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CLIMATE CHANGE AND POTATO (*SOLANUM TUBEROSUM*) GROWING POTENTIAL IN THE FAR NORTH OF ONTARIO, CANADA

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ABSTRACT

Potatoes are an "entry level" cultivar with modest thermal requirements. Potato cultivation that has a scant history in Ontario's Far North may be able to contribute to the food security of the region in the unfolding decades of this century. The potential for growing potatoes (*Solanum tuberosum*) in Ontario's Far North is examined from current climate and future climate perspectives. Using two growing-degree day thresholds, the frost free period, and available climate data, the current climatic potential for growing potatoes at Moosonee, Fort Albany, Neskantaga (formerly Lansdowne House) and Kitchenuhmaykoosib Inninuwug (formerly Big Trout Lake) is assessed. Using climate change projections the future climatic potential for growing potatoes is assessed for these communities and for Peawanuck and Fort Severn until the end of the century. Moosonee, Fort Albany, Neskantaga and Kitchenuhmaykoosib Inninuwug had the requisite thermal conditions to grow potatoes at present. Using climate change projections for the region, Peawanuck will meet the potato growing threshold by the 2020s and Fort Severn will do so by the 2050s. Projected intensification and lengthening of the growing season in the region suggests that other more thermally intensive produce, in addition to potatoes, may be possible this century.

Keywords: climate change, growing degree-days, frost, agriculture

1. INTRODUCTION

Food security is said to exist "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" (World Food Summit, 1996). Food security in a changing climate is a challenging issue and there is an emerging body of work examining this issue in Canada's northern regions. Most research on food security and climate change in northern communities has focused on traditional food systems (Council of Canadian Academies, 2014), while little has

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been written about the opportunities climate change brings to alternative food security strategies (Spiegelaar and Tsuji, 2013; Spiegelaar et al., 2013; Barbeau et al., 2015). In the present work, we consider how climate change may create the opportunity for sustainable agricultural activities in northern Canada.

Agricultural production is constrained by, among other factors, a species specific range of particular climate conditions. As the world's climate adjusts to an unprecedented increase in greenhouse gases, the appropriateness of agricultural practices in a given region needs to be re-assessed (Porter and Xie, 2014). We examine a region of historically marginal agricultural activity, Ontario's Far North (Figure 1), to assess if the regional changes to the climate will afford greater opportunities for agricultural activity, focusing on the "entry-level" vegetable, the potato (*Solanum tuberosum*). The potato, indigenous to North America, has over a thousand varieties and is grown throughout the world. It is the fourth largest food crop after corn, wheat and rice. A number of cultivars are well adapted to marginal agricultural climates. The literature provides a range of growing degree days (GDDs) for potatoes. A GDD is the sum of temperatures above a species-specific threshold during the growing season (typically constrained by frost) and serves as a proxy for the heat energy needed for plant growth.

Ontario's Far North is marginal for agriculture due to the short frost free season and relatively low GDDs, a metric of thermal input. Historically, conventional agricultural activity did occur in Fort Albany (Figure 1) from the 1940s to the 1970s initiated by the Roman Catholic Mission (Spiegelaar and Tsuji, 2013; ,Spiegelaar et al., 2013; Barbeau et al., 2015). The main produce included potato and turnip (*Brassica rapa*). In recent years (since 2011), personal home gardens and an agroforestry garden have been initiated in Fort Albany, igniting the promise of resuming agricultural activity in a sustainable fashion (Spiegelaar et al., 2013). Agroforestry can be defined as "a land-use system that combines woody perennials (e.g., trees, shrubs) with crops in spatial and temporal arrangements that optimize beneficial biological interactions and economic outputs" (Spiegelaar et al., 2013).

The past and present agricultural activities in Fort Albany indicate that agricultural activity is possible. In this work, we examine the climatic constraints (frost-free season and growing degree days) for the communities in Ontario's Far North, and how these will evolve in the future, using localized climate change projections. We use the hardy potato as our representative vegetable. Although precipitation is a key agricultural variable, the 600 – 800 mm annual rainfall provides more than sufficient soil moisture for soils that overlay permafrost and as such are poorly drained in a low relief landscape.

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The specific research questions addressed in this work are as follows: 1. Are the climate conditions (frost free period, growing degree days) in the communities of Ontario's Far North (Moosonee, Fort Albany) favourable for the sustained cultivation of potatoes? 2. Will a changing climate affect growing conditions whereby potatoes can be introduced as a potentially viable crop in more northerly (and/or interior) communities (Neskantaga formerly Lansdowne House, Kitchenuhmaykoosib Inninuwug formerly Big Trout Lake, Peawanuck and Fort Severn)?

1.1 Study Area

Ontario's Far North (Figure 1) is characterized by the various states of permafrost (sporadic, discontinuous, and continuous) with most of the region north of 50^{o}N having a mean annual atmospheric temperature of 0^{o}C or less with cold winters and cool summers. The region is coincident with the Ontario portion of the Hudson Bay Lowlands characterized by low relief and moist conditions. The seasonal presence of sea ice in Hudson and James Bays profoundly affects the region providing a climate considerably cooler than corresponding latitudes throughout the world (Rouse, 1991; Kowal et al., 2017). Ontario's Far North hosts the most equator-ward, non-alpine permafrost in the world (Tam et al., 2014).

Figure 1: Study Area including study sites of Moosonee, Fort Albany, Neskantaga, Kitchenuhmaykoosib Inninuwug, Peawanuck, Fort Severn, all in Ontario, Churchill in Manitoba, and Kuujjarapik in Quebec.

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2. DATA AND METHODS

2.1 Data

Climate data available from Environment Canada (http://climate.weather.gc.ca) for Ontario's Far North communities of Moosonee, Fort Albany, Neskantaga, Kitchenuhmaykoosib Inninuwug, Peawanuck, and Fort Severn are available in a number of formats and for varying periods of time. These formats include climate normals (30 year average data), monthly, daily and hourly data. Table 1 lists the six Ontario locations cataloging the available data. In addition data for Kuujjarapik, Quebec and Churchill, Manitoba are included.

Climate Station	Climate Normals	Time Series
Moosonee	1971-2000	1933-2019
Fort Albany	N/A	1969-1991
Lansdowne House/ Neskantaga	1971-2000	1941-1989, 1995-2019
Big Trout Lake/ Kitchenuhmaykoosib Inninuwug	1971-2000	1939-2019
Peawanuck	N/A	1994-2019
Fort Severn	N/A	2006-2019
Churchill	1971-2000	N/A
Kuujjarapik	1971-2000	N/A

Table 1: Available data for climate stations in Ontario's Far North and nearby stations in Manitoba (Churchill) and Quebec (Kuujarapik).

2.2 Analysis

2.2.1 Frost-Free Period

Using a threshold of -5ºC (Vega and Bamberg, 1995) a frost-free period is determined for Moosonee (the closest and most complete record with respect to Fort Albany), Neskantaga and Kitchenuhmaykoosib Inninuwug, Examining the variability of this period and extreme short frost free years, a growing season is determined.

2.2.2 Growing Degree Days

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For the growing season, the GDDs are determined using 4.4°C (Goeser et al. 2012) as the threshold, GDD = $\Sigma_i (T_i - 4.4)$ where i is a counter running from the beginning to the end of the growing season. Two thresholds are used. One is gained from the literature (Khan et al. 2011) that indicates 800 degree-days as a minimum. Thus to err on the side of being conservative we use a second threshold of 1000 growing degree days to reflect a greater level of confidence for a successful crop and to account for some variation in potato variety, soil type and soil moisture. This analysis is conducted using all stations with climate normals (Moosonee, Neskantaga, Kitchenuhmaykoosib Inninuwug) and for two other stations that had monthly and daily data (Peawanuck, Fort Severn). Data for Peawanuck is available from 1994 to the present and from 2006 to the present at Fort Severn. The coincident years of Fort Albany and Moosonee were examined to assess the representativeness of using Moosonee as a proxy for Fort Albany. The analysis was done using climate normals for Churchill, Manitoba and Kuujjarapik, Quebec to provide some geographic context. The years in which the agroforestry community gardens were active in Fort Albany (2011-2019) are examined in detail.

In addition 20°C must be attained for tuber initiation. Potatoes also have some frost resistance (Hijmanns et al., 2003) that enables a longer growing season. In studies of "volunteer" potatoes (plants that are seeded by the previous year's crop), a soil temperature of -3°C is required to kill off these largely undesired plants (Hirota et al., 2011; Yazaki et al., 2013). Atmospheric temperatures have been linked to soil temperatures (14), T_s, to the atmospheric temperature, T_a, via the following relationship, $T_s = 0.97\ T_a + 2.3$. Back calculating, a soil temperature of -3°C corresponds to an atmospheric temperature of -5°C consistent with other work (Vega and Bamberg, 1995), a value we use for frost tolerance in this work.

We note that the growing degree day metric is a relatively crude, although useful, metric for the growing potential of cultivars. It captures to some degree the heat energy needed for a plant to develop. However we note the penetration of heat from the surface as represented by the surface air temperature is a function of soil type and soil moisture.

2.2.3 Thresholds

We use the two thresholds, 800 and 1000 GDDs. The lower threshold comes from the research literature (Khan et al. 2011) and the upper limit allows for variation in soil type and soil moisture that may limit the penetration of surface heat into the soil and the potato variety chosen.

2.2.4 Projections

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We use an ensemble approach to produce climate change projections for the region using other regional work (Tam et al., 2014) to guide us. The ensemble approach has been shown to be more reliable then the use of individual model output (Gleckler et al., 2008).

2.2.4.1 Ensemble approach

Multi-model ensemble means were produced from 21 available global climate models (GCMs) and applied to project future climate conditions for Ontario's Far North using the IPCC emission scenario experiments: A1B, A2, and B1 (Nakićenović et al. 1998). These three scenarios embody the full range of potential emissions of greenhouse gases with B1 representing the high end of emissions ("Business as Usual") and A2 the other end with emissions increasing at a lower rate as a result of controls on population and an integrated world economy. A1B lies between these two extremes. The closest weather observation station to Fort Albany with at least 70% data availability as a baseline, that is, Moosonee, Ontario. The ensemble results produced mean air temperatures for the baseline period of 1971-2000, and the three future periods of 2011-2040 ("2020s"), 2041-2070 ("2050s"), and 2071-2100 ("2080s"). Future projections were produced by applying the change in mean air temperature from the baseline simulation and then adding that change to the observed baseline values. The results of the projections were applied to assess climate change impacts to the climatological conditions for potato growing-degree days.

3. RESULTS AND DISCUSSION

3.1 Frost-free period

Frost free metrics were calculated for Moosonee, Neskantaga and Kitchenuhmaykoosib Inninuwug. The average last frost day (using -5ºC as the threshold) in Moosonee is May 11th for the period 1933 to 2019. The standard deviation is just under 9 days. The earliest frost free date was April 19th (1964) and the latest date May 31 (2011). The first frost in the fall occurred on average on October 13 and ranged from September 13th (1951) to November 19th (2016). The average frost free period is 156 days ranging from 120 days (1976) to 192 days (2016). Neskantaga produced similar results with a slightly earlier last frost date, May 9th, and slightly later first frost date, October 15th and a longer growing season, 159 days, with a range of 120 (1947) to 191 (1985) days. For Kitchenuhmaykoosib Inninuwug the average last frost day is May 15th for the period 1939 to 2019 and average first frost occurs on October 13th with an average growing season of 151 days, the shortest of the three stations with a range from 119 (1965) to 175 (1998) days.

For all three locations, the months of June, July and August are frost free and we use these months as the growing season.

3.2 Growing degree days

3.2.1 Climate Normals

Climate Normals (30 year average of climate elements) were available for Moosonee, Neskantaga, Kitchenuhmaykoosib Inninuwug, Churchill and Kuujjarapik. Using the frost free period, the months of June, July and August, we calculate the growing degree days for potatoes using 4.4°C as the minimum threshold for counting degree-days. We note that most of September was frost free in Moosonee, Neskantaga and Kitchenuhmaykoosib Inninuwug. However as a conservative estimate we do not include the September growing degree days anticipating harvest well before the range of first frost dates. The growing degree days calculated from climate normals are presented in Table 2.

Climate Station	Growing Degree Days
Moosonee	874
Lansdowne House/ Neskantaga	1017
Big Trout Lake/ Kitchenuhmaykoosib Inninuwug	916
Churchill, Manitoba	538
Kuujjarapik, Quebec	409

Table 2: Potato growing degree days based on a 4.4°C threshold for the months of June, July and August. The climate normal period of 1971-2000 was used for all stations.

For the three stations located in Ontario's Far North, Moosonee and Kitchenuhmaykoosib Inninuwug fall within the two thresholds, 800 and 1000 growing degree days identified as the minimum required. Neskantaga exceeds both. Moosonee of the three had the lowest value of 874. The two stations outside of Ontario's Far North, Churchill in Manitoba and Kuujjarapik in Quebec, were well below the threshold for potato cultivation at 538 and 409 respectively.

Although this metric gives some indication of the viability of potato growing in Ontario's Far North, these values are averages and to assess the risk of crop failure, the interannual variability needs to be assessed. In addition the use of 30 year means obscures somewhat the assessment of recent changes in growing degree days that may make potato growing even more favourable. These are addressed in the next section.

3.2.2 Climate data time series

Using the frost free period from June to August, we calculate the growing degree days for potatoes using 4.4°C as the minimum threshold for counting degree days for locations with a long time series of climate data (Moosonee, Neskantaga, Kitchenuhmaykoosib Inninuwug). We also examine stations with shorter records. The short record from Fort Albany is used to assess the representativeness of other stations to act as a proxy for this location. We also turn to Peawanuck and Fort Severn to determine the viable of potato growing in Ontario's two most northerly habitations.

3.2.2.1 Moosonee

In Figure 2 the time series for the period of 1933 to 2019 is presented. We were able to calculate GDDs for 85 of these years. Thirteen (15%) of the 85 years were below the 800 GDDs threshold, a return rate of 1 in 7 years. However, the distribution of these low GDD years is not even. In the latter 20 years, the below 800 GDDs threshold occurrences have a return rate of 1 in 20 years, an indicator of a warming climate. Thirteen years (15%) exceeded the 1000 GDDs threshold, eleven of these occurring since 1975. Consistent with this, linear regression analysis with a p-value of 0.02 indicated a statistically significant increase in GDDs with time (the data was normally distributed using the Wilk-Shapiro test). For the nine years (2011 to 2019) that agroforestry community gardening has produced a potato harvest in Fort Albany, we find GDDs of 966, 1061, 877, 955, 1026, 914, 870, 887, and 976 respectively. All eight years are well above the minimum threshold of 800, with two years exceeding the 1000 GDDs value.

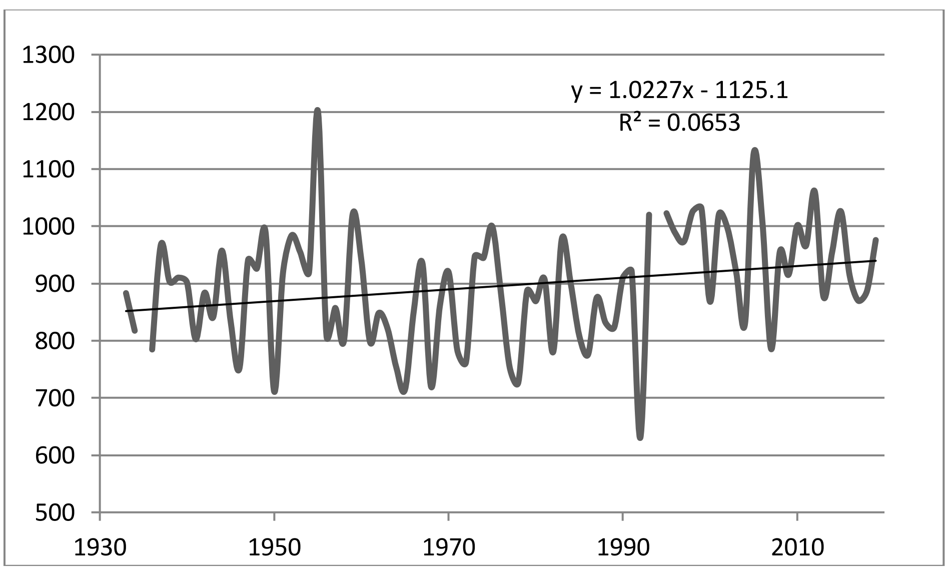

Figure 2: Time series of potato growing degree days at Moosonee, Ontario for the period 1933-2019.

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3.2.2.2 Neskantaga (Lansdowne House)

In Figure 3 the time series for the period of 1941 to 2019 with a gap from 1989 to 1994 is presented. In that time period, only one year (2004) was below the 800 GDDs threshold and 45 years were above the 1000 GDDs threshold. There appears to be no net trend in GDDs with time, although we do note that the data for the latter period, post 1995, was at a slightly different location than the earlier years and may have introduced a slight bias that could obscure a trend.

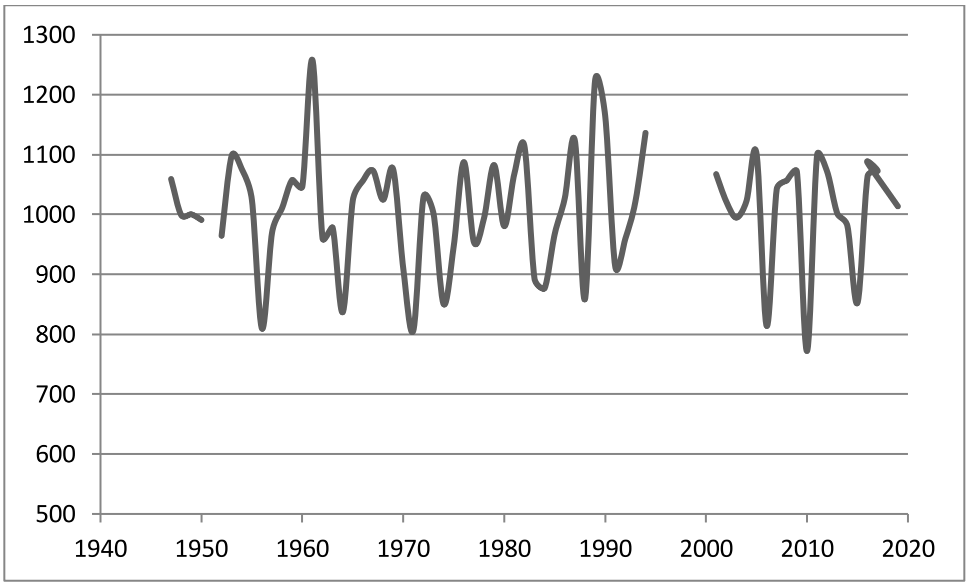

Figure 3: Time series of potato growing degree days at Neskantaga, Ontario (Lansdowne House) for the period 1941-2019.

3.2.2.3 Kitchenuhmaykoosib Inninuwug (Big Trout Lake)

In Figure 4 the time series for the period of 1939 to 2019 is presented. We were able to calculate GDDs for 78 of the years in that time period. Ten of the 78 years (13%) were below the minimum 800 GDDs threshold, a return rate of 1 in 8 years. Fifteen years were above the 1000 GDDs threshold, indicating most years lie between 800 and 1000 GDDs.

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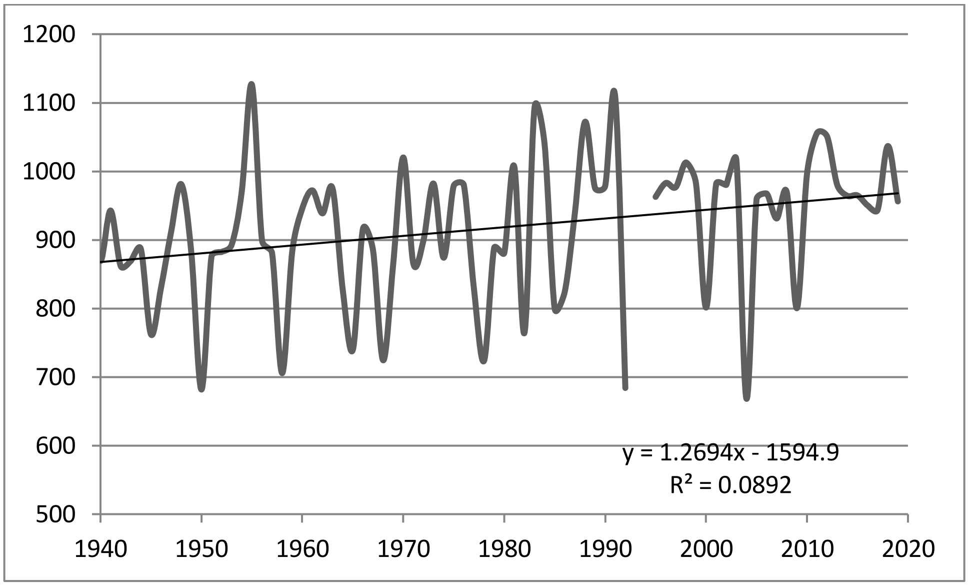

Figure 4: Time series of potato growing degree days at Kitchenuhmaykoosib Inninuwug, Ontario (Big Trout Lake) for the period 1939-2019.

3.2.2.4 Fort Albany

At Fort Albany climate data were recorded from 1969 to 1991. Of these years there is sufficient data to calculate the GDDs for 16 years. For these years GDDs have an average of 883 potato growing degree days. The corresponding years for Moosonee produced an average of 878 potato GDDs. A t-test also indicated the two time series are not different in a statistically significant way. Thus, Moosonee can act effectively as a proxy for Fort Albany.

3.2.2.5 Peawanuck

The Peawanuck uneven data record from 1994 to 2019 provides 23 useable years to evaluate GDDs. For these years there was an average of 728 growing degree days with three years above the 800 threshold and none above 1000 GDD. The average is somewhat skewed by three very low years (2000, 2004, 2009 at 590, 436 and 541 GDDs respectively). In a given year, it is more likely than not that the 800 GDDs is not met. At present, potato gardening in Peawanuck is likely precarious.

3.2.2.6 Fort Severn

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Climate data is available from Fort Severn since 2006 and ten of these years were useable. For these years the average GDDs is 635 ranging from 561 to 751. Of the ten years, all were below both the 800 and 1000 GDDs thresholds. Potato gardening at Fort Severn at present is not viable.

3.3 Projections

We now turn from the past and current conditions to projections of GDDs for the rest of the century.

3.3.1 Moosonee

Projections were generated for Moosonee using a multi-model ensemble approach described above. The results are presented in Tables 3 and 4.

Scenario	Baseline	2020s	2050s	2080s
B1	13.9	15.0 ± 0.6	15.7 ± 0.9	16.4 ± 1.2
A1B	13.9	15.0 ± 0.6	16.4 ± 1.1	17.4 ± 1.4
A2	13.9	14.9 ± 0.4	16.1 ± 0.8	17.9 ± 1.4

Table 3: 21 model ensemble climate change projections, A2 scenario, for surface temperature for Moosonee, Ontario, for the months of June, July and August (averaged).

Scenario	Baseline	2020s	2050s	2080s
B1	874	975 (920, 1030)	1039 (956, 1122)	1104 (994, 1214)
A1B	874	975 (920, 1030)	1104 (1003, 1205)	1196 (1067, 1325)
A2	874	966 (929, 1003)	1076 (1003, 1150)	1242 (1113, 1370)

Table 4: Projected values of GDDs for Moosonee, Ontario, using projected temperatures from Table 3. Values in parenthesis represents the range of values based on the uncertainty reported in Table 3.

For all scenarios and time periods, the potato GDDs are steadily increasing over the course of this century indicating continued viability of potato growing and the possible expansion to other cultivars that require additional growing degree days. By the end of the century all projections indicate exceedance of the 1000 GDDs threshold.

3.3.2 Other Locations

We now generalize the projection results from Moosonee to the other locations examined in this work, Neskantaga, Kitchenuhmaykoosib Inninuwug, Peawanuck and Fort Severn. We are using

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Moosonee as a proxy for Fort Albany. In Table 5 we use the change in GDDs for Moosonee, for the different scenarios and time periods, and add these to the baselines determined for the four locations.

Location	Baseline	2020s	2050s	2080s
N B1	1017	1117	1181	1245
N A1B	1017	1117	1245	1336
N A2	1017	1108	1217	1381
KI B1	916	1016	1080	1144
KI A1B	916	1016	1144	1235
KI A2	916	1007	1116	1280
Pea B1	731	831	895	959
Pea A1B	731	831	959	1050
Pea A2	731	822	931	1095
FS B1	663	763	827	891
FS A1B	663	763	891	982
FS A2	663	754	863	1027

Table 5: Projections of GDDs for Neskantaga (N), Kitchenuhmaykoosib Inninuwug (KI), Peawanuck (Pea) and Fort Severn (FS) for the 2020s, 2050s and 2080s.

Using the thresholds of 800 and 1000 potato GDDs, the climate conditions for growing potatoes remains viable for Neskantaga and Kitchenuhmaykoosib Inninuwug and, similar to Moosonee/Fort Albany, may be able to expand into other cultivars. Peawanuck, which is currently below viability for potato growing using the 800 GDDs threshold, exceeds this threshold by the 2020s and remains climatically viable for the rest of century, but only by the end of the century reaches 1000 GDDs. Ontario's most northerly community, Fort Severn, which does not currently have viable potato growing conditions, marginally achieves such by the 2050s and nears the 1000 GDD threshold by the 2080s. We note also that the projections used here may be a conservative estimate of the actual warming for these Hudson Bay coastal communities. An examination of the fate of palsas in the Hudson Bay Lowlands indicated that warming along the Hudson Bay coast (Peawanuck and Fort Severn) would be greater than in land at Kitchenuhmaykoosib Inninuwug and Neskantaga (Tam et al. 2014), a direct impact of decreasing sea ice extent (Gagnon and Gough, 2005; Kowal et al., 2017).

4. CONCLUSION

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In this work we have examined the potential of growing potatoes in Ontario's Far North (Canada). At present there is a successful agroforestry garden project in Fort Albany (Spiegelaar and Tsuji, 2013) and we have examined the climatic growing conditions for Fort Albany and other communities with available climate data in Ontario's Far North. We have focused on the temperature as the key climate variable, acknowledging the importance of precipitation to agrarian success. We acknowledge other important features such as suitable soils and an agrarian culture, Spiegelaar and Tsuji (2013), Spiegelaar et al. (2013) and Barbeau et al. (2015) address these issues at Fort Albany. They have examined the soils used in local agricultural activities during the 1940s to 1970s and report that these soils were relatively nutrient depleted compared to background-level soils due to conventional agricultural practices, but sufficient for short-term crop production. Their more recent gardening initiative addresses long-term, sustainable land-use through agroforestry practices designed to augment and sustain soil nutrients. The agroforestry project itself addresses the second issue of agrarian culture by working with the community in home and youth gardening activities (Isogai et al. 2014).

Our results indicate that recent years (2011-2019) of successful gardening in Fort Albany are not anomalous, and that Fort Albany has sufficient growing degree days to routinely support a potato crop. These conditions will continue to be increasingly favourable for the rest of the century and for an increasing variety of crops, with a projected increase of growing degree days that ranged from 26 to 42%, depending on the climate change scenario.

In examining other communities in Ontario's Far North, it was found that Neskantaga and Kitchenuhmaykoosib Inninuwug currently meet the thermal threshold for hosting potato agriculture. Peawanuck and Fort Severn, the two most northerly communities in Ontario are currently below the marginal thermal thresholds for growing potatoes. However by the 2020s, Peawanuck will move beyond marginal and Fort Severn will do so in the 2050s.

Although there are clearly threats to traditional sources of food for the communities in Ontario's Far North (Hori et al., 2013) as well as access to the communities (Hori et al., 2017, 2018a,b), food security can be enhanced by the sustainable practice of agroforestry, which is already viable in the southern communities, such as, Fort Albany. In the two northernmost communities of Peawanuck and Fort Severn, over the course of this century, agricultural activity will likely become a viable option for increasing food security.

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