  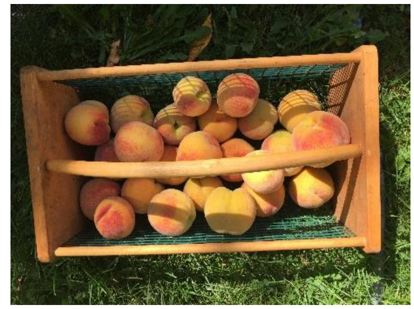

POTENTIAL CROPS SUITABLE FOR CENTRAL KOOTENAY REGION IN A CHANGING CLIMATE REGIME

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CENTRAL KOOTENAY FOOD POLICY COUNCIL

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Potential Crops Suitable for Central Kootenay Region in a Changing Climate Regime

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Executive Summary

As climate change threatens the livelihood of farmers worldwide, adaptations becomes increasingly important. Crop diversification is one of the key adaptation strategies to climate change. This report provides information and ideas regarding types of crops that would be suitable to grow in the Regional District of Central Kootenay (RDCK) under the predicted climate conditions. Secondary data on the future climate regime for the RDCK are provided from the Pacific Climate Impacts Consortium. Primary data from in-depth interview with representative farmers in the region provide insights on current impacts of climate change.

Farmers in the RDCK conveyed that an increases in precipitation over the spring has delayed the establishment of some summer crops, and excessive drought and smoke from wildfires has adversely abbreviated the growing seasons. An increase in the intensity and the duration of droughts has forced farmers to increase use of irrigation to maintain soil moisture and crop health. Reduced solar radiation due to excessive smoke has adversely affected the production of some fruits crops, and field and greenhouse vegetables, and delayed the development of fall and winter crops. This poses major challenges to farmers trying to meet their expected production and economic targets under shorter growing season.

Results suggested that the introduction of heritage or ancient grains, increasing the number of crops varieties in forage fields, or augmenting the area of short season vegetables can increase the resilience of farming operations. Additionally, key to adaptation is the use of season-extending cultural practices such as pre-germination of seeds, growing or purchasing transplants, and the use of cover crops, mulches and row covers can help farmers protect the soil erosion, prevent weed growth, moderate soil temperatures and increase the nutrient levels in the top layers.

The list of potential crops and their agronomic practices are organized into four groups: forage and pasture, grain, field crop and fruit. Example of potential crops are such as oilseed radish, sorghum sudangrass, bromegrass, lentil, spelt, rice, quinoa, elderberry, current, American pawpaw, Asian greens, and ginger. However, the cultivars referenced have not been field tested nor based on in-situ research. Additional analysis of data from field research would provide robust information about yield potential, crop quality and attributes, best agronomic practices, as well as the costs of production. Market research as well as seed sources should also be further investigated.

1. Background

There is a scientific consensus that the effects of climate change are increasingly threatening agricultural systems worldwide (Vermeulen et al., 2012). Crop production is highly sensitive to climate and resultant weather patterns. As such, farmers worldwide are experiencing the effects of a changing climate. In British Columbia (BC), the shifts in weather patterns are predicted to cause irregular and variable precipitation patterns such as excessively wet field condition in the springs and long drought over the summers (BC Ministry of the Environment, 2016). Regions that rely on snowpack for their irrigation can expect a decrease in spring and summer flows (Luce, 2017). This decrease is expected to affect water availability during the period of peak demand for agriculture. Additionally, Natural Resources Canada (2018) estimated that the frequency and severity of forest fires in Canada will increase, which can indirectly and directly impact agriculture. These changes in climate have the potential to affect productivity and severely affect agricultural activity. To increase farmers' resilience, crop diversification is essential (Lin, 2011, Rojas-Downing, 2017).

The Regional District of Central Kootenay (RDCK) is an area of diverse topography. Dominated by high elevations, the region supports a wide array of microclimates, landforms, soils, vegetation and wildlife (Holt et al., n.d). Land suitable for agricultural activities is limited and restricted to the lower valleys (BC Ministry of Agriculture, 2016). In this region, the main crop by area in production and by number of farms is forage (BC Ministry of Agriculture, 2016 and Statistics Canada, 2017). The region also has a well-established small scale fruit and vegetable production sector. To better adapt to future climatic changes, alternative crops or cropping systems should be part of the region's long-term climate change adaptation strategy. Not only could crop diversification minimize market and weather related risk, it could also increase and diversify the region's food supply (Lakhran, Kumar and Bajiya, 2017). Hence, the aim of this study is to help farmers adapt to climate change challenges by providing information and ideas regarding types of crops that would be suitable to grow in the RDCK in its eminent climate future.

The study relies on secondary data from the Pacific Climate Impacts Consortium (2019) regarding the future climate regime for the RDCK, and primary data from in-depth interview with representative farmers in the region regarding crops and production. The analysis of potential crops suitable for future climate focuses on the effects of changes in abiotic factors, such as growing degree units, growing season length, soil temperature and moisture, amount and timing of precipitation, and solar radiation on production systems, temperature stress tolerance, and drought tolerance. Thus we draw from climate models, regional crop suitability data and information from our interviews to explore the potential of agronomic crops that would be better suited for cultivation under the predicted climate conditions and can be utilized by farmers in the RDCK to offset the effects of a changing environment.

The cultivars referenced have not been field tested, and suggestion of suitability for future climate conditions and prevailing weather patterns is therefore not based on in-situ research. Therefore, one of the action plans for climate adaptation strategy and food system resilience should be conducting experimental field research to assess the suitability of crops on this list and the establishment demonstration plantings. Analysis of data from field research would provide robust information about yield potential, crop quality and attributes, best agronomic practices, as well as the costs of production.

1.1 In-depth interview methodology

The Central Kootenay Farms and Food Directory (https://centralkootenayfood.ca) provides a list of farmers operating in the RDCK region. Members of the advisory committee for the Evidence-based Food Systems Policy Development project made recommendations regarding farmers who would best represent typical farmers in the region. From November to December 2019, 10 farmers (of 30 contacted) participated in our in-depth interviews. Collectively these farms produced forage, grains, fruits, mixed vegetables, and herbs. Our interviews were designed and conducted to collect information on agronomic practices (i.e. crop selection, crop rotations, and soil and water management) that helped farmers adapt to changes in weather patterns over the last ten years. Farmers were also asked to share thoughts about what would be some of the potential crops they believe would be able to grow under future climate conditions to maintain productivity. The compiled data do not account for future retail potential, transportation factors, or consumer preferences, all of which should be taking into consideration by the producer.

1.2 Overview of agriculture in the Central Kootenay

The Canada Land Inventory's Soil Capability Classification for Agriculture classifies land suitability for crop cultivation based on mineral soils grouped according to their potential and limitations for agricultural use (Government of Canada, 2013). According to the BC Ministry of Agriculture's soil capability for agricultural database (1983), about 76% of ALR land in the RDCK is under soil classes 1, 2, 3 and 4 which are considered suitable for the cultivation of field crops. About 13% are in soil classes 5, 6, and 7 which are assessed suitable for cultivating perennial forage crops. The rest (about 11%) are assessed not suitable for production of any crop type (Government of Canada, 2013). This does not render such lands unimportant to the larger agriculture landscape, since they provide important ecological functions (i.e. wildlife habitat, ecological buffers).

Accord to the 2016 Land Use Inventory Report for the Regional District of Central Kootenay, about 30% of surveyed ALR land were actively farmed (BC Ministry of Agriculture, 2016). Forage and pasture production took place on 76% of the total farmed area. Grain production represented the second largest use of agriculture lands (17%), followed by fruit trees (2%), vegetables (1%), nursery (1%) and other crops (3%) such as vines & berries, Christmas trees, turf, nut trees, herbs, and floriculture. The following sections provides a brief overview of major crop production activities in the RDCK.

Forage and Pasture

Forage is defined as crops that are grown and cut for the production of hay or silage (BC Ministry of Agriculture, 2016). Most forage and pasture production in the RDCK takes place on land that falls under class 5 to 7 of the Canada Land Inventory's Soil Capability Classification for Agriculture (Rousin, 2014). In 2016, and according to the 2016 Agricultural Census category system, most land under forage production in the RDCK was reported by farmers to be under “Alfalfa and alfalfa mixtures”, followed by “All other tame hay and fodder crops” (i.e. clover, silage corn), and “Wheat” (Statistics Canada, 2016). Pasture is defined as land covered with crops (i.e. grasses, grains) used for grazing of livestock (BC Ministry of Agriculture, 2016). The majority of farmers in the RDCK use natural (unimproved) grasslands and open forest rangeland (often on Crown lands) for beef or dairy cattle production (Forest Practice Board, 2015; Statistics Canada, 2016). A small percentage, however, actively manage their pastures, a practice also known as tame or seeded (improved) pasture (Statistics Canada, 2016).

Photo credit: Bale of grass, Stefan Sorean, Shutterstock# 1103736869

Grain
Grain production is the second most common farming enterprise in the RDCK after forage and pasture from an acreage allocation perspective. According to the 2011 and 2016 Agricultural Census, the number reporting farms engaged in the production of “Oilseeds and grain” and “Wheat” decrease slightly over that period (Statistics Canada, 2011 & 2016). In contrast, the number of farming operations engaged in the production of “Other grains” (i.e. buckwheat, milo, broomcorn, and sorghum), increased substantially (Statistics Canada, 2011 & 2016). This indicates an increase in crop diversification among producers in the region. In 2016, grain crops predominately produced in the region included oat, barley, rye, and wheat. Additional grains varieties also grown by farmers during that year included caraway seed, hemp, spelt, dry pea, buckwheat, and sunflower (Statistics Canada, 2016).

Fruit

Fruit production is the third most common farming activity in the RDCK occupying about 2% of all cultivated land in the district (BC Ministry of Agriculture, 2016). Between 2001 and 2016 the number of farms and area of land in fruit production remained stable. Sweet cherry and apple were the two main fruit crops produced in the region based on the area of production and the number of farms (Statistics Canada, 2016). Other fruit production include peach, blueberry, raspberry and apricot.

Field Vegetable

Field vegetable production in the RDCK is a well-established activity, occupying 1% of all cultivated land (BC Ministry of Agriculture, 2016). Between 2001 and 2016 the number of farms and area of land under field vegetable production remained constant, only experiencing a slight reported decrease in 2011 (Statistics Canada, 2016). In 2016 most land under field vegetable production was in asparagus (21%), followed by potato (12%) and sweet corn (10%) (Statistics Canada, 2016). While the area in asparagus production is the largest among field vegetables, only a small number of farms (14) reported the production of this crop.

Photo credit: Abra Brynne

2. Climate predictions and their potential impacts to agriculture in the RDCK

The Regional District of Central Kootenay is an area of diverse topography, shaped by mountain ranges and an extensive fluvial system (Holt et al., n.d.). Sharp differences in elevation gives rise to a wide range of climatic and weather conditions over relatively small land areas. Data on climate predictions presented in this section were received from the Pacific Climate Impacts Consortium. The "past" or the baseline data are calculated using the average over the period 1981-2010. The future predictions refer to the changes from the baseline for the 2020s, 2050s and 2080s.

Photo credit: Abra Brynne

Historical data indicate that summers in the region are usually hot and dry, with daily average temperatures at 12.4 degrees Celsius (°C), and an average number of 969 days growing degree-days (Table 1 and Table 3). Winters can range from mild to severe, with daily average temperatures at -6.9 °C, and a total of 210 frost days per year (daily minimum temperature < 0°C) (Table 1 and Table 5). Precipitation is higher during fall and winter months (Table 2). Rainfall is lower in the valleys (less than 200 mm), and higher at high elevations (500mm to 1000 mm) (Pacific Climate Impacts Consortium, n.d.).

Records indicate that over the past decade, the annual average temperatures have increased between 1.4 – 1.8 degrees Celsius (Pacific Climate Impacts Consortium, 2019) (Table 1). This trend is expected to continue into the future (through 2100) as greenhouse gas emissions increase. Climate change predictions for the RDCK forecast shifts in weather that could result in irregular and variable precipitation patterns such as excessively wet field conditions in the spring and/or long droughts over the summer (Ministry of Forests, Lands and Natural Resources Operations, n.d). Warming and drought impacts are expected to be more severe in the summer, and increasing winter temperatures in the region could lead to a decrease in frozen precipitation (snow, etc.), which could result in less spring snowpack. A decrease in snow pack could affect peak flows, longer summer low-flow periods and increased risks to water supplies during the period of peak demand. Table 1 to Table 4 compare changes in seasonal and annual average temperatures and precipitation rates anticipated for years 2020, 2050 and 2080 to historical values.

Table 1: Past and predicted daily average temperatures in the RDCK

Season	**Changes in seasonal and annual average temperature (° C)**			
	Past (Baseline)	**2020s (changes from the baseline)**	**2050s (changes from the baseline)**	**2080s (changes from the baseline)**
Winter	-6.9	+1.6	+3.0	+5.0
Spring	2.1	+1.6	+2.9	+4.7
Summer	12.4	+1.8	+3.8	+6.3
Fall	2.4	+1.4	+3.1	+5.0
Annual	2.5	+1.6	+3.2	+5.3

Source: Pacific Climate Impacts Consortium, 2019.

Table 2: Past and predicted total precipitation in the RDCK

Season	**Changes in seasonal and annual average precipitation (mm)**			
	Past (Baseline)	**2020s (changes from the baseline)**	**2050s (changes from the baseline)**	**2080s (changes from the baseline)**
Winter	286	+12	+18	+38
Spring	231	+10	+26	+42
Summer	213	-16	-27	-42
Fall	268	+4	+18	+37
Annual	998	+11	+36	+78

Source: Pacific Climate Impacts Consortium, 2019.

Table 3: Past and predicted average number of summer days and tropical nights in the RDCK

	Past (Baseline)	**2020s (changes from the baseline)**	**2050s (changes from the baseline)**	**2080s (changes from the baseline)**
Annual average number of summer days (daily maximum temperature > 25° C)	19 days	+11 days	+25 days	+43 days
Annual average number of summer days (daily maximum temperature > 30° C)	4 days	+5 days	+13 days	+26 days
Annual average number of tropical nights (daily maximum temperature > 20° C)	0 days	+0 days	+0.6 days	+4.6 days

Source: Pacific Climate Impacts Consortium, 2019.

Table 4: Past and predicted growing and heating degree-days in the RDCK

	Past (Baseline)	2020s (changes from the baseline)	2050s (changes from the baseline)	2080s (changes from the baseline)
Annual growing season length (# days between first span of at least 6 days with daily mean > 5° C)	148 days	+19 days	+39 days	+63 days
Annual Growing Degree Days* (Threshold: 5° C)	969 degree days	+266 degree days	+580 degree days	+1,019 degree days
Annual Heating Degree Days** (Threshold:18° C)	5,656 degree days	-546 degree days	-1044 degree days	-1,654 degree days

Source: Pacific Climate Impacts Consortium, 2019.

* Growing Degree-Days (GDDs) is a derived variable that indicates the amount of heat energy available for plant growth, useful for determining the growth potential of crops in a given area. It is calculated by multiplying the number of days that the mean daily temperature exceeded 5°C by the number of degrees above that threshold.

** Heating Degree-Days (HDDs) is a derived variable that can be useful for indicating energy demand (i.e. the need to heat homes, etc.). It is calculated by multiplying the number of days that the average (mean) daily temperature is below 18°C by the number of degrees below that threshold.

Table 5: Past and predicted average number of icing, frost days, freezing degree days, and cooling days in the RDCK

	Past (Baseline)	2020s (changes from the baseline)	2050s (changes from the baseline)	2080s (changes from the baseline)
Annual average number of icing days (daily maximum temperature < 0° C)	99.2 days	- 16.1 days	- 30 days	- 48.4 days
Annual average number of frost days (daily minimum temperature < 0° C)	210 days	-24 days	-49 days	- 82 days
Annual Cooling Degree Days* (Threshold: 18° C)	27 degree days	+ 36 degree days	+ 113 degree days	+ 260 degree days
Annual Freezing Degree Days** (Threshold: 0° C)	953 degree days	-222 degree days	-389 degree days	-581 degree days

Source: Pacific Climate Impacts Consortium, 2019.

*Cooling degree-days is the number of degrees a given day's average temperature is above 18°C

**Freezing degree-days is the sum of average daily degrees below freezing for a specified period

Individually and collectively, these changes in climate are expected to have a substantial effect on the natural environment and on farming capability and activity. Table 6 summarizes the projected impacts in the RDCK.

Table 6: Projected impacts of climate changes in the RDCK

Season	Projected Climate Changes	Projected Impacts
Summer	Average daily temperature is expected to increases	A shift to warmer, drier conditions is expected to increase the frequency of wildfires and/or insect and disease outbreaks (Holt et al., 2012).
	Average number of summer days (when the daily maximum temperature is higher than 2525°C) is expected to increase.	Annual growing degree-days is going to increase from 969 days to 1,549 days by 2050, and 1,988 days by 2080 (Pacific Climate Impacts Consortium, 2019.
	Average precipitation is expected to decrease	A decrease in water supply during a longer dry season will increase drought and wildfires intensity and frequency (Ministry of Forests, Lands and Natural resources Operations, n.d.).
	Average maximum length of consecutive dry days is expected to increase	The areas occupied by grassland are expected to increase in lower elevations (Holt et al. n.d). With longer grazing seasons, management will become a challenge as surface water and feeding sources available for livestock decrease with increased drought conditions (Holt et al., 2012).
Winter	Average daily minimum temperature is expected to increase. Average number of icing days with maximum temperature that are lower than 0°C is expected to decrease	Increased temperatures and precipitation will shift the hydrologic regime from snowmelt-driven to rain/snow-driven, leading to smaller spring snowpack (Holt et al., 2012).
	Average seasonal precipitation in the form of rain is going to increase. A decrease in precipitation in the form of snow is going to increase the number of frost-free days.	Increase in precipitation will increase flooding events.
Spring	Average daily temperature is predicted to increase.	Increasing temperatures and increasing precipitation will reduce spring snowpack and earlier spring freshet (Holt et al., 2012). A decrease in spring snowpack will reduce summer low flows, lengthen the

		low-flow period, and decrease groundwater storage (BC Ministry of Forests, Lands and Natural Resources Operations, n.d.).
	Average seasonal precipitation is predicted to increase.	Shifts from snow to rain dominated hydrologic regimes could increase the frequency and intensity of flood events (Holt et al., 2012). These changes have the potentially to impact peak flows, sediment loads, channel stability and low flows (BC Ministry of Forests, Lands and Natural Resources Operations, n.d.).
Fall	Average daily temperature is predicted to increase.	Annual growing degree-days is going to increase from 969 days to 1549 days by 2050, and 1988 days by 2080.
	Average seasonal precipitation predicted to increase.	An increase in precipitation over the fall months has the potentially to impact peak flows, sediment loads, channel stability and low flows(BC Ministry of Forests, Lands and Natural Resources Operations, n.d.).

Source: Pacific Climate Impacts Consortium, 2019; Holt et al., 2012; BC Ministry of Forests, Lands and Natural Resources Operations.

Farmers in the Kootenay have been observing changes in the regions weather pattern over the last decade. As weather becomes erratic and unpredictable, the management of their traditional cropping systems has become more challenging. Increased precipitation over the spring has delayed the establishment of some summer crops, and excessive drought and smoke from wildfires has adversely abbreviated the growing seasons. According to farmers, higher than normal summer temperatures in 2017 and 2018 caused substantial crop damage, and reduced yields. An increase in the intensity and the duration of droughts has forced farmers to increase use of irrigation in order to maintain soil moisture and crop health. Reduced solar radiation due to excessive smoke throughout the summer of 2018 has adversely affected the production of some fruits crops, and field and greenhouse vegetables (i.e. squash tomatoes). Long periods of smoke at the end of the summer has also delayed the development of fall and winter crops (i.e. cilantro, parsley and broccoli) resulting in stunting of plants. This poses major challenges to farmers trying to meet their expected production and economic targets under shorter growing season.

Changes in seasonal weather patterns are expected to affect forage and pasture production and cause alterations in rangeland vegetation worldwide (Giridhar et al., 2015). By 2050 the areas occupied by grasses in the lower elevations are expected to increase as a result of increased drought conditions (Holt et al. n.d). A decrease in summer precipitation is predicted to have adverse effects on the production of drought sensitive forage crops, such as Timothy and alfalfa (Aranjuelo et al., 2006; Bertrand et al., 2008).

Research indicates that the number of frost-free days in most temperate regions have increased over the last decades (Menzel et al., 2002). Winter snow cover and ice extent has also decrease by 10% since the late 1960s. Farmers in the RDCK conveyed that a decrease in the number of frost-free days over the last years has affected the yield capacity and quality of some of the major fruit crops. Crops such as apple, cherry, blueberry and strawberry need a period of physiological dormancy and chilling (experience cold regime) to bear fruit in the summer. As weather patterns become more erratic, the production of certain fruit varieties will be compromised, thus the need to explore new and better adapted cultivars. Further, erratic winter temperatures increase the chance of cold temperature injury to woody perennial crops and snow cover protects roots from freeze damage (via insulation of rooting zone).

3. Potential crops and management practices under changing climatic conditions in the RDCK

Facing the increasingly difficult challenge of adapting to climate change, farmers in the RDCK are looking for alternatives to maintain and increase the production of their farming operations, while remaining ecologically and economically viable. Increasing the diversity of cropping systems increases genetic diversity and enhances resilience. As such, crop diversity represents a significant source for adaptation to climate change (Vermeulen et al., 2012). Equally important is the adoption of agronomic practices that can help producers mitigate the weather related effects of climate change. As extension of the growing season affects the growth and development and distributions of current crops, it might also create the conditions to grow crops that are typical of more moderate climates. The adoption of these new crops will require the adoption and transfer of agricultural practices that are more in tune with new agricultural crops and growing conditions.

Based on the climate projections issued by the Pacific Climate Impacts Consortium (2019), we assessed the suitability of crops for the anticipated climate and weather regime the RDCK will increasingly experience. Farmer interviews provided additional information on farming practices that could contribute to agricultural adaptation to the effects of a changing climate. The species/cultivars recommended in this section are based on available information and cannot substitute for research derived farm-level information (i.e. crop and cultivar trials in the RDCK). The length of the growing season required for best crop establishment, development and yields varies among varieties and environmental conditions. The compiled data does not take into account future retail potential, transportation factors, or consumer preferences.

3.1 Forage and pasture

Climate change is major problem affecting pasture and forage production worldwide (Giridhar et al., 2015, Lara et al. 2011, Lattanzi et al. 2010). As population increase, demand for livestock products is expected to double. In addition to supporting animal production, forage, pasture and rangeland provide a number of important ecological goods and services (Izurralde et al., 2012). Research indicates that crop and animal diversification are the most promising adaption measure for mitigating the effects of a changing climate (Lin, 2011; Rojas-Downing et al., 2017). Key to this adaptation is the development of crop systems comprising diverse selections of cultivars, such as legumes, annual and perennial grasses, and deep-rooted cultivars such as brassicas (i.e. turnips and radishes) that are both regionally compatible and highly adapted to extreme conditions. Table 7 presents a list of potential forage and pasture crops suitable for the future RDCK climate.

Agronomic practices

A number of agronomic practices can help farmers increase the diversity of their forage and pasture systems. Combining winter and summer crops in early spring, for example, can increases on-farm genetic diversity while protecting the soil from drought during summer and erosion in winter. Winter hardy forage and cover crops established in late summers for late fall and early winter grazing (i.e. corn silage, winter wheat) can be used to introduce genetic diversity, enhance soil structure, build soil organic matter, increase soil water infiltration and promote soil microbial activity (Kootenay Livestock Association, 2008).

Photo credit: Marnie Burkhart, Getty Images# 523072728

Herd management is used in livestock production to maintain pasture and soil quality. Research indicates rotating the herds between paddocks and avoiding overgrazing can result in higher pasture yield, persistence, forage quality, and better soil health (Halde, C., 2011; Weinert et al., 2018). Re-seeding of paddocks before moving the animals from one site to another has shown to promote seed to soil contact, increase crop establishment rate, and improve soil health by breaking capped soil allowing water infiltration and nutrient recycling as well by incorporating plant material into the soil. In addition, the adoption of longer resting periods between grazing events reduces soil erosion and improves moisture and nutrient retention (Weinert et al., 2018).

Managing the intensity and timing of plowing during sowing periods can prevent soil erosion. Plowing when soils are too wet or too dry negatively affects soil structure. In the absence of plowing, harrowing is sometimes used to stimulate canopy growth. Research has shown that surface plowing and harrowing improve soil quality by maintaining soil structure (Virto et al., 2012). Better soil structure increases water infiltration, nutrient cycling and availability, and enhances conditions that support soil microbial communities.

Table 7: Potential forage and pasture crops suitable for future climate in the RDCK

Summer Crops	Crop Characteristics	Cultivars
Dahurian Wildrye (*Elymus dahuricus* Turz. ex Grieseb.)	Sow from early spring through early-fall High drought tolerance Well adapted to sites receiving 30 to 60 cm annual precipitation, but persists longer with higher precipitation High saline tolerance Well adapted to all soil textures Very good grazing recovery No known pests	Arthur James
Oilseed radish *Raphanus sativus L. var.* oleiferus	Soil temperature for germination: 7°C Days to maturity: 50 Drought tolerant, fast growing Reduce soil compaction, suppress weeds, scavenge nitrate from deeper soil Can be planted in the spring and fall. Frost killed. Can be cut or grazed multiple times Rapid regrowth after cutting/grazing Provides protection against wind and water erosion. Improves water infiltration and soil microbial activity Provides insect, disease and nematode chemical suppression Important for potential weed pressure following year	Adagio Arena Colonel common Remonta Revena Rimbo Ultimo

Sorghum sudangrass *Sorghum × drummondii*	Soil temps at planting should be 18º F Very heat and drought tolerant Multi-cut hybrid with excellent early season vigor Produces lots of biomass, nutritional content make it a good candidate for livestock production	Blackhawk 12 (BMR 12 Gene, Sorghum x Sudangrass Hybrid) Pheasant 6 (BMR 6 Gene, Sorghum x Sudangrass Hybrid) Nighthawk 6 (BMR 6 Gene, Sorghum x Sudangrass Hybrid)
Winter/ Fall Crops	Crop Characteristics	Cultivars
Corn silage *Zea mays L.*	Soil temperature for germination: 10°C Days to maturity: 72 -78 Heat and drought tolerant Very good root lodging Ideal for short growing seasons or lower growing degree units accumulation	05ES1 (72 Days) 05ES7 (73 Days) 08B55 (78 Days)
Bromegrass *Bromus madritensis*	Soil temperature for germination: 10°C Heat and drought tolerant Very suitable as a companion for legumes Can be planted in spring, fall, or frost seeded. Successfully established with no-till Very good root lodging Very tolerant to soil salinity	Hakari Alaska brome Smooth bromegrass Hybrid bromegrass

Source: Appendix A

3.2 Grain

Prediction models indicate that global grain production is expected to decline over the next decades due to climate change (Liu et al., 2016; Morgounov et al. 2018; Wei et al., 2019). Increasing crop diversification for adaptation to higher temperatures and changing precipitation patterns is an important strategy to increase the resilience of grain operations. The introduction of new grain cultivars, such as heritage or ancient grains, is an important adaptation tool for increasing diversification. Consumer awareness for climate change has led to an increase in the sales of ancient grains over the last decade (i.e. spelt) (Boukid et al., 2018). Despite their lower yields, compared to the high-yielding crops, these ancient cultivars are highly adapted to extreme conditions, require low in fertilizer inputs, and contain important genetic diversity (Shimelis et al. 2015). Most ancient grains are grown in tropical and subtropical areas, and thus are known to be more resistant to drought and waterlogging than grains grown in temperate zones (Astrid et al., 2015; Shimelis et al. 2015). The increase in summer temperatures and the extension of the growing season in the region has the potential to create the conditions to grow grains that are typical of more moderate climates. Table 8 presents an example list of potential grain crops suitable in RDCK's future climate.

Agronomic practices

Maintaining soil health is one of the most important climate change adaptation strategies available to farmers. Key to this strategy is the adoption of well-planned crop rotation schedule. Including a 2-4 year resting period of mixed forage crops in grain rotations can enhance the long-term quality of the soil. Research shows that this practice can improve soil structure, decrease compaction, and increase soil organic matter (Viaud et al., 2018; Yates, 2014).

Photo credit: Luc Oliver, Getty Images# 986921034

Temporary grasslands in crop rotations can also provide yield benefits to subsequent cash crops and enhance the ecological services of farming operations (Franco et al., 2018). The establishment of cover crops at the end of the growing season protects the soil from winter erosion. Overwintering cover crops can later be incorporated into the soil during the spring and used as green manure to lower the cost of soil amendments. In addition, this practice has the potential to enhance soil moisture during the planting season, reducing the need for irrigation, it can decrease weed pressure, and increase water infiltration during the raining seasons.

Table 8: Potential grain crops suitable for future climate scenarios in RDCK

Summer Crop	Crop Characteristics	Cultivars
Millet *Pennisetum glaucum*	Soil temperature for germination: 18°C Days to maturity: 60-70 bloom, 90-100 grain Heat tolerant Can be cut or grazed multiple times	Japanese millet Pearl millet
Lentils *Lens culinaris*	Soil temperature: 3°C - 5°C Heat and drought resistant Moderate root lodging Very good frost tolerance Can be planted in the spring in cool climates and in the fall or winter in warmer climates	Le Puy Green Lentil Spanish Pardina Lentils Midnight lentils
Rice *Oryza sativa japonica* (temperate japonica)	Grown in diverse environments in latitudes ranging from 53°N to 40°S (Lu et al., 1980) Soil temperature <10C Cold-tolerant, early maturing Can be grown in clay, silt and loam soils, under flooded or on dry land	Dubovskij Hayayuki Kitaake Takachikuromoni
Wild rice *(Zizania aquatica L.)*	Native to North America Grown in flooded peat or clay loam soils May be seeded in the autumn or spring	K2 M3 Meter Netum Voyager
Quinoa *(Chenopodium quinoa)*	Origin: Andes Mountains of South America Can be grown in a variety of soil types	Titicaca Jesse Puno

	Soil temperature for optimal germination between 4°C and 21°C Relatively tolerant to cold temperatures and light frost One of the most salt-tolerant crops. tolerance differs among varieties Relatively drought tolerant, low water requirements	
Fall/Winter Crop	Crop Characteristics	Cultivars
Spelt (*Triticum* *aestivum* var. *spelta*)	Can be grown on poorly-drained, low-fertility soils Seeding Date: Fall, but can also be sown in the spring Winter hardy Drought tolerant	Comet Maverick Sammy Oberkulmer
Fall rye (*Secale cereal*)	Soil temperature: 3°C - 5°C, optimal 18°C to 25°C Sow from early spring through mid-fall	Hazlet
Winter wheat *Triticum aestivum*	Seeding Date: Fall, but can also be sown in the spring Soil temperature: 3°C - 5°C Winter hardy Drought tolerant	Hard Red Winter Eddy Finley Whetstone Hard White Winter Darwin Golden Spike Gary Soft White Winter ORSS1 757 Brundage96 Lewjain

Source: Appendix A

3.3 Fruit

Changes in seasonal weather patterns in the region is making conventional fruit production more difficult. The introduction of cultivars that are grown in more moderate climatic regions, and thus are more resistant to drought and flooding conditions, could be used as an important adaptation tool for diversification and to increase the resilience of fruit operations in the region. Table 9 lists a number of fruit crops that have the potential to be grown under the predicted environmental conditions for the RDCK.

Agronomic practices

A number of agronomic practices can be adopted by farmers to counteract the effects of a changing climate. Mulching, for example, can be used by growers to protect their soil from the effects of drought or extreme precipitation. Mulch, in the form of straw or wood chips, maintains soil moisture, in particular under extreme drought conditions, and decreases the need for irrigation. The decomposition of straw and woodchips can also contribute to the natural fertilization of the soil, reducing the need for fertilizers. Establishing and maintaining a cover crop in orchard floors throughout the year can protect the soil from erosion, prevent nutrient runoff, enhance water infiltration, manage dust, maintain weeds under control, and provide habitat for beneficial insects. Orchard floor management practices, such as mulching and cover crop, can promote overall crop health, and enhance yield capacity.

Photo credit: BasieB, Getty Images# 471413311

Table 9: Potential fruit crops suitable for future climate scenarios in the RDCK

Crop	Crop Characteristics	Cultivars
Elderberry *(Sambucus Canadensis)*	Native to North America Winter hardy Drought tolerant Waterlodgged tolerant, can be grown in moist areas and riparian situations	Adams Johns Bob Gordon Wyldewood
Pomegranate *Punica granatum*	Best in well-drained soil, but also thrives on calcareous, acidic loam and rock strewn gravel Drought resistant, extremely heat tolerant	Russian Wonderful Kandahar Large Red
Mulberry *(Moras spp.)*	Thrive in infertile, sandy soils Drought tolerant Shade tolerant Waterlogged resistant	M-5 Tigreada Indonesia Acorazonada
Table grape *Vitis labrusca*	Native to North America Thrive in infertile, sandy soils Drought and heat tolerant Winter hardy	Bath Coronation Einset Seedless Venus
Quince *(Cydonia oblonga)*	Grown in cooler subtropical areas to cold temperate regions Can be grown in wide range of soils Can withstand periods of very wet conditions Winter hardy	Missouri Mammoth Powell's Prize Appleshaped Pineapple
Currant *Ribes*	Native to North America Can be grown in wide range of soils Winter hardy Drought and heat tolerant	Red Lake Perfection Wilder

American Pawpaw *Asimina triloba*	Native to North America Winter hardy Can withstand periods of very wet conditions Grown in full sunlight but also very shade tolerant	Dwarf Davis Mango Mitchell P. A. Golden Sun-flower Taylor Taytow Wells Wilson Overleese

Source: Appendix A

3.4 Field vegetable

Vegetable crop production is sensitive to climate. Research indicates that in the absence of adaptation strategies, climate change will have a negative impact on vegetable production worldwide (Scheelbeek, et al., 2018). Crop diversification and the adoption of a number of agronomical management practices, such as mulching, drip irrigation, and reduced/no-till have been identified as important strategies to reduce the magnitude of the impact from and vulnerability to climate change for vegetable farming operations (Lin, 2011, Rojas-Downing et al., 2017). Conditions will require that these approaches are regionally sound and are well-adapted to extreme conditions. Table 10 presents an example list of potential crops suitable for future climate in the RDCK.

Agronomic practices

Farmers in the RDCK might find that growing seasons in their area may become too unpredictable to grow certain vegetables, most likely long-season, slow growing species (i.e. squash, tomatoes). One practice farmers can adopt to maintain their overall production is to increase the area under cultivation and number of shorter season, early maturing crops (i.e. leafy greens) (Table 10). Research indicates that crop systems with diverse rotations can withstand abiotic stressors better than those with less diverse rotations (Degani et al., 2019). In this regard, the diversification of crops via crop rotation, intercropping, cover cropping, etc. can be used to intensify food production, reduce external inputs, and increase the resilience of field vegetable crop operations to climate change (Degani et al., 2019; Koundinya et al., 2018).

As weather patterns become erratic and unpredictable, the use of season-extending cultural practices may be needed to grow some vegetable crops. A number of practices available to farmers include pre-germination of seeds, growing or purchasing transplants, and the use of cover crops, mulches and row covers. Mulches and cover crops conserve soil moisture under drought conditions, decreasing the need for irrigation. They can protect the soil from the impact of heavy rains and wind erosion, prevent weed growth, moderate soil temperatures and increase the nutrient levels in the top layers of the soil. Another cultural practice that can help farmers increase the resilience of their production systems is the use of row covers. Floating row covers are used to deter pest, but also play an important role in moderating temperature, wind, and humidity around the crops. As such, row covers create a microclimate that promotes crop maturity, increases yields, and expands areas of production (Olmstead et al. 2001). It is estimated that season extension practices will play an important role in vegetable production under varying climatic conditions.

Maintaining soil health is one of the most important climate change adaptation strategies available to farmers. The continuous disruption of the top layer in annual production is linked to the long-term deterioration of the soil. Cultivation practices, such as intensive tillage and disking, disrupts soil structure and causes soil compaction. These practices restrict plant root growth, water infiltration and nutrient uptake, decrease soil organic matter accumulation, disrupt soil microbial functions, and lowers crop yields (Ogle et al. 2019). Because soil structure is a key determinant of soil processes such as water and nutrient availability, both conventional and organic producers are looking for alternatives to reduced tillage or eliminate it altogether A number of practices available to farmers include reduced-, inverted-, and no-tillage. These practices cause minimum disturbance to soil structure, and under varying weather conditions can be used to enhance resilience. Research indicated that reduced-and no-till practices can help lower greenhouse gas emissions through carbon storage via the accumulation and maintenance of organic matter in the soil (Follett, 2001; Lal et al., 1999; Paustianet al. 1997). The benefits of reduced and no-till may be enhanced through the integration of additional conservation practices such as cover cropping and crop rotations.

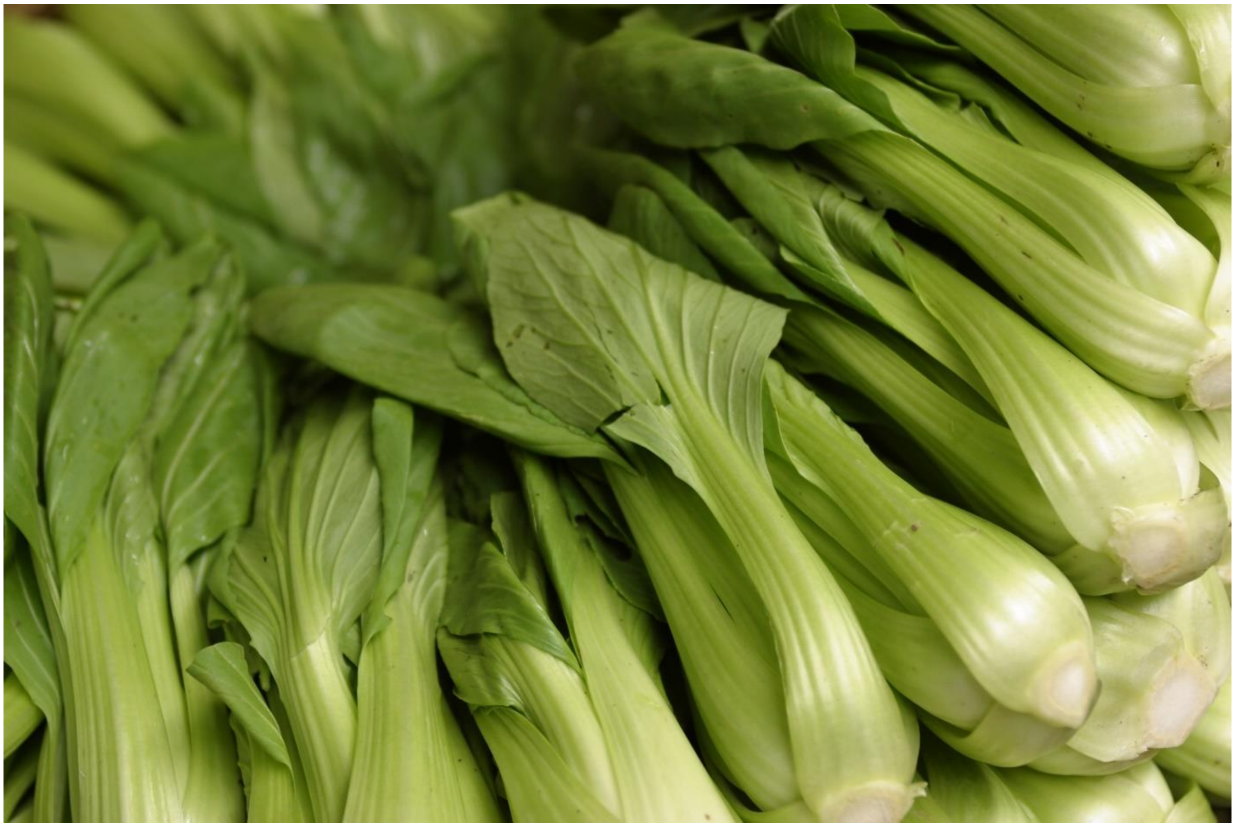

Photo credit: Jupiterimages, Getty Images# 87774520

Table 10: Potential field vegetable crops suitable for future climate scenarios in the RDCK

Crop	Crop Characteristics	Cultivars
Radish *Raphanus sativus* Turnips *Brassica rapa subsp. rapa*	20 to 40 days to maturity Can germinate in soil temperature between 10°C – 37°C Heat tolerant Adapted to the cooler temperatures and shorter day-length of spring and fall	Rover Sora (Organic) Hakurei
Broccoli *Brassica oleracea var. italica*	40 to 50 days to maturity Can germinate in soil temperature between 10°C – 37°C Heat tolerant Adapted to the cooler temperatures and shorter day-length of spring and fall	Eastern Magic Green Magic Imperial Sprouting broccoli Broccoli raab/Rapini Broccolini
Greens and Asian Greens	20 to 40 days to maturity Can germinate in soil temperature between 10°C – 37°C Heat tolerant Adapted to the cooler temperatures and shorter day-length of spring and fall Slow to bolt, attractive for chefs or stores	Astro Arugula Asian green: Mei Qing Choi (Pak Choi) Lettuce: Muir Lettuce (organic) Small head Romaine Gem lettuce
Sweet potato (*Ipomoea batatas*)	Soil temperature 18°C Planting period: late May to June 100 days to harvest Need very little water because of their deep rooting	Beauregard Centennial Jewell Georgia Jet

Okra *(Abelmoschus esculentus)*	Time to harvest 50 to 65 days Can be grown in wide range of soils Soil temperature at least 21°C Heat and drought tolerant	Annie Oakley II Cajun Delight Clemson Spineless Emerald
Ginger *(Zingiber officinale Roscoe)* and Tumeric *(Curcuma longa)*	High value crop Best adapted to warm (29°-32°C) and humid climates for growth, base temperature requirement is 13°C Required annual rainfall of at least 1500- 2000 mm Sprout indoors. After sprouting transplant to soil (temperature > 4°C)	Tumeric: Roma Suroma Ranga Rasmi Surangi Ginger: Yellow, White, Hawaiian, Chinese

Source: Appendix A

3.5 Seed sources

The use of locally adapted seed is an important adaptation for mitigating the effects of climate change. Local seeds are more tolerant to weather shocks and other regional factors. Farmers in the RDCK, especially small-scale and specialty crop farmers have limited access to affordable, quality locally adapted seed. This is due to insufficient local seed production and distribution, and the absence of an inadequate quality assurance system. Given the uncertainties of a changing climate, crop diversification strategies will require the development and support of a regional seed system that supports all the participants involved in the development and dissemination of crops, the production, processing, storage, distribution and marketing of seeds. This is no small undertaking.

4. Conclusion

Prediction studies based on climate models indicate that agricultural production may, in some ways, benefit from a warmer climate, the extension of the growing period, and increased CO_2 levels. These benefits however might be substantially attenuated by the occurrence of adverse environmental conditions (i.e. extreme precipitation events, excessive droughts, smoke from wild fires). As a result, the production of traditional agricultural crops, using traditional methods is expected to become increasingly challenging. Facing the increasingly difficult challenges of having to adapt to climate change, farmers in the RDCK are looking for alternatives to maintain and increase the production of their farming operations, while remaining ecologically and economically viable.

Diversification represents a significant source for adaptation to climate change. The introduction of heritage or ancient grains, increasing the number of crops varieties in forage fields, or augmenting the area of short season vegetables can increase the resilience of productions systems. Also key to adaptation is the use of season-extending cultural practices such as pre-germination of seeds, growing or purchasing transplants, and the use of cover crops, mulches and row covers can help farmers protect the soil erosion, prevent weed growth, moderate soil temperatures and increase the nutrient levels in the top layers. These practices have the potential to promote crop maturity, increases yields, and expands areas of production under uncertain weather conditions.

The use of local seeds is an important adaptation for mitigating the effects of climate change. Given the uncertainties of a changing climate, farmers will require the development of a regional seed system that supports all the participants involved in the development and dissemination of crops, the production, processing, storage, distribution and marketing of seeds.

The results of this study cannot substitute research knowledge derived from experimental field research which can provide additional data such as long term impacts on yield, production best practices, and costs of production. Additionally, market research will be needed to assess financial success of the crops recommended in this study.

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