQ01 (personal observation, Fig. 1d). The results here are not indicative of these lakes being unaffected by local human disturbance, they instead indicate that despite their proximity to Iqaluit, these lakes are not yet experiencing substantive enough human disturbance to elicit an ecological response from chironomids that is greater than that of ecological response to a warming climate.

5 Conclusion

Climate was found to be the primary driver of shifts in the chironomid assemblages of two urban lakes in Iqaluit, Nunavut, despite increased local human presence. Anthropogenic disturbances were either not sufficient to have a noticeable effect on chironomid assemblages of the two local lakes, or the influence of climate overshadowed these effects. It is notable that the chironomid-based paleotemperature reconstruction of mean-July air temperature from both lakes were similar, in terms of the specific temperature values reconstructed as well as the amplitude of change. Reconstructions were strongly influenced by decreases in cold-stenothermic taxa, yet the chironomid assemblages in each lake were different. The taxa present in both lakes were similar to those in other paleolimnological studies from Baffin Island, and the climate signal observed corresponds to known climate shifts during the same periods in the region. Climate change and local human influences are expected increase in the future, and continued monitoring and management of Arctic freshwater systems will be important an important part of ensuring that local freshwater resources are able to support the health and well-being of Arctic communities.

Data availability

The raw abundance of subfossil chironomids for both cores have been archived; **https://doi.org/10.5281/zenodo.11104219**. For all other data and R scripts associated with creation of the figures found in this manuscript, an archive is available on the corresponding authors github repository; **http://www.github.com/arcticecology**.

Author contribution

ASM: conceptualization, data collection, methodology, data analysis, writing – reviewing and editing, supervision. CN: visualization, data analysis, data curation, writing – original draft preparation. JE: data curation, data analysis, software, validation. RQ: Supervision, data collection, methodology, writing – reviewing and editing.

Conflicts of interest

There are no conflicts to declare.

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