Land Suitability Assessment – Climate Ratings for Forage Crops in Delta, BC

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1. Executive Summary

1.1. Overview

Intensive dairy production in the Lower Fraser Valley is dependent on a reliable source of forages, much of which is supplied from Delta. The land used for forages is economically important within the Agricultural Land Reserve in British Columbia. The project addressed climate change adaptation of Delta's agricultural sector forage crops by assessing the climate ratings of land suitability, based on the Land Suitability Rating System for the lands within the Agricultural Land Reserve in Delta, B.C. It thereby predicted the effects of future climate change scenarios.

The project was completed on the QGIS platform with soil information from Detailed Soil Survey, climate data from ClimateNA software, and land suitability analysis based on the Land Suitability Rating System. The QGIS output map contains the recommended growing area of forages in three greenhouse gas emission scenarios (RCP 2.6, RCP 4.5 and RCP 8.5) for 2010-2039, 2040-2069, and 2070-2100.

Overall, the climate rating class improved for both legume and grass forages under the climate change scenarios. The limiting factor of climate shifts from heat requirement to moisture requirement through the years. Soil ratings can limit the final land suitability rating under hot dry climate change scenarios. Land suitability assessment and mapping for multiple crops are suggested for future studies for agricultural land use planning purposes.

2. Table of Contents

3. Introduction

3.1. Background

Much of the forages for intensive dairy production in the Lower Fraser Valley is supplied from Delta (Crawford & MacNair, 2012). Delta has warm dry summer, and cold moist winter (see Figure 1). The Agricultural Land Reserve (ALR) is the land reserved as a priority for agricultural land use. Delta has the second-largest ALR area in Metro Vancouver (15% of regional ALR area, see Figure 2) (Ministry of Agriculture, 2014). Most cultivated areas in Delta are used for forage production (25%), with 1,094 ha in the ALR and 38 ha outside the ALR (Zbeetnoff Agro-Environmental & Quadra Planning, 2011).

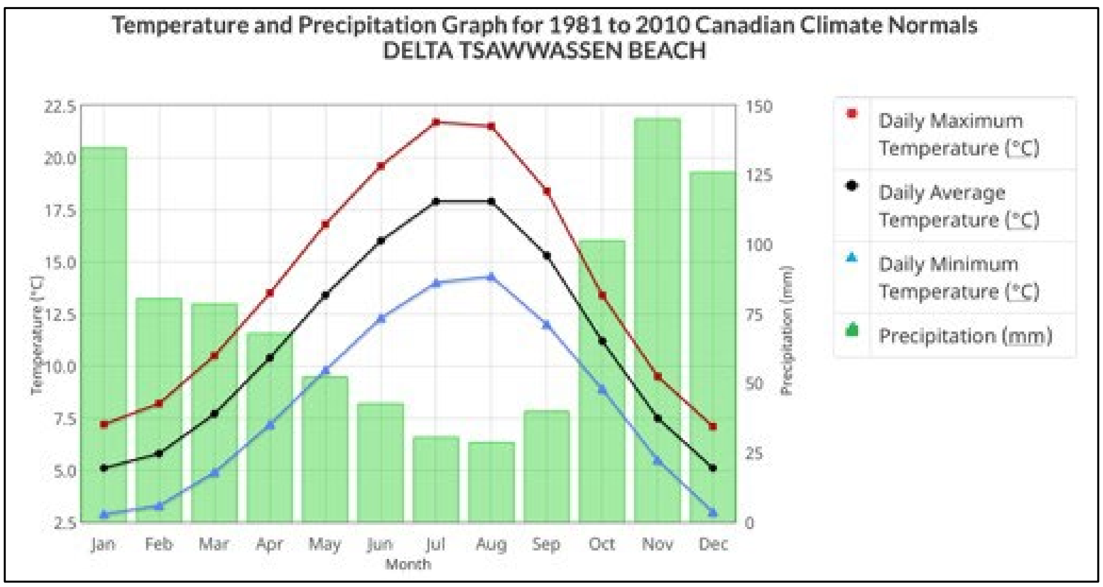

Figure 1. Temperature and precipitation in Delta (from Environment Canada, 2019)

The lands within the ALR are based on capability classification (Hughes-Games, 2018), which indicates the extent of the limitation (increases from class 1 to class 7) from soil and climate to a range of crops with best management practices (Kenk, 1983). As there is no information in the capability classification for the needs of specific crops, a Land Suitability Classification (LSRS) was introduced with consideration of crops.

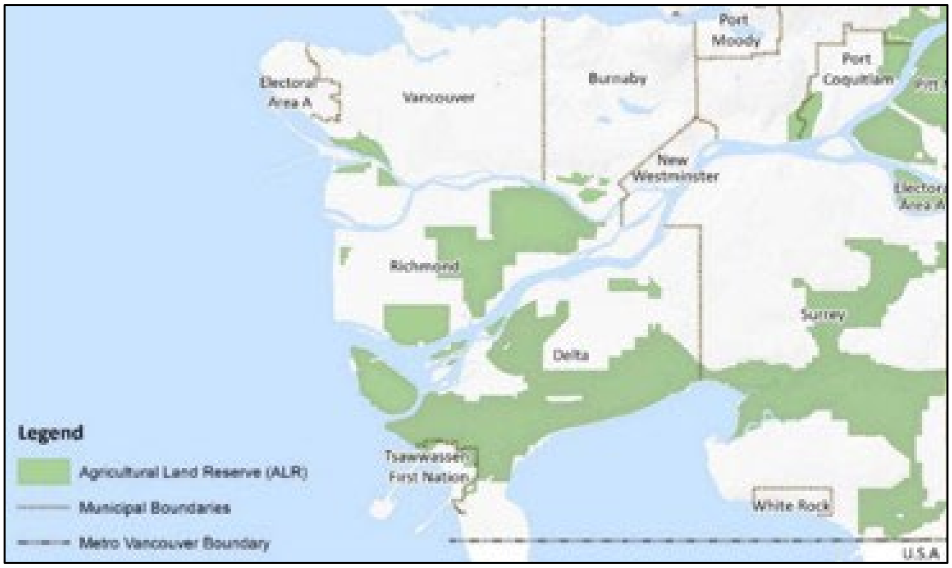

Figure 2. ALR in Metro Vancouver (from Metro Vancouver, 2017)

The LSRS is a land suitability assessment tool developed for land use planning in Canada (Bock, et al., 2018). A previous study by Gasser, et al. (2016) assessed the climate change impacts on corn production in the Lower Fraser Valley by using the Land Suitability Rating System. Bock, et al. (2018) also assessed crop suitability in Canada by using the Land Suitability Rating System. The study included multiple crops, such as spring-seeded small grains, alfalfa, brome, corn, soybeans, and canola. They did a national scale assessment on the baseline of 1981-2010. They also completed a regional scale assessment for baseline and future period in Alberta.

Climate change is increasingly affecting Delta's agriculture, as well as issues including soil salinization and summer drought (City of Delta, 2020). This is a framework for assessing the effects of climate change on land suitability for forage production for Delta's land base is of considerable interest. The combination of land suitability information with Geographic Information Systems (GIS) can aid efficient spatial planning and address climate change dynamics (Anilkumar, Chikkaramappa, Gopala, Arunkumar, & Patel, 2019; Bock, et al., 2018). This study is an assessment in Delta ALR for forage crops and addresses the effects of future climate change scenarios for year range 2010-2039, 2040-2069, and 2070-2099.

Both legume and grass are used as common forages for livestock production in Canada. Alfalfa (*Medicago sativa* L.), as a legume that adds nitrogen to the soil, is widely grown in Canada in crop rotations (McCartney & Horton, 1997). Thus, the alfalfa was chosen as the representative for legume forages (Bock, et al., 2018). Brome (*Bromus inermis* L.) is commonly used for forage crop in western Canada as one of the C3 grasses (Bock, et al., 2018), most of which share similar growth requirements (Moser, Buxton, & Casler, 1996 as cited in LSRS version 5 by Agriculture and Agri-Food Canada, 2017). This study focuses on how climate change would affect forage crops in Delta, BC by using alfalfa and brome as representative models for legume and C3 grasses respectively.

LSRS includes four major factors for rating: climate requirements, mineral soil requirements, organic soil requirements, and landscape requirements. The rating index range from 0 (most limiting) to 100 (least limiting), and then converted to suitability class from 7 (most limiting) to 1 (least limiting) (see Table 1). **Error! Reference source not found.** summarizes components and parameters for each major factor, which may be adjusted for certain model crops.

Table 1. Rating index and rating class conversion

(from Agronomic Interpretations Working Group, 1995)

Rating Index	Rating Class
80-100	1
60-79	2
45-59	3
30-44	4
20-29	5
10-19	6
0-9	7

Table 2. LSRS factors, components, and parameters (from Bock, et al., 2018)

Factor	Component	Parameter
Climate	Heat (energy) supply	Growing degree days, growing season length
	Moisture supply	Precipitation, evapotranspiration
Mineral Soil	Moisture supply	Texture, rooting depth, water table
	Nutrient supply	Organic matter content, soil reaction
	Physical conditions	Soil structure, soil bulk density
	Chemical conditions	Soil salinity, soil reaction
	Drainage	Depth to the water table, drainage class
Organic Soils	Moisture supply	Fibre content, water table
	Nutrient supply	Fibre type, soil reaction
	Physical conditions	Soil structure, soil density
	Chemical conditions	Soil reaction, soil salinity
	Drainage	Depth to the water table, climate
Landscape	Erodibility potential	Slope steepness, slope length, climate
	Management factors	Stoniness, drainage, pattern
	Flooding potential	Wetness, duration of flooding, landform position

3.2. Assumptions

With the focus on the climate factor in LSRS, this paper assumes that climate change will follow the predictions, and soil properties will not change with climate change and crop production. The full assumptions for LSRS may be found in: *The Land Suitability Rating System Is a Spatial Planning Tool to Assess Crop Suitability in Canada* (Bock, et al., 2018), *Land Suitability Rating System for Agricultural Crops* (Agronomic Interpretations Working Group, 1995), and *Alfalfa and Brome-Timothy Crop Models* (Agriculture and Agri-Food Canada, 2017).

3.3. Objectives

1. Develop an LSRS to the regional assessment for land suitability for forage crops in Delta, BC,
2. Assess land suitability dynamics incorporating climate change scenarios, and
3. Facilitate communications with a GIS framework and derived maps.

4. Methods

The project combines GIS and Land Suitability Rating System. There are three major stages, data preparation, LSRS analysis, and mapping. Data were collected from the City boundary polygon (the year 2019) (https://www12.statcan.gc.ca/census-recensement/2011/geo/bound-limit/bound-limit-eng.cfm), Agricultural Land Reserve (ALR) polygon (https://www.alc.gov.bc.ca/alc/content/alr-maps/maps-and-gis), Detailed Soil Survey (DSS) polygon (http://sis.agr.gc.ca/cansis/nsdb/dss/v3/index.html), Canadian Digital Elevation Model (DEM) (https://maps.canada.ca/czs/index-en.html), and ClimateNA software (http://climatena.ca).

On the open-source GIS platform QGIS 3.12 software (www.qgis.org), the soil data are stored in the polygons for the study area by using the QGIS tool intersection between the origin polygon layers from the City boundary, ALR polygon, and DSS polygon. The polygon centroids tool output centroids for each polygon and those centroids are used as climate representative points for each polygon. The location information of the centroids is driven by adding geometry attributes tool (for latitude and longitude) and point sampling tool (QGIS plugin) with the Canadian DEM raster layer. The polygon centroids latitude, longitude, and elevation data are export in a comma-delimitated spreadsheet (CSV) file and run through ClimateNA_v6.30 software for climate data acquisition.

ClimateNA software downscales the gridded historical and future climate data to scale-free point locations for North America (Wang, Hamann, Spittlehouse, & Carroll, 2016). The monthly baseline data for British Columbia are PRISM at 800 m x 800 m resolution from Pacific Climate Impact Consortium (PCIC). In this project, the monthly climate data are from three future periods, the 2020s (2010-2039), 2050s (2040-2069), and 2080s (2070-2099). ClimateNA includes fifteen General Circulation Models (GCMs) of the Coupled Model Intercomparison Project Phase 5 (CMIP5) in the fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

Different climate inputs cause the variation of results (Bock, et al., 2018; Gasser, et al., 2016). Murdock and Spittlehouse (2011) suggest three projections as minimal for a climate change study in British Columbia, and additional combinations are also recommended. This project used the multiple ensemble GCMs average in three greenhouse gas emission scenarios (RCP 2.6, RCP 4.5 and RCP 8.5) for climate change analysis. Due to the data limitation, RCP 4.5 and RCP 8.5 are 15 GCMs Ensemble, while RCP 2.6 is 13 GCMs Ensemble. ClimateNA allows running multiple-location and multiple GCMs with CSV file output. The climate data then joins with the soil information for each polygon centroids for LSRS analysis.

LSRS calculations are based on three major references: *The Land Suitability Rating System Is a Spatial Planning Tool to Assess Crop Suitability in Canada* (Bock, et al., 2018), *Land Suitability Rating System for Agricultural Crops* (Agronomic Interpretations Working Group, 1995), and *Alfalfa and Brome-Timothy Crop Models* (Agriculture and Agri-Food Canada, 2017). The forage crops land suitability ratings are based on the alfalfa crop model for legume forages and the brome-timothy crop model for grass forages (Agriculture and Agri-Food Canada, 2017). Each model rates the climate, mineral soil, organic soil, and landscape requirements. This project focuses on how climate ratings change under climate change scenarios.

After the LSRS calculation, the results are combined with soil polygons in QGIS based on their polygon IDs for each climate change scenario and each period of time. Then, they are visualized as maps based on the climate rating classes.

4.1. Climate Ratings

Alfalfa and brome are perennial crops that do not require annual seedling and lack of frost damage concerns (Agriculture and Agri-Food Canada, 2017; Bock, et al., 2018). Climate ratings for both the alfalfa model and the brome model contain three requirements: heat, length of the growing season, and moisture requirement. The final climate rating value is the lowest value of those three requirements (Agronomic Interpretations Working Group, 1995).

4.1.1. Heat Requirements and Ratings

Compared to the spring-seeded small grains model, as perennial crops have a longer growing season, the alfalfa model and the brome model assess the heat requirements by growing degree days (GDDs). Growing degree days are calculated as the difference between daily mean temperature and base temperature, where the daily mean temperature is the average of daily maximum temperature and minimum temperature.

$$\mathrm{GDD} = \frac{\mathrm{T}_{!''\#} - \mathrm{T}_{!\$\%}}{2} - \mathrm{T}_{\&'''(}$$

The extended growing season for perennial forages is assumed to begin when the daily mean temperature is higher than 5 ◦C (Champman & Brown, 1966, as cited in Bootsma & Boisvert, 1991). Therefore, the base temperature is set as 5 ◦C in GDD's equation. For both the alfalfa model and the brome model, the GDDs are accumulated from April to October (Bock, et al., 2018), where the original data from ClimateNA as monthly GDDs. In the following content, GDD is the abbreviation of the accumulated growing degree days with base temperature as 5 ◦C from April to October if without special notice.

Perennial forages can be harvested multiple times during a year. The point deductions for heat requirements were set based on the available number of cuts. For alfalfa, the first cut requires 480 GDDs, and crop carryover requires 450 GDDs (Bootsma & Boisvert, 1991), which means it requires 480 GDDs to harvest once without a carryover, 930 GDDs (= 480 GDDs + 450 GDDs) to harvest once with carryover, 1410 GDDs (= 2 * 480 GDDs + 450 GDDs) to harvest twice with carryover, and 1890 GDDs (= 3 * 480 GDDs + 450 GDDs) to harvest three times with carryover (Bock, et al., 2018). Figure 3 shows the relationship between the alfalfa heat rating point deduction and GDDs. The calculation equation comes to $\text{point deduction} = 89.02 + 0.0067 \times \mathrm{GDD} - 0.000016 \times \mathrm{GDD}^{)}$ (Agriculture and Agri-Food Canada, 2017).

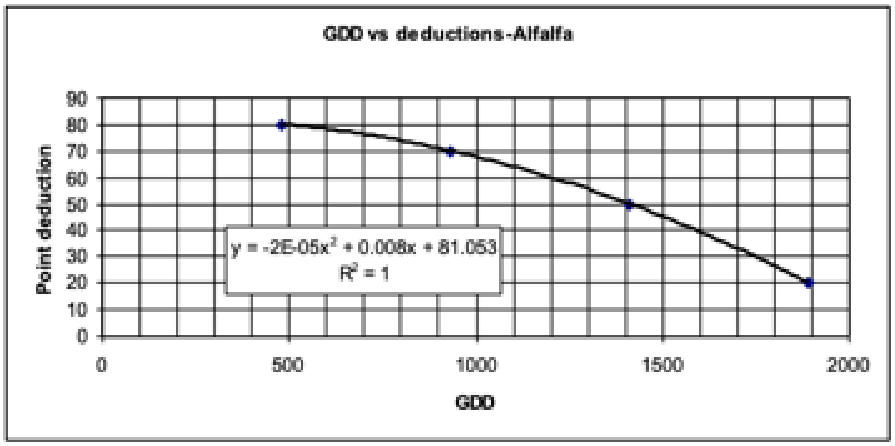

Figure 3. The relationship between point deductions and GDDs for alfalfa (from Agriculture and Agri-Food Canada, 2017)

For the brome model, the GDDs required for the first cut remain the same, while the GDDs required for carryover reduced to 400 GDDs (Agriculture and Agri-Food Canada, 2017). Similarly, the GDDs' requirements are 480 GDDs for 1 cut without carryover, 880 GDDs (= 480 GDDs + 400 GDDs) for 1 cut with carryover, 1360 GDDs (= 2 * 480 GDDs + 400 GDDs) for 2 cuts with carryover, and 1840 GDDs (= 3 * 480 GDDs + 400 GDDs) for 3 cuts with carryover (Bock, et al., 2018). Figure shows the relationship between the brome heat rating point deduction and GDDs. The calculation equation comes to $\text{point deduction} = 89.28 + 0.0085 \times \text{GDD} - 0.000016 \times \text{GDD}^{)}$ (Agriculture and Agri-Food Canada, 2017).

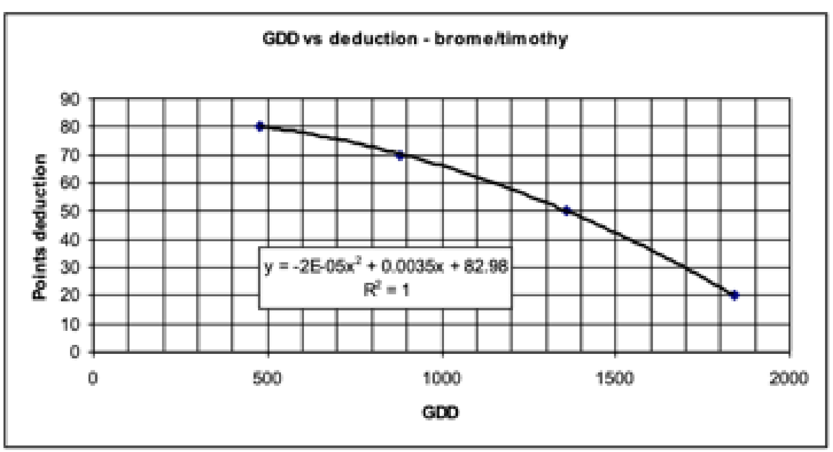

Figure 4. The relationship between point deductions and GDDs for brome (from Agriculture and Agri-Food Canada, 2017)

4.1.2. Length of Growing Season Requirements and Ratings

Similar to heat requirements, the length of growing season requirements assessed by the available number of cuts. Table 3 summarizes the GDD and GSL requirement for each cut and carryover for alfalfa and brome. For alfalfa, the minimum growing season length in days (GSL) required for each cut is 45 days, which is the minimum GSL to reach the maximum leaf area index (Bootsma & Boisvert, 1991). At the beginning and the end of the growing season, the GSL requirement is longer than the minimum GSL due to the lower temperature, which needs a longer time to accumulate heat (Agriculture and Agri-Food Canada, 2017).

Table 3. DGG & GSL requirement for each cut (from Agriculture and Agri-Food Canada, 2017)

Cut	Alfalfa GDD	Alfalfa GSL	Brome GDD	Brome GSL
1	480	65	480	65
2	480	45	480	50
3	480	45	480	50
Carryover	450	55	400	55

For the alfalfa model, the first cut requires 65 GSL (growing season length in days); 45 GSL is required for each following cut, and the carryover requires 55 GSL (Bock, et al., 2018). That means it requires 65 GSL to harvest once without carryover, 120 GSL (= 65 GSL + 55 GSL) to harvest once with carryover, 165 GSL (= 65 GSL + 45 GSL + 55 GSL) to harvest twice with carryover, and 210 GSL (= 65 GSL + 45 GSL + 45 GSL + 55 GSL) to harvest three times with carryover (Agriculture and Agri-Food Canada, 2017). Figure 4 shows the relationship between the alfalfa heat rating point deduction and GSL. The calculation equation comes to $\text{point deduction} = 72.052 + 0.2889 \times \mathrm{GSL} - 0.0026 \times \mathrm{GSL}^{)}$ (Agriculture and Agri-Food Canada, 2017).

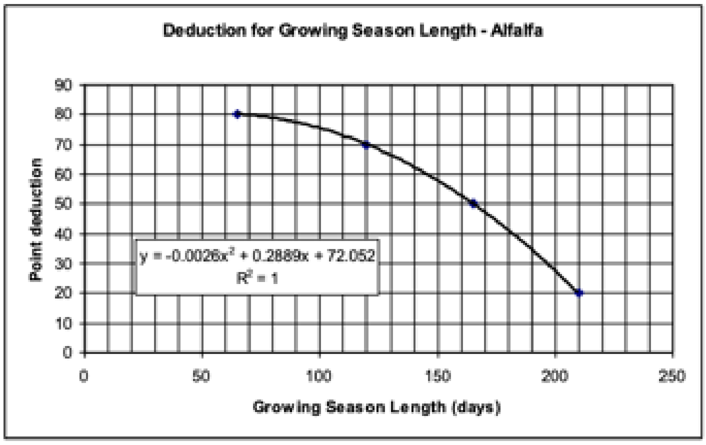

Figure 4. The relationship between point deductions and GSL for alfalfa

(from Agriculture and Agri-Food Canada, 2017)

For the brome model, the first cut and carryover GSL requirements remain the same as alfalfa's, while the GSL required for cut 2 and cut 3 are higher (50 GSL). The optimum temperature for cool-season C3 grasses is 20◦C, and the higher temperature reduces C3 grass growth (Moser, Buxton, & Casler, 1996 as cited in Agriculture and Agri-Food Canada, 2017). Figure 5 shows the relationship between the alfalfa heat rating point deduction and GSL. The calculation equation comes to $\text{point deduction} = 76.01 + 0.194 \times \text{GSL} - 0.002 \times \text{GSL}^{)}$ (Agriculture and Agri-Food Canada, 2017).

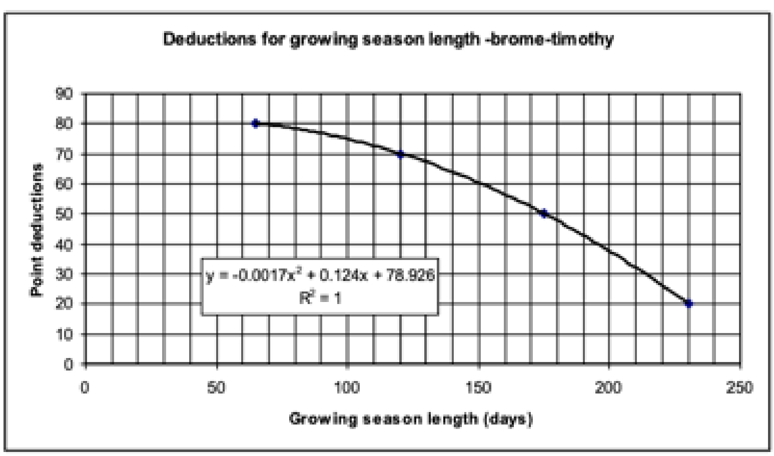

Figure 5. The relationship between point deductions and GSL for brome

(from Agriculture and Agri-Food Canada, 2017)

Table 4. Summary table of point deductions for GDD and GSL

(from Agriculture and Agri-Food Canada, 2017)

Point Deduction	Class description	Cuts	Alfalfa GDD	Alfalfa GSL	Brome GDD	Brome GSL
80	Class 5-6 boundary	1 – no carryover	480	65	480	65
70	Class 4-5 boundary	1 – carryover	930	120	880	120
50	Lower part of Class 3	2	1410	165	1360	175
20	Bottom of Class 1	3	1890	210	1840	230

Table 4 summarizes the heat rating and GSL rating calculations. The GSL is converted from GDDs based on the relationship shown in Figure 6. On the west coast of Canada, where the scattered data GSL > 230 days (Agriculture and Agri-Food Canada, 2017), this conversion would underestimate the GSL in Delta, BC. However, coastal BC's growing season length does not limit forage growth as much as the heat requirement (Bock, et al., 2018). Even with underestimated GSL, the result shows that GSL ratings are higher than corresponding GDD ratings. Therefore, the underestimated effect is acceptable in this project.

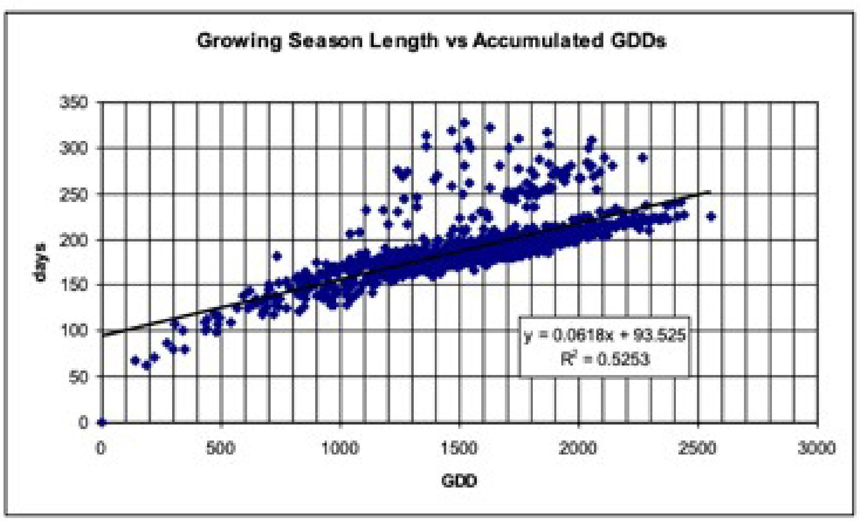

Figure 6. The relationship between GSL and GDDs

(from Agriculture and Agri-Food Canada, 2017)

4.1.3. Moisture Requirements and Ratings

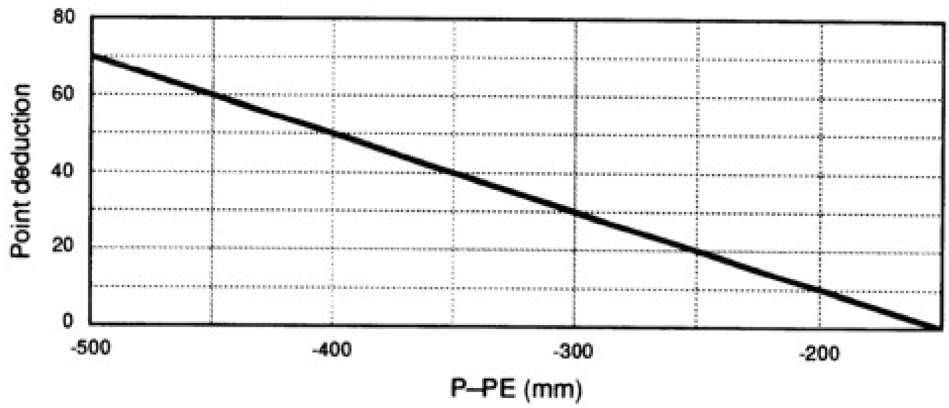

Figure 7. Point deduction for moisture index values for spring-seeded small grains

(from Agronomic Interpretations Working Group, 1995)

The parameter of moisture ratings for the alfalfa model and brome model is the same as the parameter of moisture rating for small grains (P-PE), which comes from the function: Moisture deficit (or surplus) = precipitation (P) – potential evapotranspiration (PE) + soil moisture. The P-PE values for small grains are accumulated from May to August, while the P-PE for alfalfa and brome are accumulated from May to September because of the extended growing season. The climate moisture rating deductions for small grains (see Figure 7) are also appropriate for alfalfa and brome with the data conversion shown in Figure 8 (Agriculture and Agri-Food Canada, 2017).

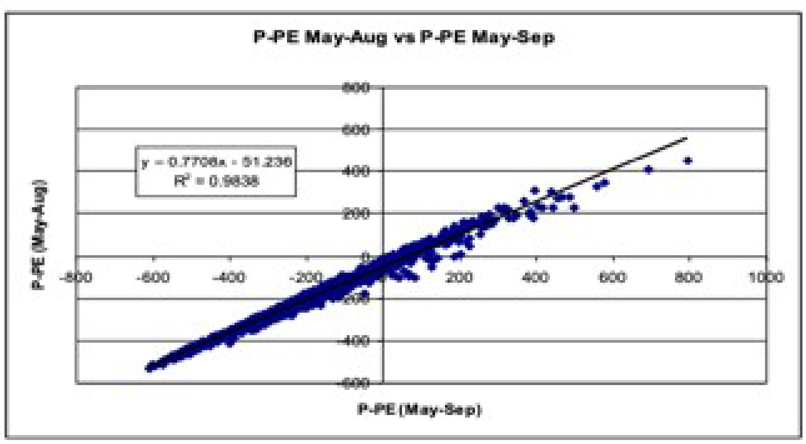

Figure 8. Comparison of P-PE (May to August) to P-PE (May to September)

(from Agriculture and Agri-Food Canada, 2017)

5. Results & Discussion

There are 425 soil polygons in the study area (Delta ALR) with 219.91 km^2. The area is calculated by the Add Geometry attributes tool for each soil polygon under the projected coordinate reference system (CSR) EPSG:3857 - WGS84 / Pseudo-Mercator. The climate ratings in all future climate projections are better than the normal climate ratings for both legume and C3 grass (see Figure 9). As the final climate rating is the lowest value among heat requirement, length of the growing season requirement, and moisture requirement, the lowest value of the determined requirement's parameter is named as the limiting factor (i.e., GDD, GSL, or P-PE).

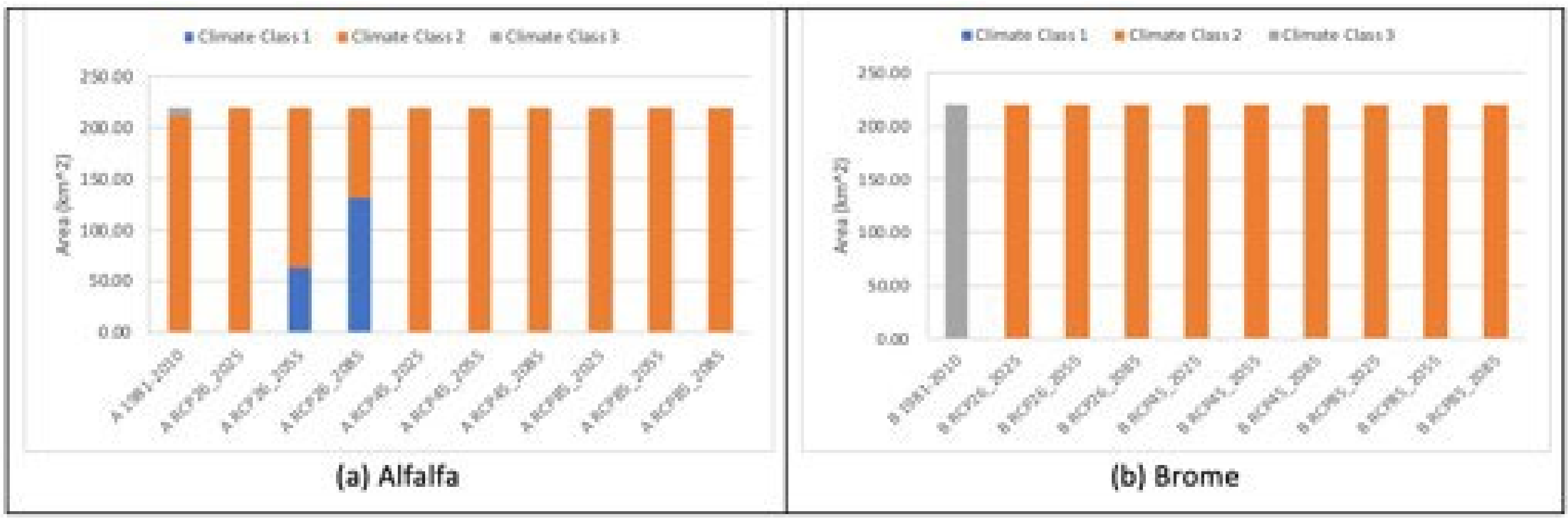

Figure 9. Climate rating class in the area: the years in future climate projections represent certain time periods (2025 for 2010-2039, 2055 for 2040-2069, 2085 for 2070-2099)

The result shows that the climate in Delta, BC suits alfalfa legume better than bromegrass. Under the normal climate (1981-2010), for the alfalfa model, 375 polygons (212.23 km^2) are rated as the climate class 2, and the rest of 50 polygons (7.68 km^2) are rated as the climate class 3 (see Figure 10), while most Delta ALR (423 polygons, 219.71 km^2) are rated as the climate class 3, and only 2 polygons (0.20 km^2) are rated as the climate class 2 for the brome model (see Figure 11). GDD is the limiting factor for all polygons in both models under the normal climate (1981-2010).

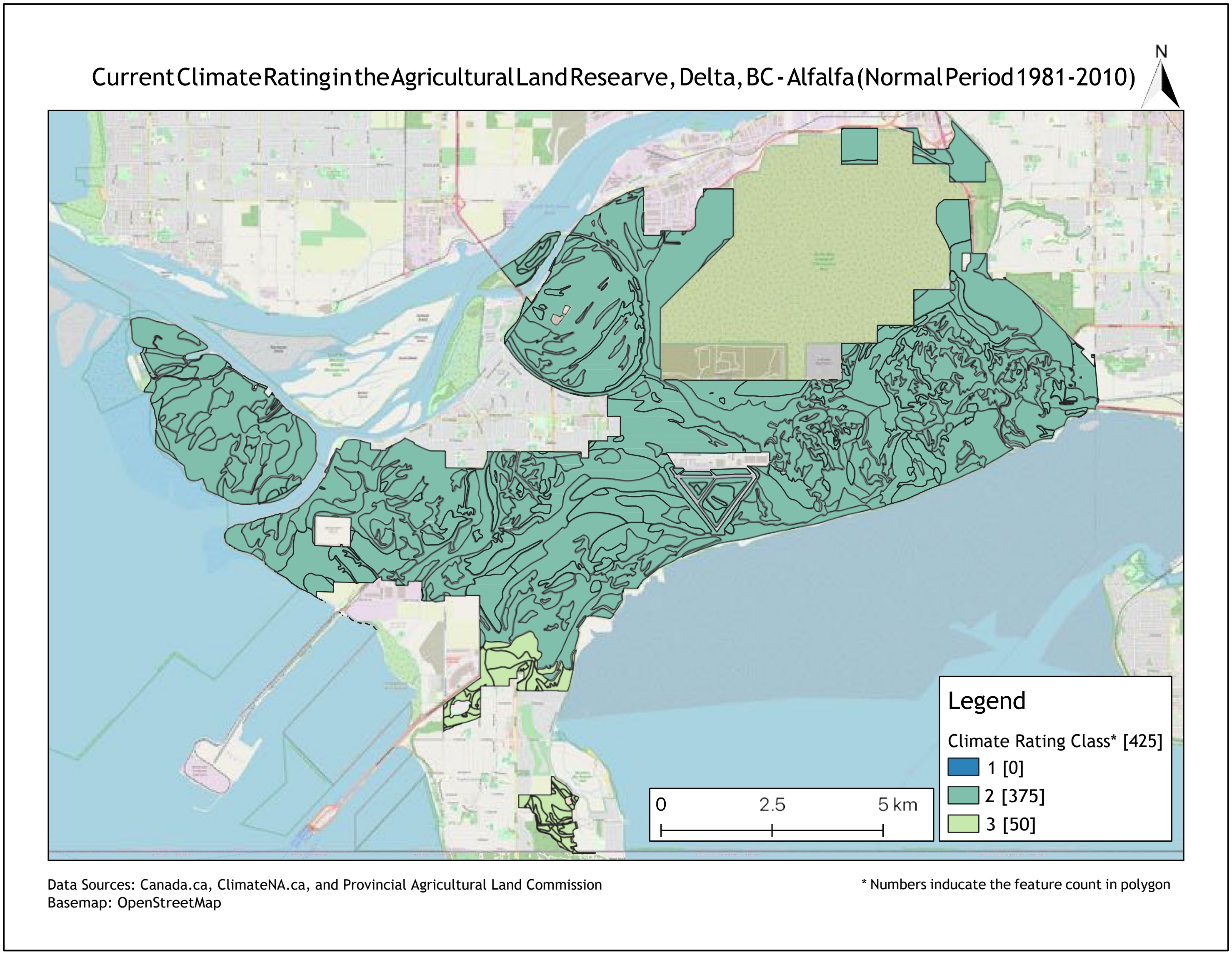

Figure 10. Map of climate ratings - Alfalfa (1981-2010)

Since the GDDs for alfalfa and brome in a certain time period are the same, the difference in the heat ratings comes from the point deduction function. The higher the GDD, the higher the difference. Even though alfalfa requires a higher GDD for carryover, with the same point deduction for one cut without a carryover, the slope of point deduction is flatter.

$$\text{Alfalfa point deduction} = 89.02 + 0.0067 \times \text{GDD} - 0.000016 \times \text{GDD}^2$$

$$\text{Brome point deduction} = 89.28 + 0.0085 \times \text{GDD} - 0.000016 \times \text{GDD}^2$$

$$\text{Point deduction difference (B} - \text{A)} = 0.26 + 0.0018 \times \text{GDD}$$

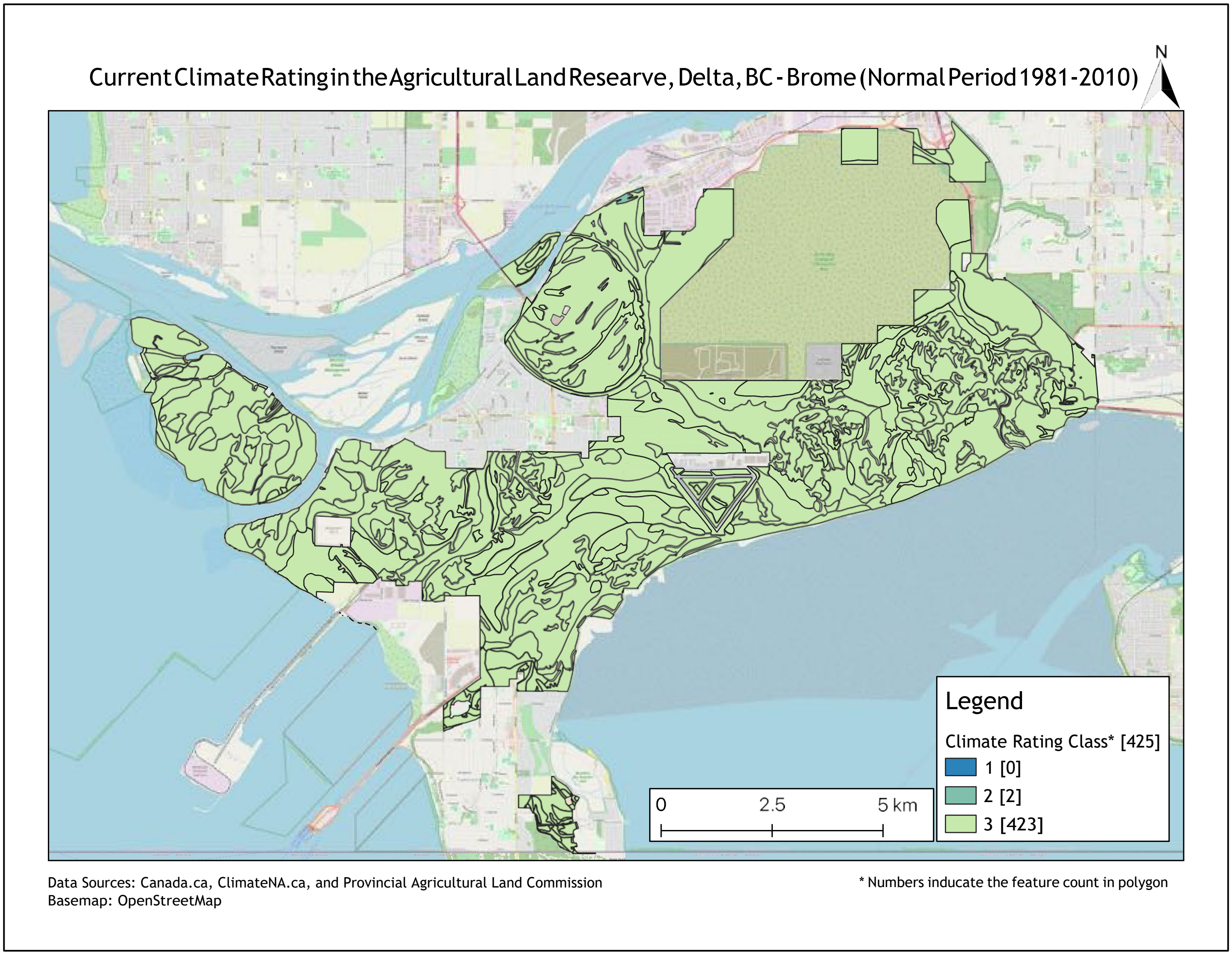

Figure 11. Map of climate ratings - Brome (1981-2010)

There is a clear trend of limiting factor shifts from GDD to P-PE in most future projections (see Figure 12). The limiting impact of GDD reduces with a high temperature in the future climate projections, while the decreased precipitation and increased potential precipitation increase the P-PE limiting effect (see Figure 13). This could explain why climate class 1 appears in the alfalfa model under RCP 2.6 scenarios (see Appendix 1).

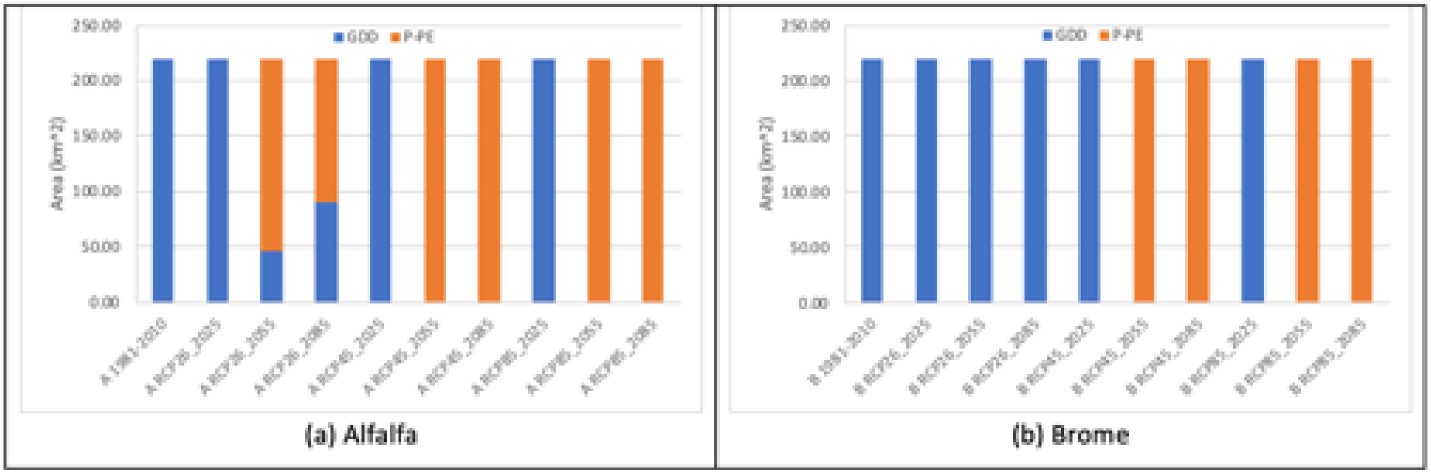

Figure 12. Limiting factors in the area: the years in future climate projections represent certain time periods (2025 for 2010-2039, 2055 for 2040-2069, 2085 for 2070-2099)

The landscape ratings do not change with climate parameters because the landscape rating assessment only considers slope (%) and stoniness for the alfalfa model and the brome model (Agriculture and Agri-Food Canada, 2017). The landscape rating class is available in Appendix 2.

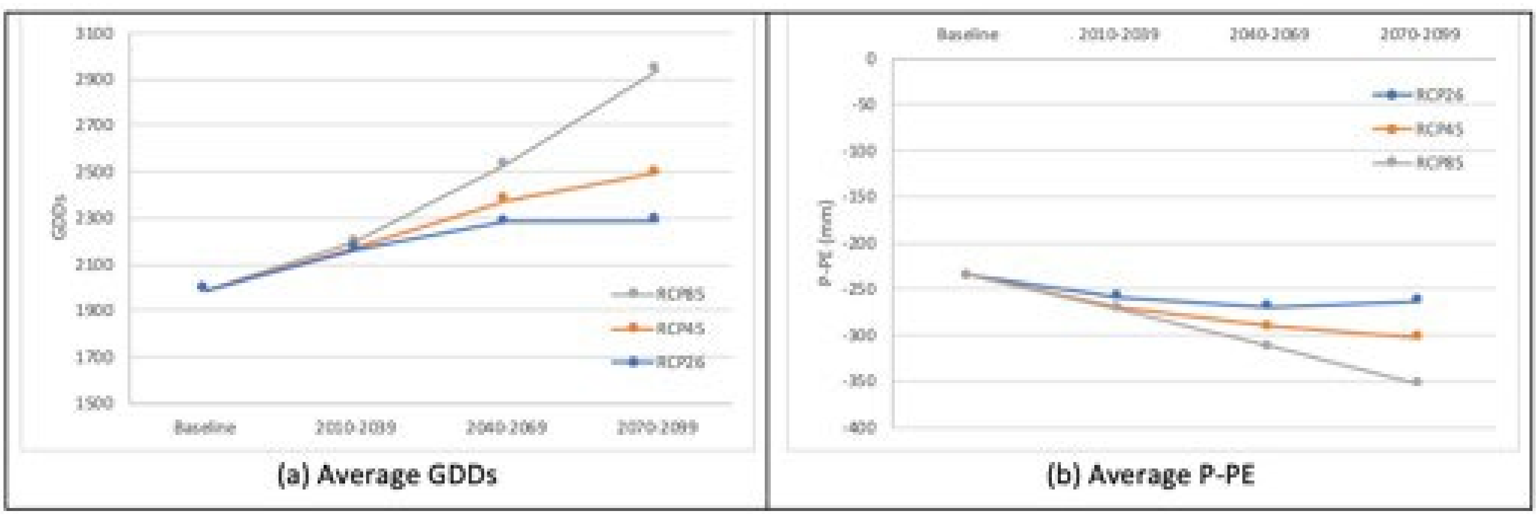

Figure 13. Average GDDs and average P-PE (for 425 soil polygons) in each future climate projection

Both mineral soil ratings and organic soil ratings for the brome model are the same as the those for small grain model, while for the alfalfa model, the organic soil rating assessment remains the same as the small grain model's assessment, but the mineral soil rating assessment changes (Agriculture and Agri-Food Canada, 2017). The adjustment made were the surface soil reaction (pH) and subsurface soil reaction (pH). Both mineral soil rating and organic soil rating contain climate parameter P-PE. The soil ratings could be negatively affected by climate change with lower P-PE. However, due to the lack of information, the completed soil assessment is not included in this project report. The soil moisture requirement assessments of alfalfa and brome are the same, which is one of the soil factors' components that contains P-PE. The lower the P-PE, the lower the soil moisture ratings (see Table 5). Most Delta ALR are rated as soil moisture rating class 3 (without adjustment by subsurface texture and water table) under the RCP 8.5 scenario for the period 2070-2099 (see Appendix 3 to Appendix 7), which hints the final land suitability rating class would be lower than the climate rating class.

Table 5. Point deduction for combinations of available water holding capacity (surface texture or % clay plus silt) and climate factor A. [1] (Agronomic Interpretations Working Group, 1995)

Climate(A) P–PE	% clay + silt texture[2] mm/m[3]	 25	10 S 40	20 LS 60	40 SL 100	60 L 150	70 CL 170	75 SiL 180	80 C 190	85 SiCL 200	95 HC 225	95 SiC 225
0		40	15	0	0	0	0	0	0	0	0	0
–50		50	25	0	0	0	0	0	0	0	0	0
–100		60	35	10	0	0	0	0	0	0	0	0
–150		70	45	25	10	0	0	0	0	0	0	0
–200		80	55	40	20	10	10	10	10	10	10	10
–250		90	65	50	35	25	20	20	20	20	20	20
–300		95	75	60	50	40	30	30	30	30	30	30
–350		95	85	70	60	50	45	45	40	40	40	40
–400		95	90	80	70	60	55	55	50	50	50	50
–450		95	95	90	80	70	65	65	60	60	60	60
–500		95	95	95	90	80	75	75	70	70	70	70

[1]Use measured data for AWHC, if available.
[2]S = sand, L = loam, Si = silt, C = clay.
[3]mm available water per 1 m soil depth.

6. Conclusions and Recommendations

Overall, under the climate change scenarios (RCP 2.6, RCP 4.5, and RCP 8.5), the climate rating class improved for both legume and grass forages in the Agricultural Land Reserve of Delta, BC. The climate rating is the minimum value of heat rating, length of growing season rating, and moisture rating. The current limiting factor of climate rating for both legume and grass forages are GDDs, which shifts to P-PE in the future years of climate projections.

Almost all study areas (421 polygons, 219.47 km^2) have a landscape rating class 1, and in the models, the landscape rating is not affected by climate change. Mineral soil ratings and organic soil ratings contain climate parameters. Due to the lack of information, the completed assessment of soil requirements is not included. The study area in the ALR is based on capability classification, which means the soil in the ALR has a high capacity to support plant growth and could be assumed that it would not limit land suitability ratings. However, when facing climate change with dramatic P-PE decrease (i.e., scenario RCP 8.5, 2070-2099), soil ratings can become the shortboard of LSRS, which also shows the importance of complete land suitability assessment.

Land suitability assessment for single species can help with deciding whether certain land and certain species match. However, in the real world, agricultural land use planning usually requires deciding from multiple crops. Future studies can contribute to the land suitability assessment and mapping for other major crops and share the result in a database under certain standards so that the combined maps can be used to balance the multiple species for efficient land use management purposes.

7. References

Agriculture and Agri-Food Canada. (2017). *Alfalfa / Brome / Timothy model development*. Retrieved July 2020, from Land Suitability Rating System (LSRS): http://lsrs.landresources.ca/contents.html

Agronomic Interpretations Working Group. (1995). *Land suitability rating system for agricultural crops: 1. Spring-seeded small grains.* Ottawa: Centre for Land and Biological Resources Research, Agriculture and Agri-Food Canada.

Anilkumar, S. N., Chikkaramappa, T., Gopala, Y. M., Arunkumar, J. S., & Patel, G. M. (2019). Soil resource inventory, land capability and crop suitability assessment of Haradanahalli micro-watershed using remote sensing and GIS. *Acta Scientific Agriculture, 3*(2), 129-137.

Bock, M., Gasser, P.-T., Pettapiece, W. W., Brierley, A. J., Bootsma, A., Schut, P., . . . Smith, C. A. (2018). The land suitability rating system is a spatial planning tool to assess crop suitability in Canada. *Frontiers in Environmental Science, 6*(77).

Bootsma, A., & Boisvert, J. B. (1991). *Modelling methodology for estimating forage yield potential in Canada. Technical Bulletin 1991-6E.* Ottawa: Research Branch, Agriculture Canada. Retrieved from https://ia601901.us.archive.org/22/items/modellingmethodo19916boot/modellingmethodo19916boot.pdf

City of Delta. (2020). *Farming challenges*. Retrieved from http://www.delta.ca/environment-sustainability/agriculture/farming-challenges

Crawford, E., & MacNair, E. (2012). *Fraser Valley & Metro Vancouver.* The Britich Columbia Agriculture & Food Climate Action Initiative.

Environment Canada. (2019, December 4). *Canadian climate normals 1981-2010 station data*. Retrieved from https://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnName&txtStationName=delta&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=766&dispBack=0

Gasser, P. Y., Smith, C. A., Brierley, J. A., Schut, P. H., Neilsen, D., & Kenney, E. A. (2016). The use of the land suitability rating system to assess climate change impacts on corn production in the lower Fraser Valley of British Columbia. *Can. J. Soil Sci.*, 256-269.

Hughes-Games, G. (2018). *Agricultural land soil investigation.* Metro Vancouver, Agricultural Land Commission.

Kenk, E. (1983). *Land capability classification for agriculture in British Columbia.* Kelowna: Ministry of Environment, Ministry of Agriculture and Food.

McCartney, D., & Horton, P. R. (1997). *Canada's forage resources.* Retrieved from https://cariboo-agricultural-research.ca/documents/CARA_lib_McCartney_Horton_1997_Canadas_Forage_Resources.pdf

Metro Vancouver. (2017). *2016 Census of agriculture bulletin.* Retrieved from http://www.metrovancouver.org/services/regional-planning/PlanningPublications/2016CensusofAgricultureBulletin.pdf

Ministry of Agriculture. (2014). *Metro Vancouver regional district land use inventory.* Retrieved from https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/strengthening-farming/land-use-inventories/metrovanregional2010_11_aluireport.pdf

Moser, L. E., Buxton, D. R., & Casler, M. D. (1996). *Cool-season forage grasses. Agronomy series No. 34.* Wisconsin: Amer. Soc. of Agron. Madison.

Murdock, T. Q., & Spittlehouse, D. L. (2011). *Selecting and using climate change scenarios for British Columbia.* Victoria, BC: Pacific Climate Impacts Consortium, University of Victoria.

Wang, T., Hamann, A., Spittlehouse, D., & Carroll, C. (2016). Locally downscaled and spatially customizable climate data for historical and future periods for North America. *PLoS ONE, 11*(6), e0156720.

Zbeetnoff Agro-Environmental & Quadra Planning. (2011). *Delta agricultural plan phase 1: Delta agriculture profile.* Delta: The Corporation of Delta.

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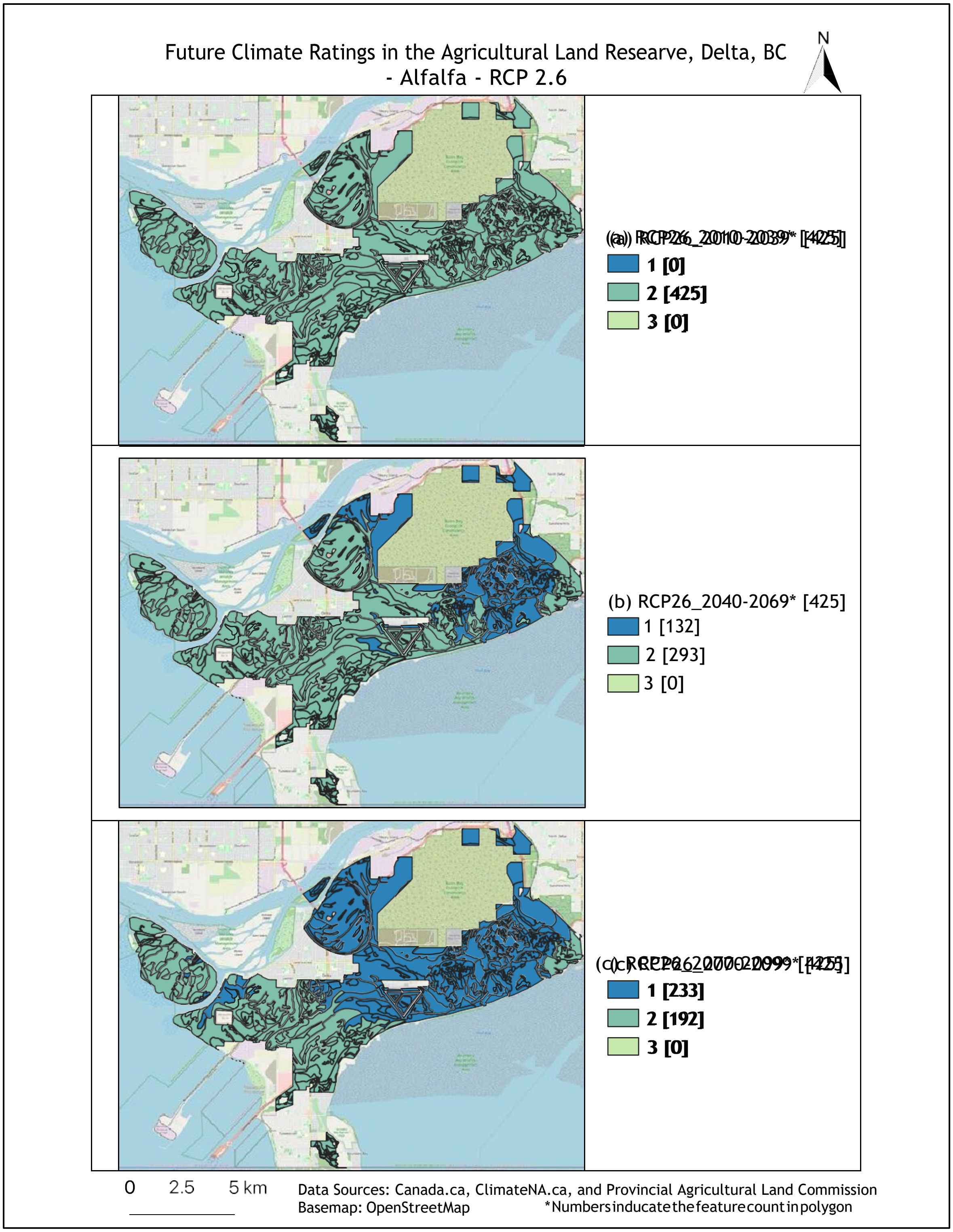
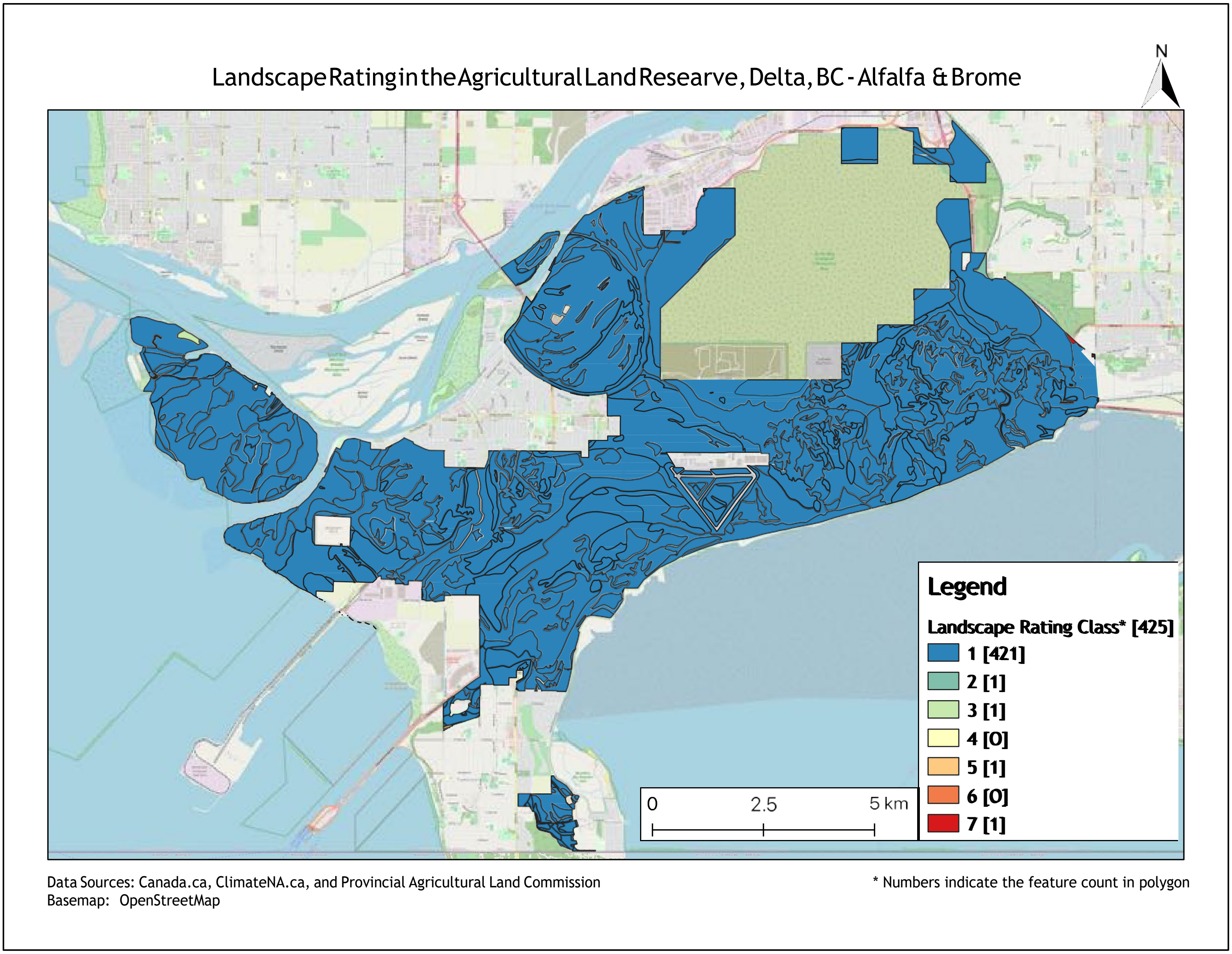
9. Appendices

Appendix 1. Future climate ratings' map of the alfalfa model: RCP 2.6



Appendix 2. Landscape ratings' map of the alfalfa model and brome model



Appendix 3. Soil moisture rating in area (km^2) for (a) baseline and RCP26, (b) baseline and RCP45, and (c) baseline and RCP85 (Note: the soil moisture ratings were not adjusted by subsurface texture and water table)

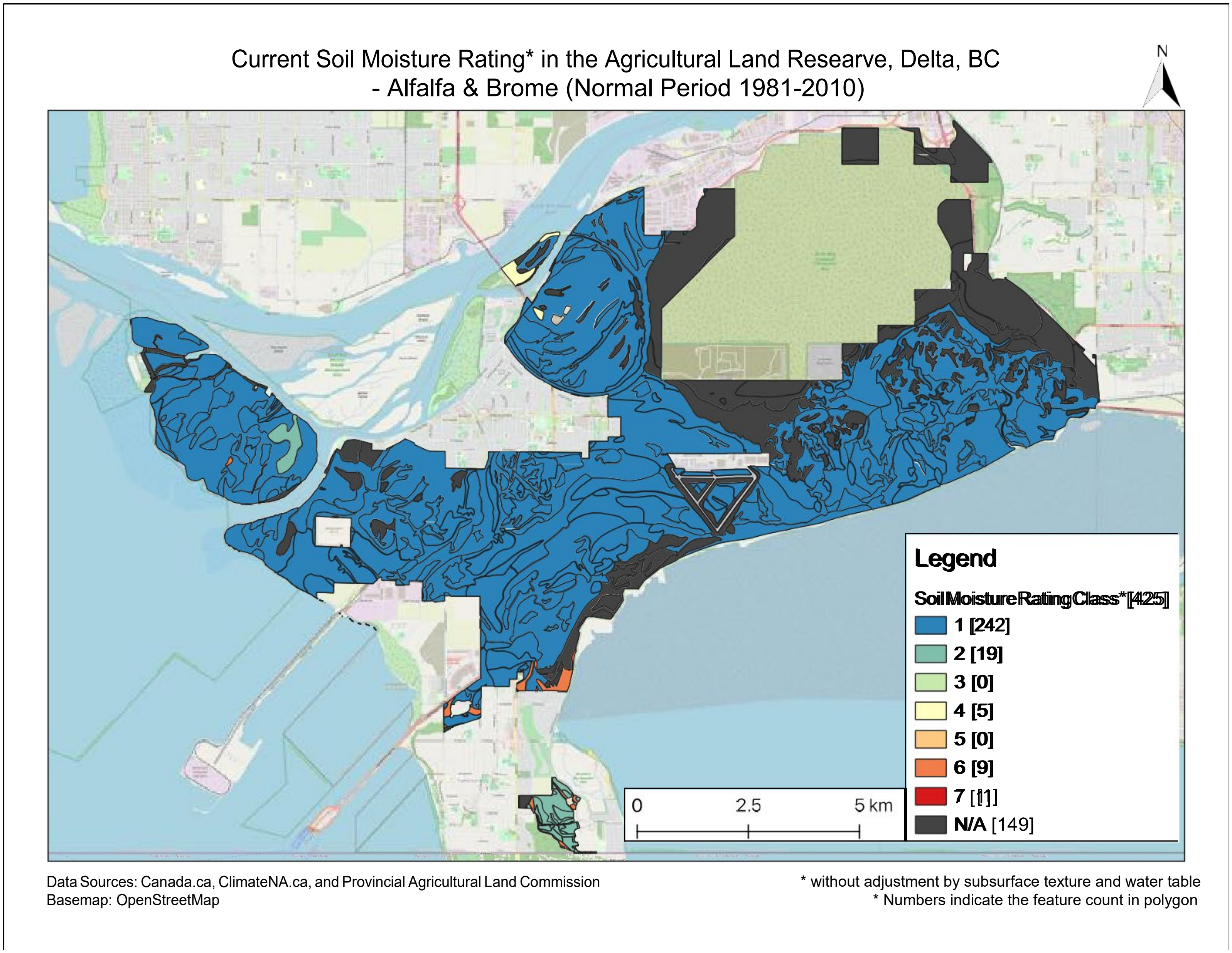
(a)	1981-2010	RCP26_2025	RCP26_2055	RCP26_2085
Class 1	165.49	45.61	0.00	20.08
Class 2	3.24	123.11	168.72	148.65
Class 3	0.00	0.00	0.00	0.00
Class 4	0.67	0.67	0.67	0.67
Class 5	0.00	0.00	0.00	0.00
Class 6	1.16	0.00	0.00	0.00
Class 7	0.01	1.18	1.18	1.18
N/A	49.34	49.34	49.34	49.34

(b)	1981-2010	RCP45_2025	RCP45_2055	RCP45_2085
Class 1	165.49	0.00	0.00	0.00
Class 2	3.24	168.72	168.70	168.70
Class 3	0.00	0.00	0.03	0.03
Class 4	0.67	0.67	0.00	0.00
Class 5	0.00	0.00	0.67	0.67
Class 6	1.16	0.00	0.00	0.00
Class 7	0.01	1.18	1.18	1.18
N/A	49.34	49.34	49.34	49.34

(c)	1981-2010	RCP85_2025	RCP85_2055	RCP85_2085
Class 1	165.49	0.00	0.00	0.00
Class 2	3.24	168.72	166.49	0.00
Class 3	0.00	0.00	2.23	168.72
Class 4	0.67	0.67	0.00	0.00
Class 5	0.00	0.00	0.67	0.00
Class 6	1.16	0.00	0.00	0.67
Class 7	0.01	1.18	1.18	1.18
N/A	49.34	49.34	49.34	49.34

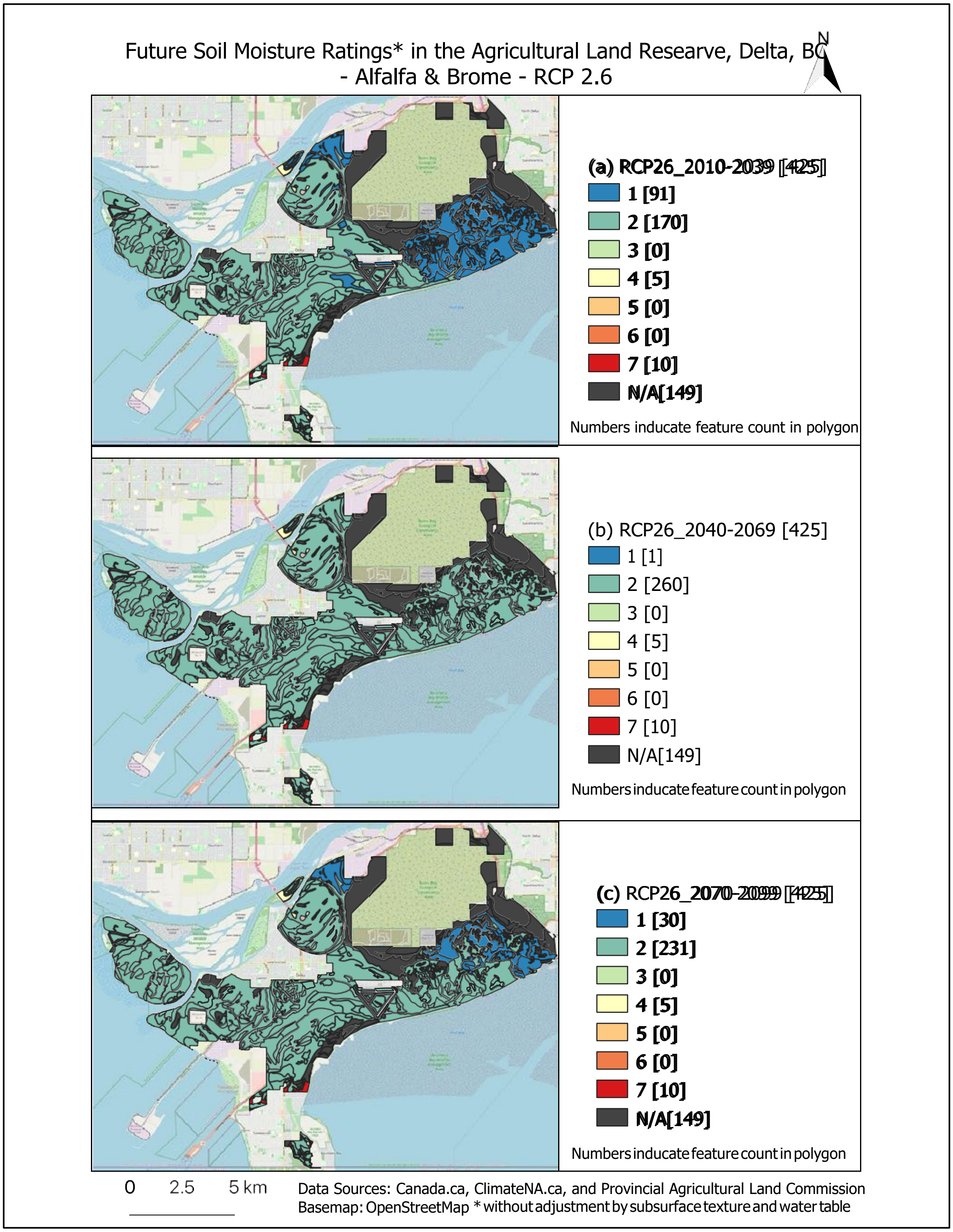
Appendix 4. Map of soil moisture rating class (1981-2010)*

**without adjustment by subsurface texture and water table*



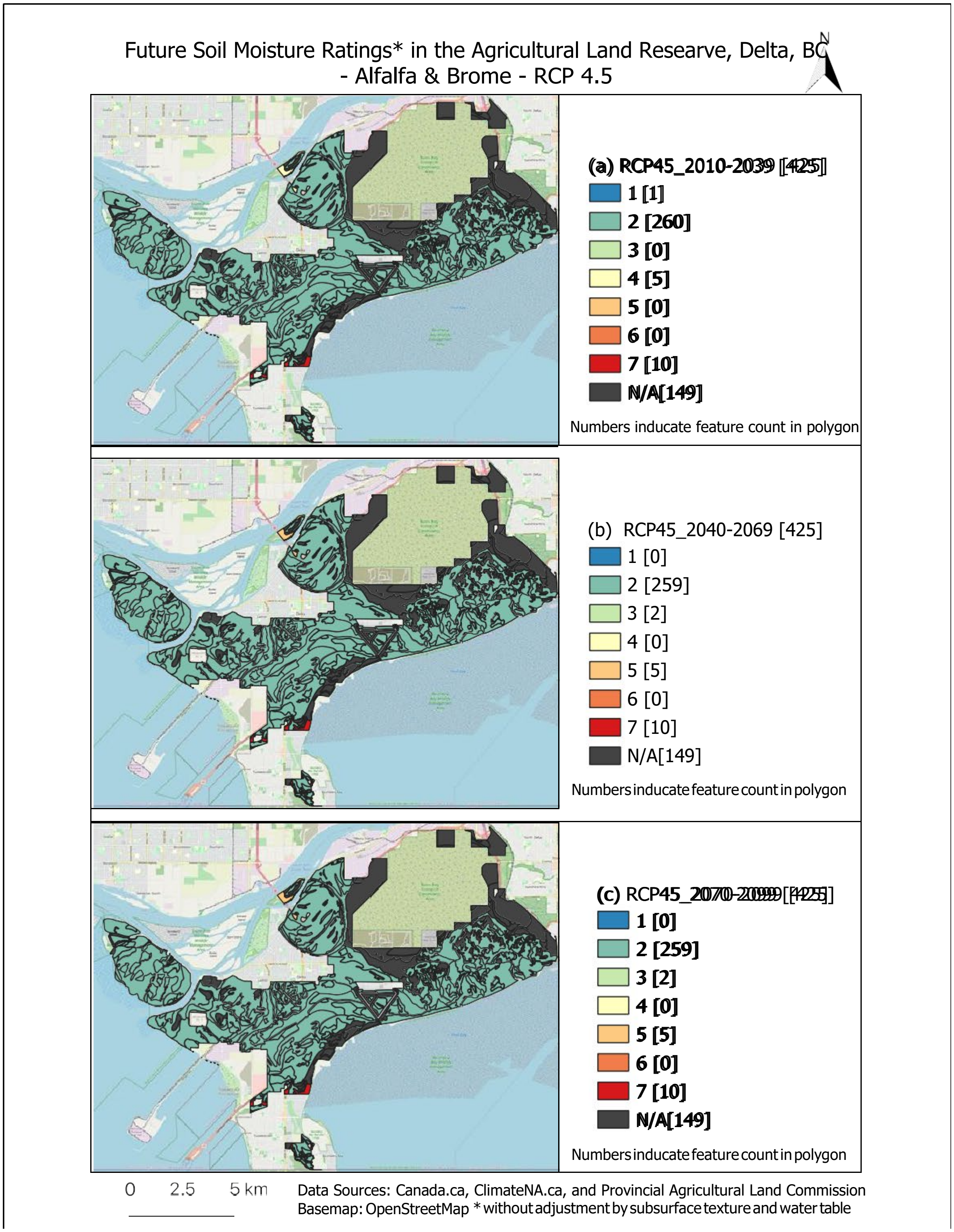
Appendix 5. Future soil moisture rating class (RCP 2.6)*

**without adjustment by subsurface texture and water table*



Appendix 6. Future soil moisture rating class (RCP 4.5)*

**without adjustment by subsurface texture and water table*



Appendix 7. Future soil moisture rating class (RCP 8.5)*

**without adjustment by subsurface texture and water table*