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ORIGINAL RESEARCH

Use of traditional environmental knowledge to assess the impact of climate change on subsistence fishing in the James Bay Region of Northern Ontario, Canada

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ABSTRACT

Introduction: In Canada, unique food security challenges are being faced by Aboriginal people living in remote-northern communities due to the impacts of climate change on subsistence harvesting. This study used traditional environmental knowledge (TEK) to investigate whether there was a temporal relationship between extreme climatic events in the summer of 2005, and fish die-offs in the Albany River, northern Ontario, Canada. Also, TEK was utilized to examine a potential shift in subsistence fish species distribution due to climate change.

Methods: To investigate whether there was a temporal relationship between the fish die-offs of July 2005 (as identified by TEK) and an extreme climatic event, temperature and daily precipitation data for Moosonee weather station were utilized. To determine if there was an increasing trend in mean maximal summer temperatures with year, temperature data were examined, using regression analysis. Present-day fish distributions were determined using unpublished TEK data collated from previous studies and purposive, semi-directive interviews with elders and experienced bushman.

Results: Fish die-offs in 2005 occurred during the time period 11–18 July, as reported by participants. Recorded air-temperature maxima of the two July 2005 heat waves delineate exactly the time period of fish die-offs. Two heat waves occurring during the same summer season and so close together has never before been recorded for this region. A highly significant ($p<0.0009$) positive relationship between mean maximal summer temperatures and year was evident. Regionally novel fish species were not apparent, utilizing TEK.

Conclusions: Traditional environmental knowledge coupled with climate data revealed temporal relationships between extreme climatic events in 2005, and fish die-offs in the Albany River. Thus, climate change can directly impact food security by decreasing the number of fish through mortality – and indirectly through population dynamics – by impacting the yield of fish subsistence harvests in the future. By contrast, TEK did not reveal northward expansion of novel fish species in the Albany River or fish distributional contraction in the western James Bay region.

Key words: Aboriginal issues, Canada, climate change, fish die-offs, fish distribution, food security, health, James Bay, traditional environmental knowledge.

Introduction

The Food and Agriculture Organization of the United Nations maintains (p.5)[1]:

> *…food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. The four pillars of food security are availability, stability of supply, access and utilization.*

When people do not have adequate access (ie physical, social, cultural or economic) to food, food insecurity exists. Food security is important as it has been recognized as a determinant of health, with individuals experiencing food insecurity being at greater risk for negative health outcomes[2]. It should be noted that traditional food consumption has been related to increased health and wellbeing[3,4]; thus, any factor that negatively impacts consumption of traditional foods negatively impacts health and wellbeing of Aboriginal people.

In Canada, unique food security challenges are being faced by Aboriginal people living in remote-northern communities[5] from the impacts of climate change on subsistence harvesting[6]. Climate change is of particular importance to people of the western James Bay region of northern Ontario, Canada, because of the potential impacts of climate change on subsistence activities (and food security). The procurement of wild game, fish, and other material from subsistence pursuits (ie hunting, fishing, and gathering) was worth CA$9.4 million in 1990 to the Omushkego Cree of the western James Bay region, being approximately one-third as large as the cash economy[7]. The subsistence lifestyle has been called the cornerstone of the regional mixed (ie subsistence lifestyle, government transfer payments, and wage work) economy[7]. The importance of fish as a staple food cannot be over-emphasized[8]. Subsistence fishing in spring, summer, and fall seasons occurs in all major rivers of the western James Bay region; while fishing in the winter is more widely dispersed[9]. In the period 1947–1948, the type of fish eaten were identified as whitefish (*Coregonus* spp.; most commonly caught and consumed), northern pike (*Esox lucius*), brook trout (*Salvelinus fontinalis*), sucker (*Catostomus* spp.), walleye (*Sander vitreus*), sturgeon (*Acipenser fulvescens*), and burbot/ling (*Lota lota*)[8]. Similarly, in a 1990 harvest study of the Omushkego Cree, whitefish were the most commonly harvested fish (44 707 were reported), followed by northern pike (19 758), walleye (17 678), sucker (9710), brook trout (6384), burbot/ling (4451), and sturgeon (3850)[7]. Clearly, subsistence fishing is still an important activity for the Omushkego Cree.

In a recent report on climate change impacts, vulnerabilities, and adaptation in Ontario, it was recognized that the northern part of Ontario is the least studied region of Ontario even though remote and resource communities in northern Ontario are highly susceptible to climate change[10]. At a recent climate change impact workshop sponsored by Indian and Northern Affairs Canada, one area of potential concern was climate change impact on traditional food supplies[10]. It has been suggested that Indigenous knowledge, also known as traditional ecological knowledge or traditional environmental knowledge, could act as an important source of information[11] for the western James region with respect to fish distribution[12] and climatic change[10]. This article examines the potential use of traditional environmental knowledge (TEK) in assessing the impact of climate change on subsistence fishing in the western James Bay region of northern Ontario, Canada. Specifically, TEK was used to examine whether there has been any change in fish species distribution, as predicted in climate change fish distribution models for the western James Bay region[13,14]. A potential shift in fish species distribution could introduce a new food species and/or diminish a traditional food source for the Omushkego Cree[15]. Finally, the study sought to investigate whether there is a temporal relationship between extreme climatic events in the summer of 2005, and fish die-offs in the Albany River of the western James Bay region.

Background

Climate change: There is increasing evidence that northern Canada is undergoing major climatic change[15-17]. Although the global-average surface temperatures have risen by 0.6 ± 0.2°C over the past century – the arctic and subarctic regions have experienced a general warming of up to 5°C[15,18] – the most rapid rates of increasing average surface temperatures among the world's regions during the last century[15,17]. Thus, the Hudson and James Bay regions of northern Ontario, Canada (Fig 1) have been affected disproportionately by such rising temperatures[19,20]. For example, the duration of sea-ice cover in Hudson and James Bay – a key indicator of climatic changes and trends in the north[17,21] – has been decreasing as a consequence of earlier break-up and later freeze-up dates over the past few decades[22,23]. Indeed, Gough et al[23] reported a statistically significant increase in the length of the ice-free season for the southwestern region of Hudson Bay and the northwestern region of James Bay for the period 1971 to 2003. The trends in river-ice break-up dates in the western James Bay region are not as consistent because there are many confounding variables, although the average temperatures in spring and winter have increased in the region[24].

Fish biology: Although subsistence fishing is important in northern Canada, the geographic distribution of fish species is not well known in arctic[25] and subarctic regions of Canada, such as the western James Bay region of northern Ontario[12,26]. As fish are ectothermic, their body temperature is dependent on water temperature, which is primarily dependent on air temperature. However, fish can use behavior to control body temperature by choosing areas where optimal physiological temperature is attainable, that is, fish species have specific thermal preferenda[27,28]. Thermal preferenda or temperature preferenda can be defined as the water temperature a fish gravitates to irrespective of previous acclimation[29]. Nevertheless, the thermal range a fish species can tolerate is often narrow, and differs depending on the life stage of the fish[27,28]. Thus, water temperature is a key factor influencing the distribution of freshwater fish species, but the presence of competitors is also important[30].

There are three thermal guilds identified for fish species (note: fish do not necessarily, exclusively belong to one guild), as characterized by summer temperatures: cold water (11–15°C; whitefish, brook trout); cool water (21–25°C; northern pike, walleye, yellow perch [*Perca flavescens*]); and warm water (27–31°C; sturgeon, suckers)[28,29]. An increase in air temperature (and increase in water temperature) due to climate change will alter the thermal aquatic habitat and may impact the range of several fish species[31]. Indeed, Reist et al[25] reported an observed range extension of 500 km north in the Canadian arctic of the bull trout, *S. confluentus*; while Babaluk et al[32] reported the northern extension of the distribution of several salmonid species (sockeye, *Oncorhynchus nerka*; pink, *O. gorbuscha*; coho, *O. kisutch*). Taking into account that shifts in temperature and precipitation will result in direct and indirect effects on ecosystems and the fish species present, there is a paucity of information on basic fish biology and habitat requirements with respect to fish of northern Canada to accurately predict northern range changes[28]. However, the scenarios that have been presented indicate that climate change will result in an increase in fish diversity, as well as competition, as a result of the changing distribution of fish species[28].

Figure 1: Study area of the western James Bay region.

There are several factors, other than increasing temperature, potentially aiding the northward shift of some fish species' distributional range with respect to the western James Bay region: watersheds drain northward allowing northward movement of fish[31,33]; and the low gradient change from southern Ontario to the north is ideal for expansion along the subarctic river systems[13]. Specifically, it has been suggested by researchers[13,14] that climate change (ie increasing air temperature) has the potential to lengthen the growing season of smallmouth bass (*Micropterus dolomieu*) with a concomitant increase in body condition, thereby increasing over-winter survival of young-of-the-year which typically determines population viability and northern distribution of this species. In addition, it has been reported that in areas of Ontario where the July temperature approached 16°C, the viability of smallmouth bass was zero – a mean July temperature of 18°C was required for the presence of smallmouth bass – and the southern James Bay region mean July temperature was at the 18°C threshold[13,14]. If the smallmouth bass extend their distributional range northward, as has been predicted by Jackson and Mandrak[13], there will be negative impacts on many fish species[10,13]. Adding further, Chu et al[34] examined the potential impact of climate change on the distribution of selected freshwater fish in Canada, using the Canadian Global Coupled Model 2 (CGCM2) with the IS92a ('business as usual') emission scenario and report that coldwater species (ie brook trout) may be extirpated from their present western James Bay region range by 2020, except for an isolated population on Akimiski Island.

Traditional environmental knowledge:

> *Traditional environmental knowledge [TEK] is a body of knowledge and beliefs transmitted through oral tradition and first-hand observation. It includes...a set of empirical observations about the local environment... The quantity and quality of TEK varies among community members... With its roots firmly in the past, TEK is both cumulative and dynamic, building upon the experience of earlier generations and adapting to the new technological and socioeconomic changes of the present.* (Dene Cultural Institute, cited in Stevenson, p281)[35]

The present study incorporated two epistemologies, science and traditional environmental knowledge (TEK) in a complementary fashion as suggested by Tsuji and Ho[11], in order to assess the impact of climate change on subsistence fishing in the western James Bay region. This approach was taken as TEK can complement or supplement a purely scientific approach through spatial, temporal, and social/cultural frames of reference[36]. These frames of reference are not mutually exclusive and TEK may even be the sole source of baseline data, as in northern Canada[37].

Methods

Study area

The western James Bay region is characterized as having a subarctic climate with short and fairly warm summers, and long and cold dry winters[38]. There are approximately 10 000 First Nations people inhabiting the communities of this region (Fig 1): Moose Factory (Moose Cree First Nation); the town of Moosonee; Fort Albany First Nation; Kashechewan First Nation; and Attawapiskat First Nation[39]. As described previously, the Cree communities of the western James Bay region are still dependent on wildlife harvesting, predominantly fish and game meat[7,40,41].

In a study by McDonald et al[42], TEK was collected during the time period 1992 to 1995 for 28 communities of the Hudson Bay bioregion, including the First Nations of the western James Bay region. Although the McDonald et al[42] study included a section describing environmental change and its impact on the western James Bay Cree traditional lifestyle, there was no mention of sightings/harvesting of novel fish species or any other climatic effects with respect to known fish species. Similarly, in a TEK study 2002–2004 (initiated to meet requirements of an environmental assessment for the Victor Diamond mine located near Attawapiskat First Nation), although there were reported rare sightings, defined as organisms not 'commonly found' in the Attawapiskat River Basin and associated coastline, there were no reported sightings/harvesting of novel fish species (p.87)[43]. Nevertheless, 'bass' have been reported in the Attawapiskat River basin in Missisa Lake by a guide operating a fishing camp, and in a second lake near the Little Attawapiskat River by Attawapiskat First Nation community members[43]. It should be emphasized that there is no Cree name for any species of bass[43] because this fish species is novel to the region.

In the present study, a species of fish is considered novel to the western James Bay region if the Omushkego Cree do not have a Cree name for the species of fish. Indeed, Omushkego

Cree names for 38 species of fish from 26 genera have been recorded, and many are not subsistence species[43]. In a review of Cree fish names for the eastern James Bay Cree, there was good agreement with the western James Bay Cree names for subsistence species; and like the western James Bay Cree, eastern James Bay Cree have names for prey species, even though these 'forage' fish species are too small to be caught by the gillnets used for subsistence[44]. It is important to note that eastern James Bay Cree names for fish species closely parallel the actual distribution of these fish as reported in the scientific literature[44]. In other words, certain First Nation communities on the east coast of James Bay have never encountered a fish species due to subsistence activities occurring beyond the said fish species distribution; thus, there is no Cree name, as the fish species has not been encountered previously[44]. The same has been assumed for the western James Bay region because novel fish species should not have a traditional Cree name. The relatively regular capture of a specific species of fish at the same location over time is probably indicative of an established population not a rare extralimital occurrence[25].

There are three major river systems in the region (Fig1): the Moose River basin is a highly fragmented river system containing natural (ie waterfalls) and human-made (ie dams) barriers[12]; there is some hydro-electric development upriver on the Albany River, with 17% of its flow diverted from its origin; and the Attawapiskat River basin which remains essentially unaltered[26]. Taking into account that the Moose River is highly fragmented and there are many impediments to the northward migration of regionally novel fish species, and TEK with respect to the Attawapiskat River basin has already been collected[43], the focus of the present study was on the Albany River.

Present-day fish distribution: TEK

Relevant unpublished TEK data were collated from the authors' research team's previous western James Bay projects. Briefly, in June of 1999, 146 people (≥18 years; 71 females, 75 males) residing in Fort Albany First Nation participated in a survey study documenting land use on and around Anderson Island, the site of an abandoned mid-Canada radar line base and source of terrestrial organochlorine contamination, which is located in the Albany River[45]. Data were gathered through a questionnaire developed in partnership with Fort Albany First Nation. Potential participants were chosen at random. However, Chief and Council of Fort Albany First Nation also requested that an effort should be made to include all people who had lived on Anderson Island. Community participation rate was 41% of eligible community members; specifically, 43% of females participated and 39% of males[45]. The authors have previously reported on the mapping and questionnaire data from this study[45], but have not reported the results of the open-ended questions, which are relevant to the present study. These questions had been added to the Anderson Island land use study at the request of Fort Albany First Nation Band Council, the local government, because they had concerns about organochlorine contamination of the Albany River system[46,47], and the health and distribution of the fish inhabiting the Albany River. The present study reports any unusual fish observed by people fishing in the Albany River around Anderson Island. An unusual fish was defined as one that is either phenotypically deformed or species novel to the region.

In 2002, a TEK climate change project was conducted in the western James Bay region. Ten semi-directive interviews, three in Fort Albany and seven in Moose Factory were conducted with local Elders in their preferred language (Cree or English) who were identified as knowledgeable people by members of the community who regularly worked with Elders. A 'knowledgeable' person was defined as a local Elder who had either grown up in the bush or had spent extended periods of time in the bush. The semi-directive interviews were conducted in person. The semi-directive interview is the most widely used method of TEK collection, as this method allows for the narrative nature of First Nation communication to be unhindered. The semi-directive interview approach allows for a conversational style of communication – with topical guidance from the interviewer – allowing for the inclusion of atypical or unanticipated responses, which respondent might feel are relevant. Thus, the interviews were structured to allow participants to identify what they felt were important indicators of climate change, and allow them to elaborate in an unstructured manner on observations of those indicators. Questions related to indicators of climatic change (eg Have you noticed any changes in the fish [distribution, novel species etc]?) were posed to the interviewees in a given sequence. The use of a series of questions was meant to facilitate discussion. In general, the questions were posed as guidelines for an open dialogue between the researchers and participants. It should be stressed that collecting TEK is not meant to be a survey. Rather, the most relevant and knowledgeable persons were interviewed.

Additional TEK was collected in the present study by the research team. Sampling was purposive as not all community members were equally knowledgeable. In 2009, seven semi-directive interviews were conducted with four experienced bushman and three Elders (six members of Fort Albany First Nation and one from Kashechewan First Nation), in English, who were known by our research team as being knowledgeable people with respect to fish of the Albany River. The semi-directive interviews were conducted in person and focused on the topic of subsistence fishing (and contaminants) and novel fish species in the Albany River. Further, in the winter of 2010, four semi-directive interviews were conducted with two experienced bushman and two Elders (three members of Fort Albany First Nation and one from Kashechewan First Nation) who are known to fish for brook trout. The semi-directive interviews were conducted in English, in person, and focused on the abundance of brook trout at traditional fishing areas. A follow-up interview was conducted in April 2010, by phone with one Elder. Finally, gillnets were set daily and checked once a day, as part of the regular routine of subsistence fishing, in the Albany River near the community of Fort Albany First Nation, for a four-week period in June and July 1999. Likewise, gillnets were set daily and checked once a day, in the Albany River near the community of Fort Albany, for a 10 day period in August 2009 and for a 10 day period in August 2010. The catch for these time periods was checked for phenotypically deformed fish and regionally novel fish species. The use of subsistence fisheries to document the distribution of novel fish species in northern Canada has been used previously[32].

Fish die-offs: TEK

In 2005, TEK was provided, unsolicited, to one of the authors of the present study, during an unusually hot and dry period of time during the summer. This information is presented in the Methods section instead of the Results section because the TEK informs the type of climate data analyzed.

> *I found one dead whitefish around Old Post [old Fort Albany fur trading post]. It was small.* (Experienced Kashechewan bushman, 17 July 2005)

> *I found three, small, dead whitefish around Old Post.* (Experienced Kashechewan bushman, July 18, 2005)

> *Last week [11–15 July], [I] saw 4 to 5 suckers [6–8'] and 2 whitefish [6–8'] [dead] by Old Post.* (Fort Albany First Nation elder, 17 July 2005)

> *I saw fresh fish carcasses, and two dead, older carcasses. One was a sucker and the rest were whitefish [4–8']. They were down by the youth camp, approximately one mile downstream by Old Post.* (Member of Fort Albany Band Council, 18 July 2005)

It should be noted that the reported dead fish were not caught in nets, but were observed in-situ along the Albany River.

Fish die-offs: climate data

To investigate whether a temporal relationship exists between the fish die-offs of July 2005 (as identified by TEK) and an extreme climatic event, temperature (the daily maximum, minimum and mean temperatures, °C) as well as daily precipitation data (mm) for July 2005 were examined. Climate data were obtained from climate datasets maintained by the National Climate Data and Information (NCDI) Archive of Environment Canada. The Moosonee weather station (51°16'200' N, 80°39'000' W[48]) is situated in the south of the James Bay area, and this is the only station located in this northern region, with an extended, intact climate record; the other weather station at Fort Albany was only operational for a short period of time and data are incomplete[49]. The Moosonee weather station climate records were used to examine daily maximum temperatures for the exceedence of a specific thermal threshold. In Canada, a 'heat wave' is defined as 'three or more consecutive days in which the maximum temperature is greater than or equal to 32°C' (p.1)[50].

To determine if there is an increasing trend in mean maximal summer temperatures with year, in the western James Bay region, past summer (June, July, and August) temperature data were examined using regression analysis. To this end, the historical homogenized temperature datasets (ie adjustment for non-climatic inhomogeneities such as station relocations and changes to observational procedures[51,52]) were obtained from Environment Canada (the Adjusted and Homogenized Canadian Climate Data[53]). The homogenized climate datasets available for the Canadian north prior to the mid-1940s are limited[53]; thus, the present study concentrated on monthly maximum mean temperatures (°C) from 1960 to 2006 (Moosonee UA weather station; 51°27' N, 80°65' W).

Results

Present-day fish distribution: TEK

Unpublished TEK from our research team's previous studies did not reveal sightings/harvesting of regionally novel fish species. Further, none of the people who participated in semi-directive interviews in 2009 reported observing regionally novel fish species. Although there were two reports that brook trout were not being caught in the winter of 2010 in traditional subsistence fishing locations, by April 2010 brook trout were again being harvested from these same locations. No regionally novel fish were observed in the subsistence harvest of 1999, 2009, and 2010.

Fish die-offs: TEK

In the present study, no fish die-offs were reported by participants to have occurred prior to or after the 11–18 July 2005 time period.

Fish die-offs: climate data

The daily maximum temperature, daily minimum temperature, and daily mean temperature (°C) for the 11–18 July 2005 period and the corresponding temperatures for the summer of 2005 are summarized (Table 1). The daily maximum temperatures for the summer of 2005 are illustrated (Fig2); there were two heat waves during the period of reported fish die-off, as well as a period of reduced precipitation. Moreover, it should be noted that recorded air-temperature maxima of the two July 2005 heat waves delineate exactly the period of time of the fish die-offs. In other words, on 11 July air temperature reached 37°C and this was the first day that fish die-offs were observed; while, on 18 July, air temperature was recorded as 35°C, the last day of observed fish die-offs (Fig 2). Further, two heat waves occurring during the same summer season, let alone so close together, has never been recorded for the James Bay region for the period 1960–2008. What is also of interest is the relatively elevated daily minimum temperatures recorded during the period of fish die-offs (Fig2).

Homogenized-monthly, mean-maximum temperatures data (in the summer season) were normally distributed (Shapiro-Wilk's Test, p=0.44). The relationship between the homogenized-monthly, mean-maximum temperatures (in the summer season) versus the years 1960 to 2006, is presented (Fig3). A highly significant (p<0.0009) positive relationship was evident (Fig 3), where approximately 22% of the variation in homogenized-monthly, mean-maximum temperature was explained by year. There was no correlation between residuals for consecutive years (Pearson r=0.107, p=0.48) and the Durbin-Watson statistic (D=2.190) exceeded the upper bounds critical level (dU=1.38, p=0.01, for simple linear regression) indicating that the residuals are independent[54].

Table 1: Summary of the daily maximum temperature, daily minimum temperature, and daily mean temperature for 11–18 July 2005, and the summer of 2005 (June, July, and August)

Interval	Daily measurement	Temperature (°C)	
		Mean ± SD	Range
11-18 July 2005	Maximum temperature	31.6 ± 5.29	22.0–37.0
	Minimum temperature	16.5 ± 4.23	10.5–21.5
	Mean temperature	24.1 ± 4.52	17.5–28.5
Summer 2005	Maximum temperature	23.1 ± 6.19	7.0–37.0
	Minimum temperature	10.2 ± 4.97	-1.0–21.5
	Mean temperature	16.7 ± 4.94	4.0–28.5

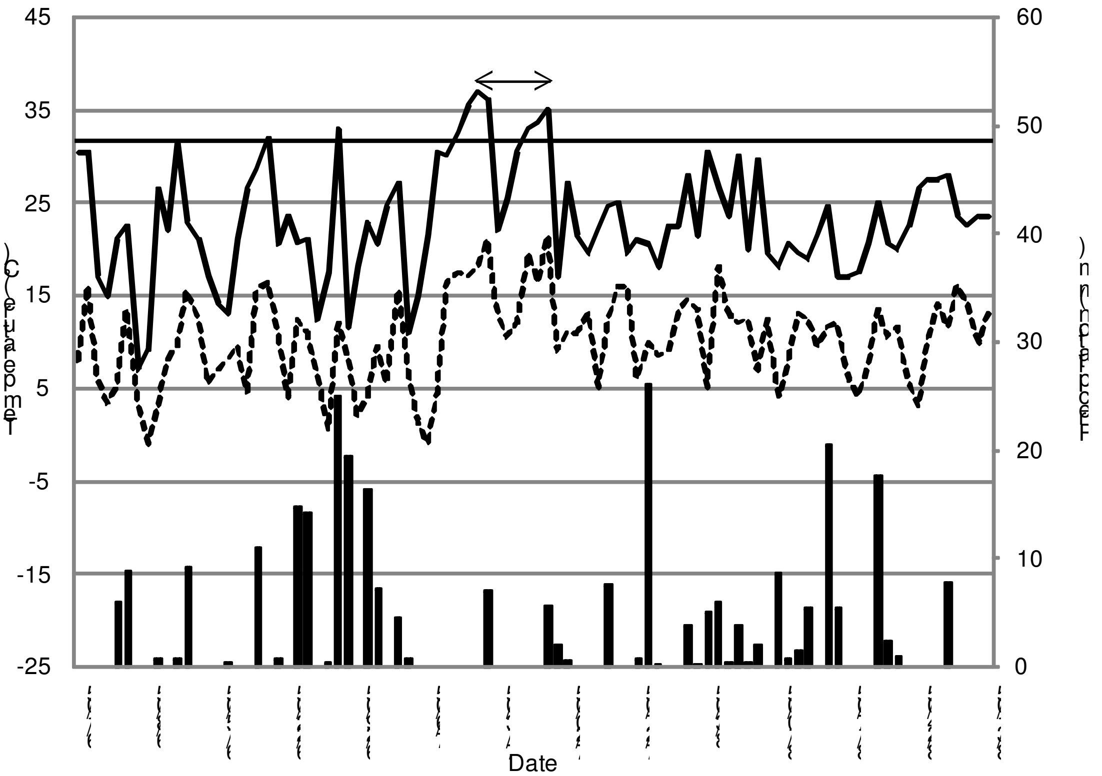

Figure 2: The daily maximum temperature (solid line), daily minimum temperature (dashed line), and daily total precipitation (bars) for June, July, and August 2005. The solid horizontal line indicates 32°C. Three or more consecutive days of at least 32°C is considered a 'heat wave' in Canada. The occurrence of fish die-offs, 11-18 July 2005, is indicated by the double arrow. Note the temporal relationship between the maximal temperatures recorded during the two heat waves and the fish die-offs.

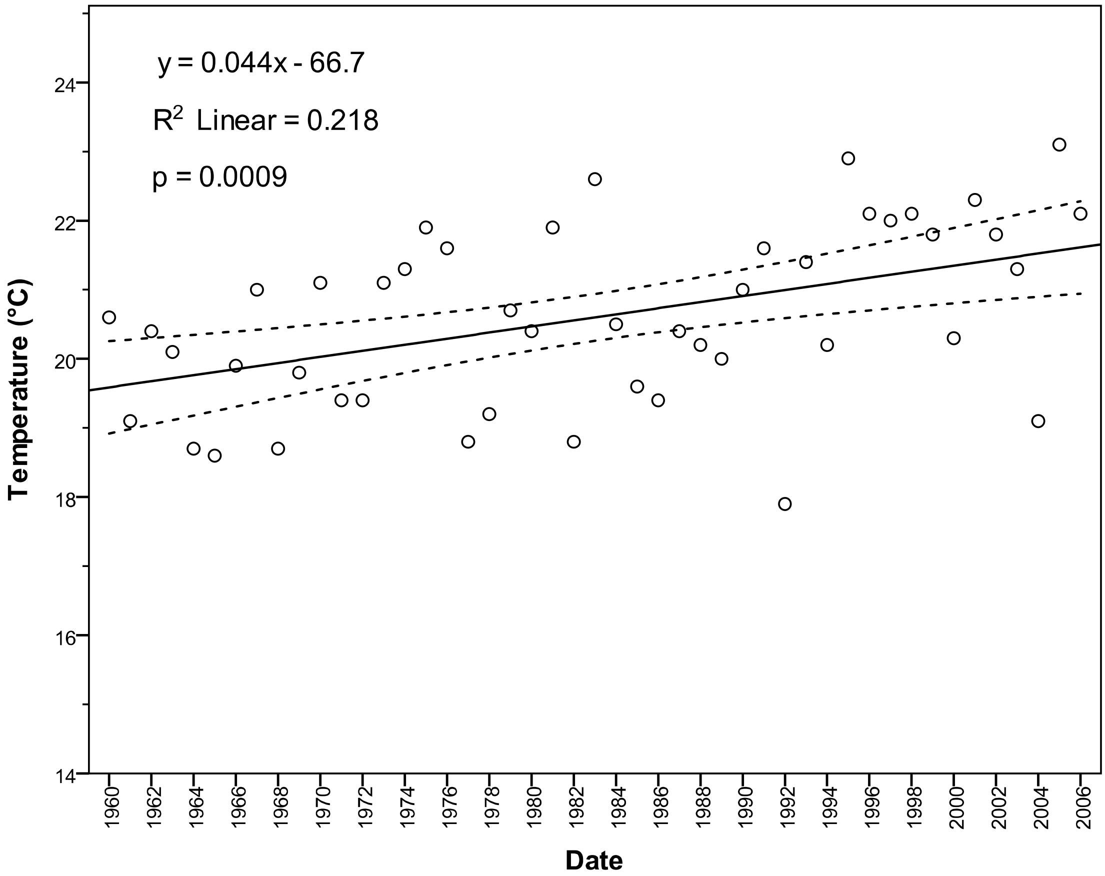

Figure 3: The relationship between homogenized-monthly, mean-maximum temperature (°C) and year in summer (June, July, and August) for the period 1960–2006.

Discussion

Fish distribution

Reist et al suggested three potential outcomes for fish and fish species, as related to temperature increases: (i) the extirpation of a fish species due to thermal stress; (ii) the rapid evolution of a fish species due to natural selection; and (iii) the northward shift of a fish species' distributional boundary[33]. With respect to distributional boundary shifts, it is important for fish young-of-the-year to attain a minimal amount of growth to sustain them over the winter season; this constraint has been used to explain the northern distribution of yellow perch and smallmouth bass[14]. No evidence was found that the smallmouth bass is present in the Albany River close to James Bay. Smallmouth bass were introduced to the headwater lakes in the Canadian Shield of Ontario in the 1920s, and the smallmouth bass has spread to several river systems including the Missinaibi River (part of the Moose River Basin) as far north as Thunder House Falls, but the distribution has been spotty[12]. Very little is known about the riverine smallmouth bass population in the Moose River tributaries[12]; however, the smallmouth bass may be spreading northward because one smallmouth bass has been reported to have been caught in the Moose River[26]. Further, there have been reports of 'bass' in the Attawapiskat River basin[43]. In addition, Chu et al[43] reported that coldwater species such as brook trout may be extirpated from their present western James Bay region range by 2020, but TEK collected in the present study do not indicate a range contraction for brook trout, at this time.

Fish die-offs

The present study is the first to report on fish die-offs as an observed climate change impact on specific fish species (ie suckers and whitefish) and a specific age class, in the western James Bay region. The temporal relationship between the start of the fish die-offs in 2005 and the maximal temperature of the first heat wave – and the temporal relationship between the last fish die-offs with the maximal temperature of the second heat wave – imply causality. In addition, TEK revealed that fish die-offs in the Albany River had not been observed prior to 2005 and not seen since 2005. Further, two heat waves in one summer in the western James Bay region is a rare occurrence, and has not been recorded for the time period 1960–2008, other than in 2005. When the temporal relationships of these rare events are considered as a whole, causality is inferred.

Although direct effects on individual fish may differ because of life stage, temperature-related mortality may have populational effects[28]. As reported earlier with respect to the die-offs, the dead suckers and whitefish were described as being small or estimated to be in the 4–8' range; however, it is unknown what life stage these fish correspond to, because very little is known about fish biology in the subarctic region. Nevertheless, it can be assumed that these dead fish were sub-adults by the morphological descriptions given by the Cree individuals, and this assumption is supported by other studies where yearling suckers have been found to inhabit the edge of main water channels[12]. Although water at the periphery of water courses can have elevated temperatures and marginal oxygen supplies, juvenile fish (ie striped bass, *Morone saxatilis*) often reside in the warm shallows, where there is abundant small food and protection from predators[27]. The Albany River is home to two main piscivorous fish, northern pike (a lie-and-wait predator) and walleye (a roving predator), that most often inhabit the interface between open water and the near-shore region[55]. Predatory pressure may have kept the small suckers and whitefish in the shallow water of the Albany River – even though warming in-stream/river temperatures reduced oxygen[56,57] and the ability of fish to maintain or re-establish homeostasis[58] – ultimately, leading to the death of a fish.

Climate data specific for the period of the fish die-offs in the Albany River and the western James Bay region revealed not only a temporal relationship between the two heat waves and the fish die-offs, but also a concurrent period of reduced precipitation (Fig 2). The climate data show that the mean daily maximum and minimum air temperatures for the 11–18 July 2005 period were elevated compared with the rest of the summer of 2005 (Table 1). Thus, during the fish die-offs, it was not just the daily maximum air temperatures, but the elevated daily minimum air temperatures coupled with a period of time of decreased precipitation (Table 1, Fig2) that led to an inhospitable aquatic environment. Moreover, TEK collected in the present study has documented that no fish die-offs have occurred prior to or after the two heat waves of July 2005, providing further evidence of a causal relationship between these events. Other potential causes for fish die-offs are unlikely; water pollution is not an issue, as development has been limited in the Albany River basin area. However, it is not possible to definitively pinpoint the actual climatic variable that led to the fish-die offs in the Albany River with the data on hand. The fish die-offs may have been triggered by the maximal air temperatures recorded during the two heat waves or the cumulative impact of two heat waves over a prolonged period of time coupled with relative little precipitation. One cannot ignore the importance of rainfall to the freshwater budget[59]. An interesting note, is that in Finland, during:

> *…the exceptionally warm autumn of 2005, an unusually high mortality of* C. lavaretus *[whitefish] eggs was reported within 2 weeks of fertilization in a hatchery by the River Kemijoki [Finland] … During the … spawning run that year, the water temperature in the River Kemijoki reached 9.6°C.* (J. Rytilahti, pers. comm., cited in Cingi et al, p.503)[56].

Perhaps, the year of 2005 provided a glimpse of the future with respect to the impact of climate change on fish and fish populations.Reiterating, the Food and Agriculture Organization of the United Nations maintains (p.5)[1]:

> *...food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. The four pillars of food security are availability, stability of supply, access and utilization.*

Thus, food insecurity would exist if food were unavailable, the food supply unstable, the food supply inaccessible, or not utilizable. Although the fish die-offs of 2005 may have an impact on the population dynamics of suckers and whitefish in the future, and then indirectly impact the yield of Cree fish harvests in the future, food insecurity would be an indirect effect of the 2005 fish die-offs. However, there was a direct effect of the July 2005 heat wave on food security related to the Cree fish harvesters, as detailed by TEK:

> *This is the only time I have seen this. [It was] really hot, never seen this before. Fish got all mushy [and not edible] because they were left in the net too long [the afternoon]. Had to go early in the morning after the tide went out, and check after every tide [so the fish did not rot]. Fish net [set] by old post.* (Experienced Kashechewan bushman, 18 July 2005; reaffirmed 26 March 2010)

> *[I had to check] the net early in the morning, not late in [the] day. Fish already mushy, quickly. [When] it is cooler, it is okay [to leave the fish]. First time in [his] life [that he has seen this].* (Fort Albany First Nation Elder, 18 July 2005)

Thus, fish nets could not be checked once a day during the 2005 summer season in the western James Bay region, as typically done in the past[8]; the Cree fish harvesters had to adapt their traditional practice or else risk losing their harvest to spoilage. Similarly, in the arctic region, it has been reported that individuals are changing their behavior such as shifting timing and/or location of particular subsistence activities to adapt to local environmental change[15,60].

Conclusions

Clearly, there is great potential to use TEK in assessing the impact of climate change on subsistence fishing in the western James Bay region of northern Ontario. To the point, TEK coupled with climate data revealed temporal relationships between extreme climatic events in the summer of 2005, and fish die-offs in the Albany River of the western James Bay region.

Although TEK did not reveal northward expansion of novel fish species into the western James Bay region, specifically in the Albany River or fish distributional contraction (ie brook trout disappearance), the warming trend may lead to distributional changes in fish species in the future. Further, gillnetting was restricted to the area on the Albany River near the mouth of James Bay, which is the northernmost area of the Albany River. There may already be movement of novel fish species northward in the Albany River, but at the more southern end of the river. Taking into account these factors, there is a need to continue monitoring for changes in fish species distribution in the Albany River. Indeed, 'bass' may be moving northward in the two other major rivers of the western James Bay region, the Moose River and Attawapiskat River, highlighting the need for a regional monitoring program, as changes in fish species abundance will negatively impact Cree subsistence fishing. However, it should be stressed that the present study examined environmental change only in the context of temperature and precipitation. Not considered was the post-glacial isostatic adjustment and its influence on hydrology in the western James Bay region, which is an important driver of environmental change, but beyond the scope of the present study[61].

Finally, climate change in the form of rising temperature has not only the potential for direct effects on fish, but also indirect effects on fish. For example, in a food security study investigating the timing of the first appearance of furunculosis (identified using TEK) in fish of the eastern James Bay region, Quebec, Canada – regression analysis revealed a significant, positive relationship between mean air temperature and year – whereby the temperature range conducive for *Aeromonas salmonicida* (this bacteria causes furunculosis in fish) survival corresponded to the time period furunculosis was first observed[62]. Climate change and food security issues in subarctic regions are areas that require further research.

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