PROJECT: MONITORING FOREST AND RANGELANDS TO ANTICIPATE AND RESPOND TO CLIMATE CHANGE, PHASE 4
Part 2: Applying Abiotic Indicators to the South Selkirks Study Area

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Background

This project is a collaborative effort between the Ministry of Forests and Range and the University of British Columbia's Department of Forest Resources Management. Phases 1 and 2 were conducted during 2008/09 by John Innes and Margie Eddington; Phases 3 and 4 are underway.

Phases 1 and 2 resulted in a selection of recommended indicators for monitoring for natural resource management in BC in light of climate change, along with a list of potential data sources and suppliers that could support analyses of those indicators. Phases 3 and 4 of the project, funded by the Future Forest Ecosystems Council during late 2009 and early 2010, built on work conducted through phases 1 and 2 to develop a more consolidated monitoring and reporting framework. The first key activity of phase 3 was to more fully identify the framework's target audience and their key information needs and management questions in light of climate change. As well, during this activity, researchers sought to identify and examine pathways and media that may be used for making information generated from the framework available to the target audience. This first activity of phase 3 was accomplished by surveying about 550 forest and range mangers operating in the province (Eddington and Innes 2008).

During phases 3 and 4, work also began on individual indicators to better determine the extent to which current monitoring and inventory programs are able to support their analysis. This is being done by refining and further developing technical approaches to measuring the indicators and evaluating the extent to which those approaches could be supported using existing data collections and inventory processes available in the Province. This included examining factors such as the number and distribution of permanent sample sites and the extent of the data collections available. For phase 3 and 4, indicators were divided into two groups (ones addressed during phase 3 and those left for phase 4) depending on when they received funding. Table 1 lists the indicators and phase of work under which they are included.

Table 1: Indicator work phase

INDICATOR	***WORK PHASE***
Criterion 1 – ecosystem drivers	
Temperature	Phase 4
Precipitation	Phase 4
Snowpack	Phase 4
Streamflow	Phase 4
Water temperature	Phase 4
Water quality	Phase 4
Unseasonable or unexpected weather conditions	Phase 4
Criterion 2 - Natural Disturbances	
Insects and diseases	Phase 3
Wind throw	Phase 4
Fire	Phase 3
Mass movements	Phase 4
Criterion 3 - Biodiversity	
Ecosystem distribution and composition	Phase 3
Ecosystem productivity	Phase 3
Species diversity	Phase 3
Genetic diversity	Phase 4
Ecosystem connectivity	Phase 3

Work on the Phase 4 indicators began in earnest in late spring of 2011 and will be completed in early 2012. Phase 4 indicators focus on abiotic processes (such as temperature, snowmelt, precipitation, streamflow and wind) rather than the more biological indicators of phase 3 (e.g., ecosystem composition, ecosystem productivity, insects and disease). (The split was not purely along abiotic/biotic lines as fire was considered during phase 3 and genetic diversity is considered under phase 4).

In a companion report (Kremsater and Innes 2012), we explore approaches for measuring Phase 4 indicators, and assess the ability of current monitoring programs to support their evaluation province-wide. This report attempts to apply those indicators to the South Selkirks area. Margie Eddington is completing a similar pilot for the phase 3 indicators -- gathering and synthesizing data for the South Selkirks area.

Priorities for Phase 4 indicators
Abiotic indicators of climate change such as temperature, precipitation, snowpack (including extents of glaciers), streamflow, water temperature, water quality, and unexpected weather conditions were identified by the survey during phase 3 as high priority indicators. Of lower priority were mass wasting, windthrow and genetic diversity.

Criterion 1: Ecosystem Drivers

1. Temperature and Precipitation

Rationale: Temperatures are expected to warm, with BC becoming less cool (minimum temperatures are expected to rise more than maximums). Precipitation is predicted to shift to warmer, wetter years, more frequent wet years, greater year-to-year variability, and more extreme precipitation events. More precipitation is expected to fall as rain and less as snow. In some areas of the Province, summer droughts are expected to increase even though annual precipitation may increase. Such changes will almost certainly have significant effects on forest and rangeland ecosystems and monitoring these changes will be important to inform management.

Applying data to the South Selkirks: For the South Selkirks area, as for the Province as a whole, the main source of temperature and precipitation data useful for broad tracking of climate change is Environment Canada. Other sources are BC Hydro and Province of BC data bases. Fortunately, Pacific Climate Impacts Consortium (PCIC) has undertaken projects to synthesize and analyse the available data. Rodenhuis et al. (2009) updated PCIC's work of 2007 to report on several climate variables, looking at both past trends and future projections. The information on past trends includes information on temperature and precipitation (annual means, maximums, and minimums; seasonal (summer, fall, winter, spring) maximums, minimums; and seasonal trends). Values can be pulled off their figures for any area of BC. Results are based on 1900 to 2004 data and calculated as degree Celsius change per century. They indicate statistically significant values. Rodenhuis et al. (2009) also examine affects of ENSO and PDO cycles and note those have had a pronounced influence on seasonal temperature and precipitation in BC, especially during winter and spring seasons[1].

PCIC intends to repeat the analyses as new data are added. As well, PCIC (Faron Anslow, pers. comm.) is working to provide temperature and precipitation data through a publically available, user-friendly interface. The intention is that by sometime during 2012, users will be able to select the types of data they wish reported (e.g., temperature minimums, means, precipitation maximums, etc.) and select an area of the Province of interest. Data will be automatically summarized and reported for the variables in the area selected.

PCIC graphs indicator that historically, from 1900 to 2004, minimum annual temperatures rose more than maximums (Figure 1):

- annual minimum temperatures in the South Selkirks rose at 1.5 to 2 ^{o}C per 100 years

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[1] The impact of ENSO on climate in Canada is well-documented, but much less is understood about the PDO, which was identified in the mid-1990s. Therefore, the question remains whether the range and scale of effects observed in instrumental records is representative. It appears that these impacts have occurred for much longer than the instrumental records can demonstrate. BC's record likely shows only a part of the potential range of climate variability.

- annual mean temperatures over most of the South Selkirks rose at 1.5 to 2 °C per 100 years, but some areas were less at 1 to 1.5 °C per 100 years.
- annual maximum temperatures in the South Selkirks rose at 1 to 1.5 °C per 100 years

Figures

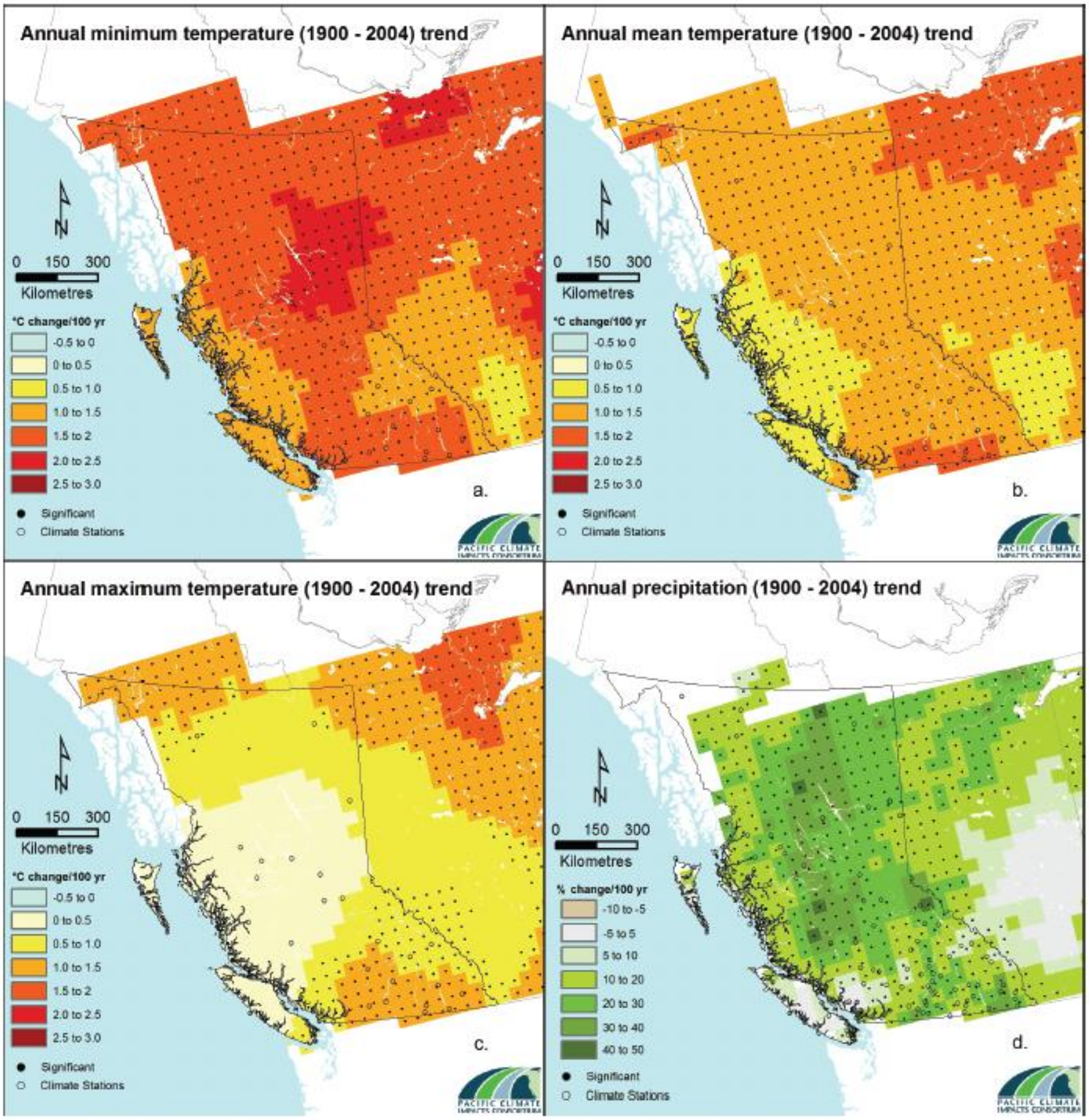

Figure 1. Annual trends in (a) minimum, (b) mean, (c) maximum temperature and (d) precipitation for British Columbia. Results are based on 1900 to 2004 data and calculated as degree Celsius change per century. Black solid circles indicate statistically significant results (95% confidence level). Open circles show the location of Adjusted Historical Canadian Climate Station sites (AHCCD). Source: Rodehuis et al. 2009.

When seasonal patterns are considered it is evident that in both winter and summer in the South Selkirks, minimums rose more than maximums, and winter temperatures increased more than those in summer (Figure 2).

- Winter minimum temperatures rose 3 to 4 ^{o}C per 100 years; while maximums rose 1.5 to 2 ^{o}C per 100 years
- Summer minimum temperatures rose 1.5 to 2.5 ^{o}C per 100 years; while maximums rose 0.5 to 1.5 ^{o}C per 100 years

The shoulder seasons experienced less change in winter, but maximum temperatures during fall rose considerably.

- Spring minimum temperatures rose 1 to 2 ^{o}C per 100 years; while maximums rose 1 to 1.5 ^{o}C per 100 years
- Fall minimum temperatures rose 0.5 to 1 ^{o}C per 100 years; while maximums rose 1.5 to 2.5 ^{o}C per 100 years

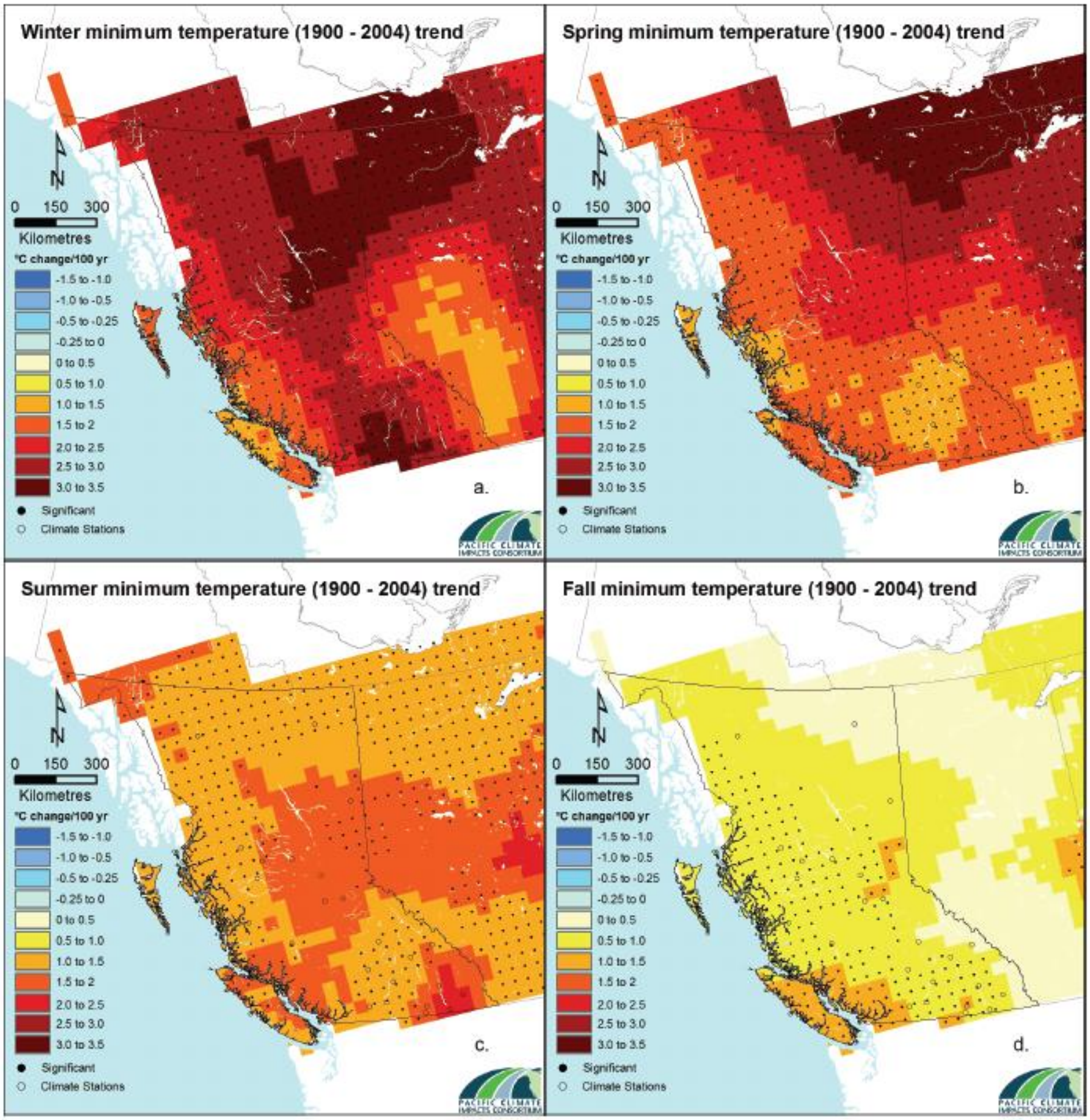

Figure 2. Seasonal trends in minimum temperature (a) winter, (b) spring, (c) summer and (d) fall for British Columbia. Results are based on 1900 to 2004 data and calculated as degree Celsius change per century. Black solid circles indicate statistically significant results (95% confidence level). Open circles show the location of Adjusted Historical Canadian Climate Station sites (AHCCD). Source: Rodenhuis et al. 2009.

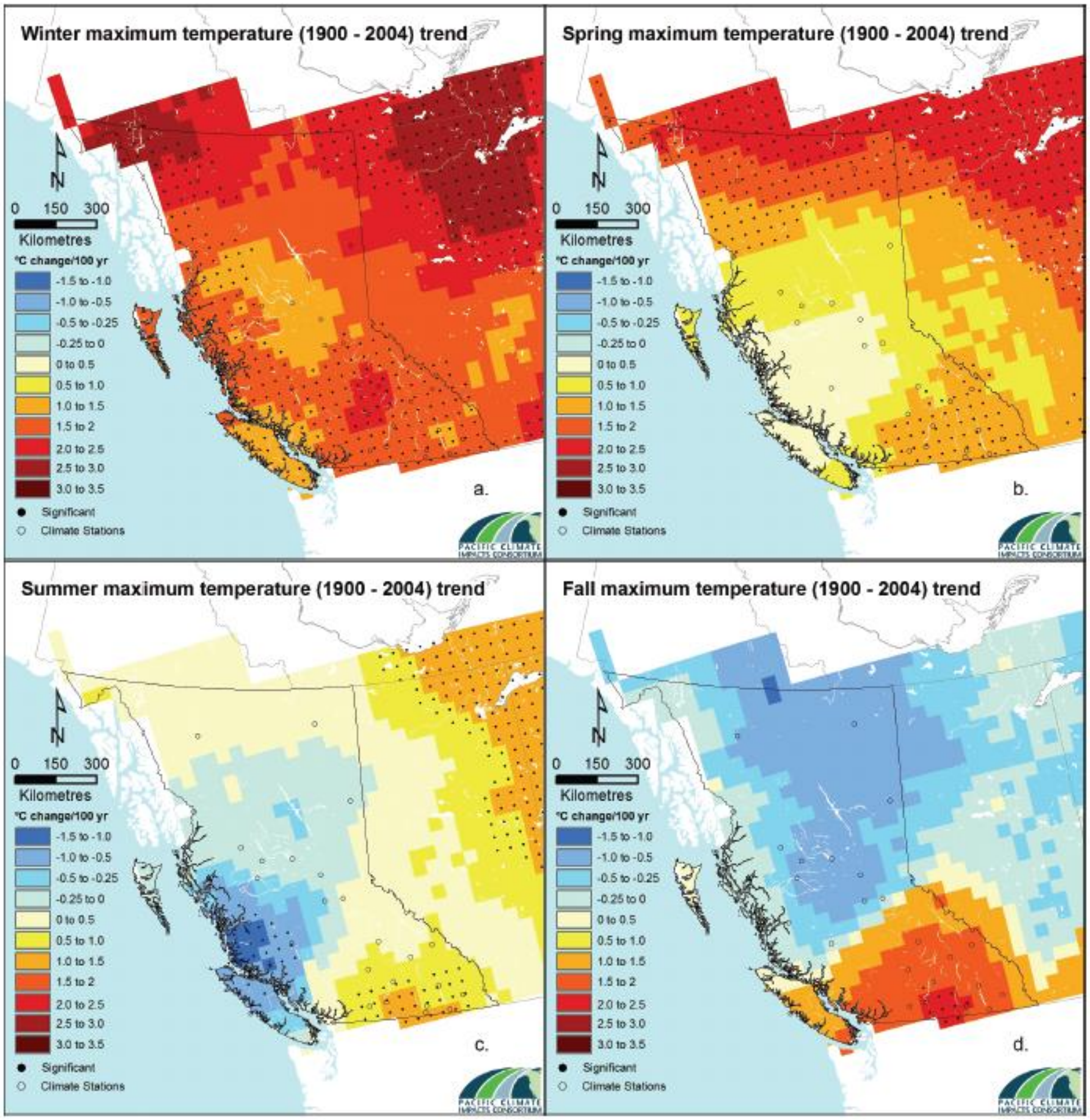

Figure 3. Seasonal trends in maximum temperature (a) winter, (b) spring, (c) summer and (d) fall for British Columbia. Results are based on 1900 to 2004 data and calculated as degree Celsius change per century. Black solid circles indicate statistically significant results (95% confidence level). Open circles show the location of Adjusted Historical Canadian Climate Station sites (AHCCD). Source: Rodenhuis et al. 2009.

Trends in precipitation can similarly be read off the PCIC summary graphs. During 1900 to 2004 for the South Selkirks area, summer precipitation increased more than the other seasons (Figure 4):

- Winter precipitation increased 10 to 20 percent.
- Spring precipitation increased 10 to 30 percent.
- Summer precipitation increased 20 to 40 percent.

- Fall precipitation increased 5 to 10 percent in most areas and 10 to 20 percent over other parts of the study area.

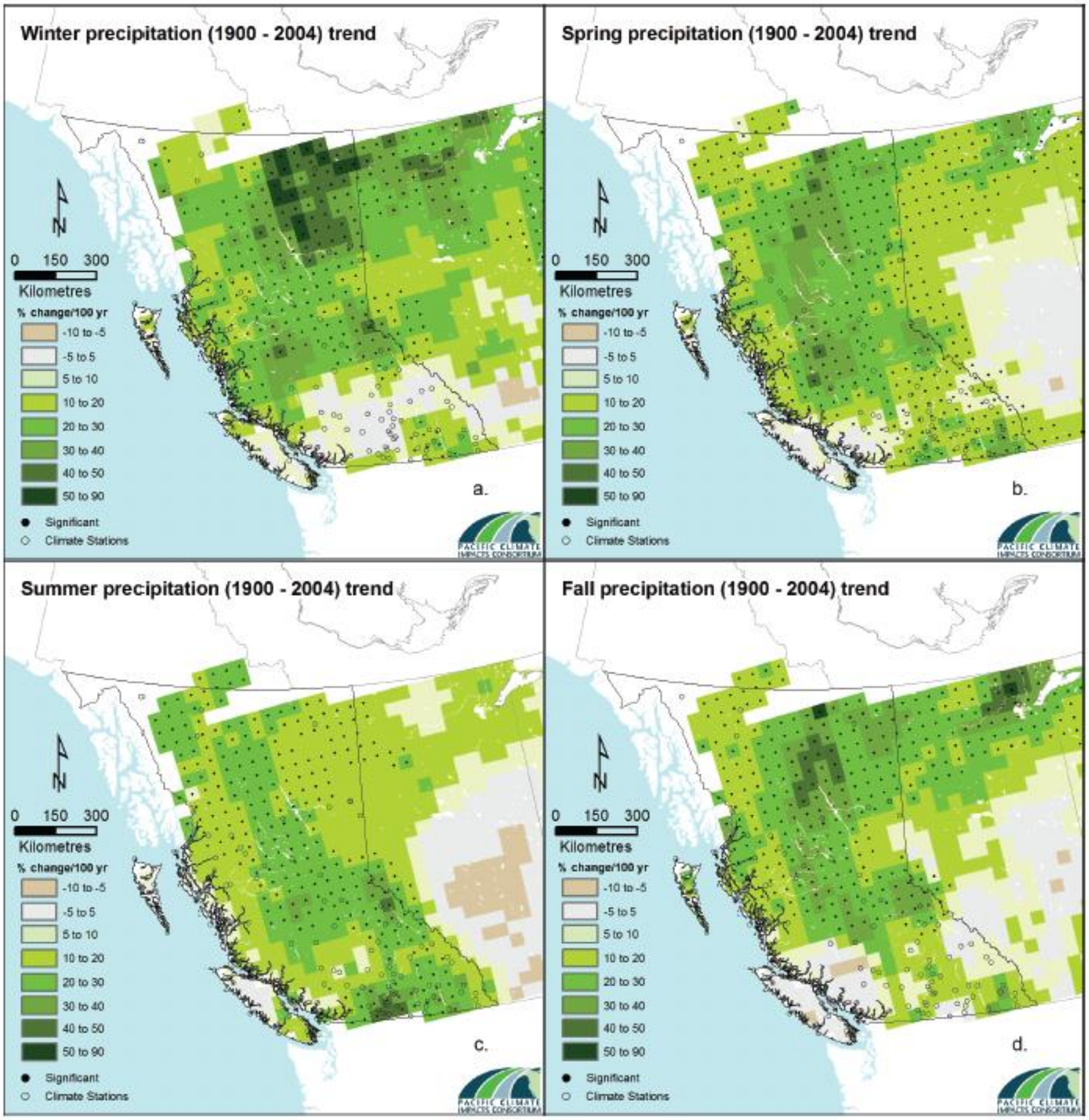

Figure 4. Seasonal trends in precipitation (a) winter, (b) spring, (c) summer and (d) fall for British Columbia. Results are based on 1900 to 2004 data and calculated as degree Celsius change per century. Black solid circles indicate statistically significant results (95% confidence level). Open circles show the location of Adjusted Historical Canadian Climate Station sites (AHCCD). Source: Rodenhuis et al. 2009.

Spatial responses in precipitation patterns in BC are strongly affected by topography and distance from the coast, therefore precipitation responses are mixed across the Province. Hence, valleys and mountain ranges influenced the response and created the pattern observed.

During El Niño winters, the Province is generally drier, with the exception of northern Vancouver Island, Haida Gwaii and parts of the south coast, which display an opposite (wet) signal (Figure 5). The south Selkirks area does not show a significant response to El Nino (during winter or spring). Most of the Province is wetter during La Niña winters (Figure 5), including the South Selkirks. During spring, La Niña causes drier conditions in the South Selkirks area. Warm (cool) PDO conditions during winter generally exhibit the same pattern as El Niño (La Niña) winter but signals are weaker (Figure 6). During spring, the PDO warm (cool) precipitation response is strong and wide spread over the Province (Figure 6). The interaction of PDO and ENSO can amplify responses in a particular region. For example, results from southwestern BC illustrate that in-phase La Niña/cool PDO precipitation is +19% to +25% higher than during non-ENSO and out-of-phase (PDO) years, and +39% greater than during in-phase El Niño/warm PDO years. During these in-phase periods, ENSO and PDO reinforce each other and hence there may also be increased likelihood of extreme weather events.

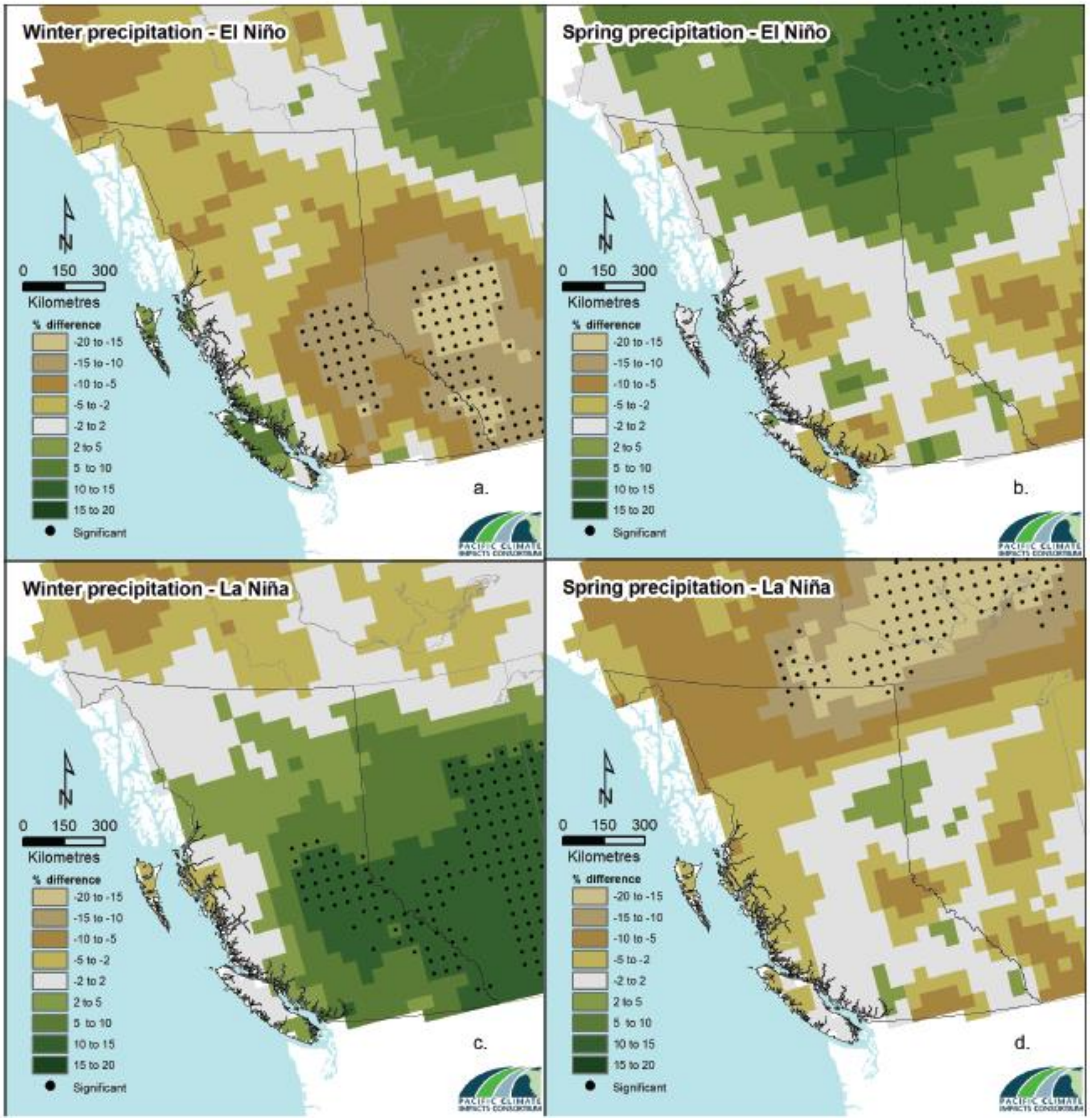

Figure 5. Seasonal climate variability for precipitation (a) El Niño winter, (b) El Niño spring, (c) La Niña winter and (d) La Niña spring for British Columbia. Results are based on 1900 to 2007 (ENSO) and calculated as a difference from the long-term average, percent of the 1961 – 1990 climatology. Source: Rodenhuis et al. 2009.

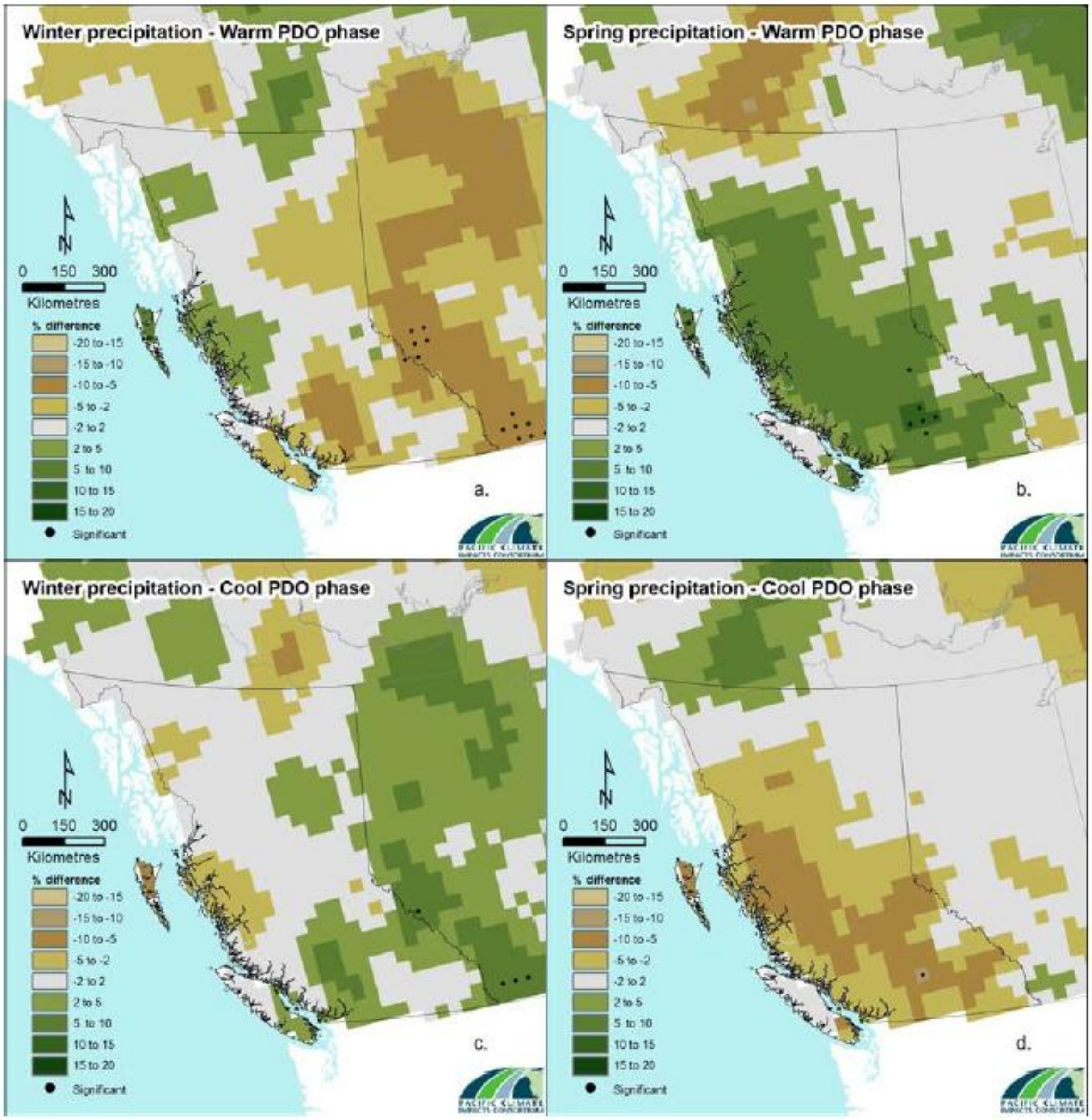

Figure 6. Seasonal climate variability for precipitation (a) warm PDO phase winter, (b) warm PDO phase spring, (c) cool PDO phase winter and (d) cool PDO phase spring for British Columbia. Results are based on 1900 to 1998 (PDO) and calculated as a difference from the long-term average, percent of the 1961 – 1990 climatology. Source: Rodenhuis et al. 2009.

2. Snowpack

Rationale: Snowmelt runoff contributes 50 to 80% of the total water flow in nival basins (those dominated by snowmelt) and thus is an important hydrologic variable for recharge and sustenance of baseflow conditions. Snow accumulation and its characteristics are the result of air temperature, precipitation, storm frequency, wind, moisture in the atmosphere, and PDO and ENSO cycles. Changes in these and other climate properties will therefore affect snowpack. Reduced snowpack is anticipated as climate changes and the snowline in mountainous areas is forecast to rise in elevation. Changes in the timing of accumulation and loss of snowpack are uncertain but could have considerable effects on forest ecosystem processes.

Applying data to the South Selkirks: Rodenhius et al. (2009) summarize snowpack data. Their analysis extends previous efforts to examine a comprehensive snowpack dataset from northern and southern BC, updates trend analysis on snowpack to 2007, and highlights historical variability in snowpack over the past century. They estimated trends in snow water equivalent (SWE, % difference) from the long-term average, relative to the initial trend condition at the first year of record over specific periods: (a) 1951-2007, (b)1961-1990, and (c) 1978-2007. Their figures show magnitude, direction and statistical significance of the changes. They also show affects of ENSO and PDO cycles on snowpack. They use data from the River Forecast Centre and Zhang et al. (2001), which includes data of BC Hydro and Alcan. For most purposes this analyses will be the best available, especially if the summaries are repeated regularly as planned (contingent on funding). Just as for temperature and precipitation data, PCIC plans to add snow data to its publically available, user-friendly data web site. Accessibility to Information on snow will be developed after the temperature and precipitation data interfaces are developed (Faron Anslow, pers. comm.)

Rodenhuis et al. (2009) reported losses of April 1st snowpack of -25% on average at BC sites and as much as -50% at a few sites over the past 50 years. For shorter record lengths, however, the variability was large and not homogeneous across the Province. In addition, ENSO influenced snowpack by -12% to +21%. The geographical complexity of snowpack in BC prevents a simple interpretation of results.

For the South Selkirks area, negative trends in snowpack are evident when considering 1951 to 2007 or the 1961 to 1990 period. However, trends from 1978 to 2007 tend to be positive (5 to 40%). In the South Selkirks, El Nino years reduced April 1 snowpack by 5 to 50% and La Nina years increased snowpack from 5 to 50% depending on the location. Similarly, warm PDOs reduced April snowpack whereas cool ones increased it. As a cautionary note, a large proportion of the April 1st values can be indicative of the timing of melt rather than the accumulation of winter snowpack.

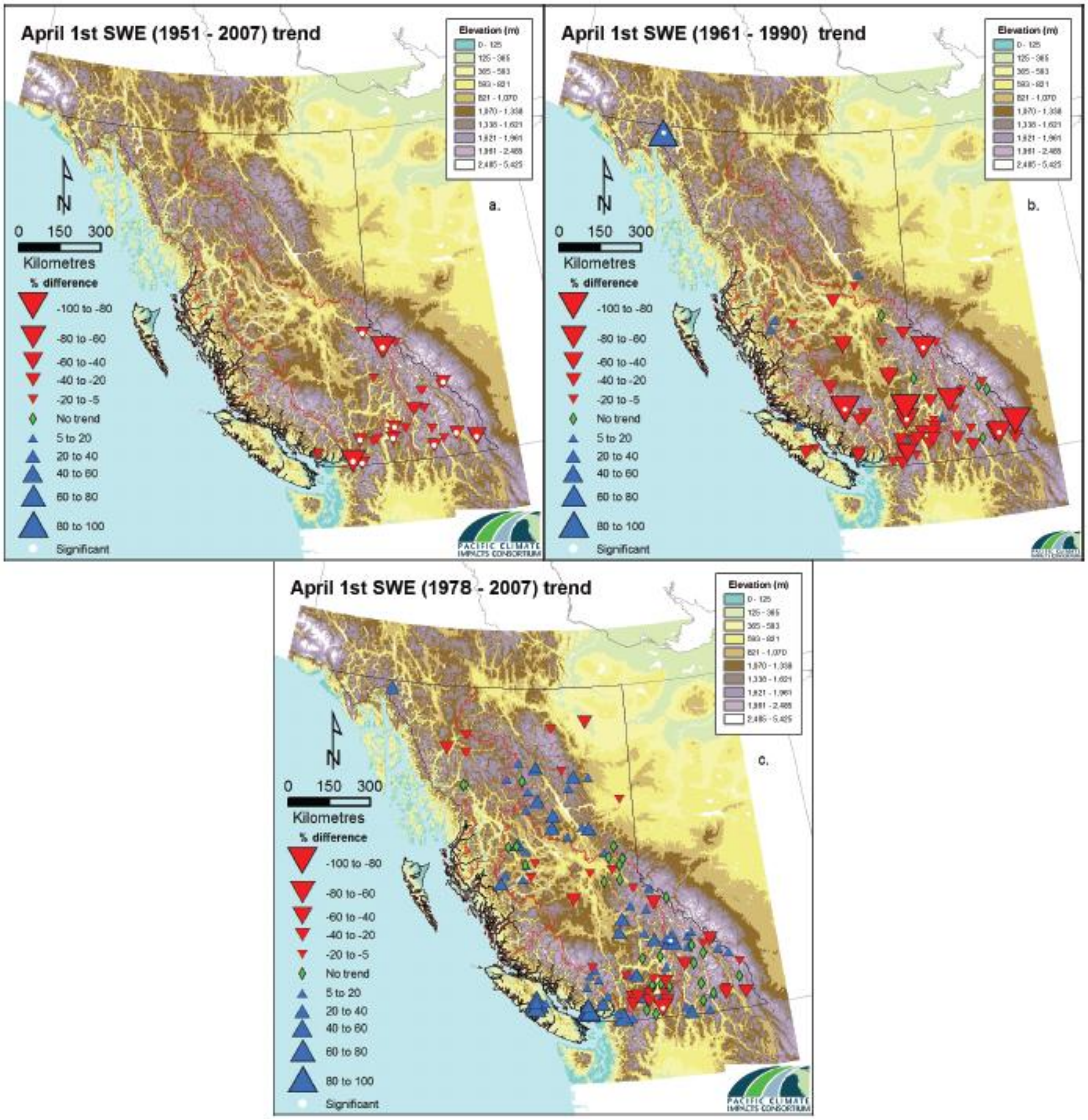

Figure 7. Estimated trends in snow water equivalent (SWE % difference from the long-term average, relative to the initial trend condition at the first year of record over the specific periods: (a) 1951-2007, (b)1961-1990, and (c) 1978-2007. Downward (red) triangles indicate decreasing trend, upward (blue) triangles indicate increasing trend. Green diamonds indicate no change. Triangles are sized according to trend magnitude. White dots show significance (95% of greater). Elevation (m) for BC is illustrated by the colour ramp in the upper right corner of the map. (RFC-BC, 2007 data; Zhang et al. 2000. Source: Rodenhuis et al. 2009).

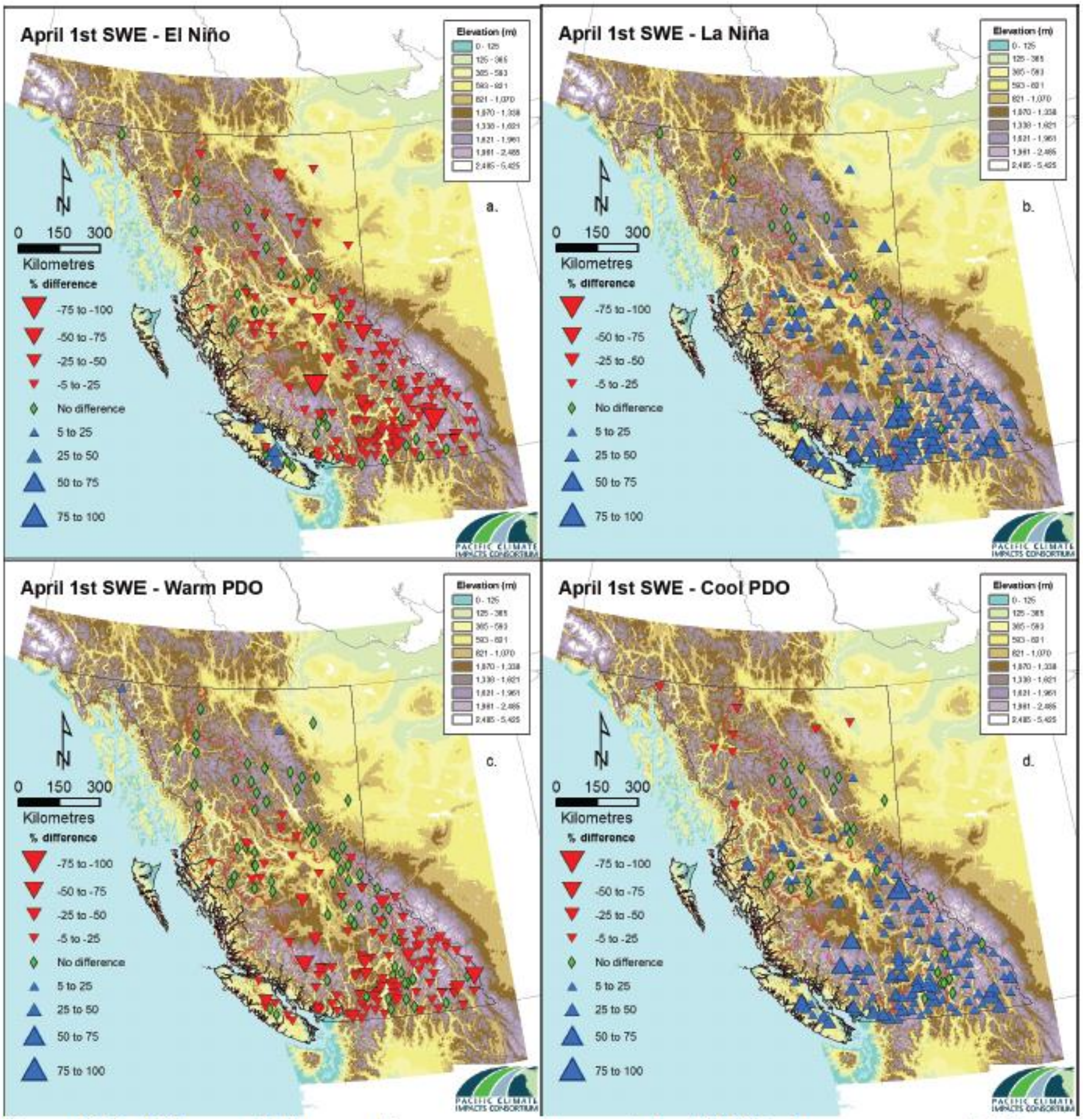

Figure 8. Influence of teleconnections on snow water equivalent (SWE), shown as a percent difference from the long-term average for ENSO (1940-2005) and PDO (1940-2005). Results are shown for (a) El Niño, (b) La Niña, (c) warm PDO phase and (d) cool PDO phase for British Columbia. Downward (red) triangles indicate decreasing influence, upward (blue) triangles indicate increasing influence. Green diamonds indicate no change. Triangles are sized according to magnitude of difference. Elevation (m) for BC is illustrated by the colour ramp in the upper right corner of the map. (RFC-BC data; Zhang et al. 2000. Source: Rodenhuis et al. 2009).

3. Glaciers

Rationale: Glaciers are an important water resource in BC, covering an area of 30,000 km2 and 48% of BC's gauged systems. Glacier-melt moderates inter-annual variability in streamflow and helps to maintain higher runoff volume in times of extreme warm and dry conditions. Glacier-melt also supports ecosystem functions by maintaining cooler water temperatures. Glacier retreat may cause changes in the flow patterns and temperature of some forest and rangeland streams and rivers. These changes, along with other climate-driven changes to hydrological systems, are likely to have significant impacts on freshwater and estuarine ecosystems and aquatic species. As glaciers begin to melt they often discharge more water into streams and rivers than before the glacier melt phase, potentially increasing stream turbidity and damaging fish habitat and riparian areas. Dan Moore (pers. comm.) indicates most of BC's glaciers (except for those in the extreme northwest of the Province) are already past this stage and in sufficient negative mass balance that glacier retreat now corresponds with reduced water volume in glacier-fed streams and rivers, especially during the summer months, potentially exacerbating changes in streamflow and temperature. Similarly, Rodenhuis et al. (2009) indicated that glaciated basins in BC showed a statistically significant *decrease* in August streamflow from 1976 to 19961. Since decreases in streamflow resulting from changes in glacier contributions are usually preceded by *increased* streamflow, current glacier conditions appear to be in an advanced state of change. Rodenhuis et al.'s (2009) review also includes other Information which indicates the retreat of glaciers is not a phenomenon that has just recently begun; rather, most glaciers have been in retreat since the late1800s, since the last cool period. Even within this general warming trend, some periods of expansion have occurred during cool phase of PDO cycles. These observations indicate a melting trend in BC's glaciers has occurred over many centuries but is exacerbated by recent trends in climate change.

Applying data to the South Selkirks: No individual glaciers in the South Selkirks have been monitored over time for volume changes. The work on glaciers most applicable to the South Slekirks is that completed by the former Canadian Cryospheric Information Network (CCIN) and continued by its members after the dissolution of the network. The study on area change of glaciers by Bolch et al. (2010) includes all of BC (and Alberta). They used semi-automated methods to extract glacier extents from Landsat Thematic Mapper (TM) scenes for 2005 and 2000 using a band ratio. They compared these extents with glacier cover for the mid-1980s from high-altitude, aerial photography for British Columbia and from Landsat TM imagery for Alberta. A 25 m digital elevation model helped to identify debris-covered ice and to split the glaciers into their respective drainage basins. Glaciers in British Columbia and Alberta respectively lost −10.8±3.8% and −25.4%±4.1% of their area over the period 1985– 2005. The region-wide annual shrinkage rate of −0.55% per year is comparable to rates reported for other mountain ranges in the late twentieth century. Least glacierized mountain ranges with smaller glaciers lost the largest fraction of ice cover: the highest relative ice loss in British Columbia (−24.0±4.6%) occurred in the northern Interior Ranges, while glaciers in the northern Coast Mountains declined least (−7.7±3.4%).

Bolch et al (2010) divided the province into regions, so results can be looked for regions of interest. For the South Selkirks, data from both the Southern Interior and Southern Rocky Mountain regions are applicable. The Southern Interior lost an average of 15.2% of area from 1985 to 2005 while the Southern Rockies lost 14.6% during that period. Annually, that equates to -0.72 % loss per year for the Southern Interior, and 0.67% loss per year for the Southern Rockies. Figure 9 below indicates that loss varied across glacier size classes, with most loss coming from smaller glaciers. The yellow bars in the figure reflect Southern Interior values and the red bars the Southern Rockies. While large glaciers in these areas lost in the range of 10 to 20% of their area, smaller glaciers lost 20 to 40% with losses in the Southern Rockies often removing whole glaciers.

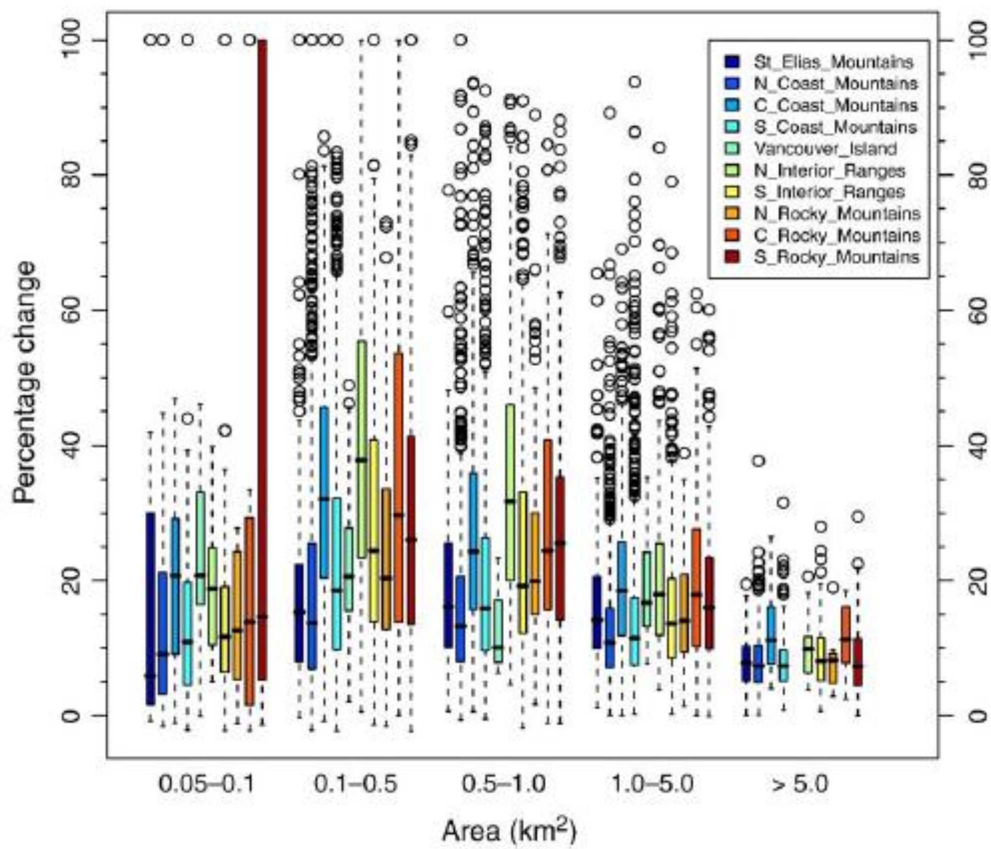

Figure 9. Glacier area loss 1985–2005 for different size classes (size in 1985) in the different regions. Middle of box is median and box width defined by interquartile range (25 and 75 percentiles). Whiskers are 5 and 95 percentiles. Symbols are <5 or >95 percentiles (source Bolch et al. 2010). The yellow bars in the figure reflect Southern Interior values and the red bars the Southern Rockies.

Table 2. Glacier area and area changes, 1985-2005 for the inventory of Western Canada (source Bolch et al. 2010).

Region	Area 1985 [km²]	Area 2000 [km²]	Area 2005 [km²]	Number of Glaciers (85)	Number of Glaciers (05)	Mean size (85) [km²]	Area change 85-05 [km²]	Annual change 85-05 [km² a⁻¹]	Area change 85-05 [%]	Area change 85-00 [%]	Area change 00-05[%]	Annual rate 85-05 [% a⁻¹]	Annual rate 85-00 [%a⁻¹]	Annual rate 00-05 [%a⁻¹]
SE	3615.6 (87)	No data	3330.4 (04)	510	647	7.01	−285.2 ± 122.6	−15.9 ± 6.8	−7.9 ± 3.4	No data	No data	−0.44 ± .0.19	No data	No data
NC	10,863.2 (83)	3983.0 (99)	10,029.1 (05)	3131	3746	3.47	−834.1 ± 367.0	−37.9 ± 16.7	−7.7 ± 3.4	−4.4 ± 4.1	−3.1 ± 4.1	−0.35 ± 0.15	−0.27 ± 0.25	−0.44 ± 0.58
2000 cv.	4164.2 (83)		3855.0 (05)				−309.2 ± 133.0		−7.4 ± 3.4			−0.34 ± 0.15		
CC	2077.9 (87)	No data	1625.0 (05)	2293	2962	0.91	−452.9 ± 101.9	−25.2 ± 4.8	−21.8 ± 4.9	No data	No data	−1.21 ± 0.27	No data	No data
SC	7911.7 (87)	7409.4 (00)	7097.3 (04)	3620	4507	2.10	−814.4 ± 300.5	−47.9 ± 14.4	−10.3 ± 3.8	−6.3 ± 4.5	−3.9 ± 4.5	−0.61 ± 0.22	−0.49 ± 0.34	−0.79 ± 0.86
VI	18.2 (87)	No data	14.5 (05)	61	65	0.30	−3.4 ± 1.24	−0.20 ± 0.04	−20.0 ± 7.3	No data	No data	−1.11 ± 0.40	No data	No data
NI	696.9 (85)	No data	529.9 (05)	729	1083	0.96	−167.0 ± 31.7	−8.65 ± 1.12	−24.0 ± 4.6	No data	No data	−1.20 ± 0.23	No data	No data
SI	2252.6 (85)	2034.1 (01)	1910.4 (06)	1855	2304	1.21	−342.2 ± 98.9	−16.3 ± 3.1	−15.2 ± 4.4	−10.5 ± 5.1	−5.5 ± 5.3	−0.72 ± 0.21	−0.66 ± 0.32	−0.92 ± 0.89
NR	496.8 (86)	448.6 (01)	418.0 (06)	464	540	1.07	−78.8 ± 22.8	−3.94 ± 0.74	−15.9 ± 4.6	−9.7 ± 4.9	−6.2 ± 5.2	−0.79 ± 0.23	−0.69 ± 0.35	−1.03 ± 0.86
CR	509.1 (86)	No data	420.0 (06)	361	462	1.41	−89.1 ± 20.9	−4.46 ± 0.82	−17.5 ± 4.1	No data	No data	−0.88 ± 0.21	No data	No data
SR	1587.0 (84)	1447.7 (00)	1351.7 (06)	1089	1271	1.46	−235.3 ± 65.2	−10.70 ± 2.3	−14.8 ± 4.1	−7.5 ± 5.2	−7.2 ± 5.7	−0.67 ± 0.19	−0.47 ± 0.36	−1.21 ± 0.96
Whole Inventory	**30,063.0**		**26,728.3**	**14,329**	**17,595**	**2.10**	**−3335.8 ± 1141.9**	**−166.74 ± 48.1**	**−11.1 ± 3.8**	No data	No data	**−0.55 ± 0.19**	No data	No data
2000 cv.	16,389.8	15,322.8	14,615.2	n.c.	n.c.	2.10	−1774.6	88.73	−10.8 ± 3.5	−6.5 ± 4.5	−4.3 ± 4.6	−0.54 ± 0.17	−0.43 ± 0.30	−0.86 ± 0.88
BC only	28,232.8		25,218.2	13,403	16,428	2.11	−3056.0 ± 990.4	−152.8 ± 41.0	−10.8 ± 3.5	No data	No data	−0.54 ± 0.17	No data	No data
Alberta	1053.5		785.7	926	1167	1.14	−267.9 ± 43.2	−13.39 ± 1.8	−25.4 ± 4.1	No data	No data	−1.27 ± 0.20	No data	No data

Region codes: SE: St. Elias, NC: northern Coast, CC: central Coast, SC: southern Coast, VI: Vancouver Island, NI: northern Interior, SI: southern Interior, NR: northern Rockies, CR: central Rockies, SR: southern Rockies.
The dates in brackets (abbreviated to the last 2 digits) represent the averaged mean of the acquisition dates for the different regions.
The row for Whole Inventory is set in bold to highlight overall statistics. 2000 cv. refers to the portion mapped for the year 2000.

4. Streamflow

Rationale: Predicted lower flows in summer and early fall may reduce the amount of water available to forest and range ecosystems. These lower flows may be further exacerbated when water is drawn for human use. Low flows may be associated with warmer water temperatures and declining water quality, both of which would threaten the health of aquatic ecosystems. Increased storms and precipitation amounts predicted as a result of climate changes may result in higher than usual water volume and velocity for winter months in some regions, potentially leading to increased river turbulence, scouring, and reduced in-stream channel stability (although these effects will depend on the nature of the hydrological system, such as whether it is rain or snowmelt dominated).

Short record lengths and extended periods of missing data hamper investigations of the influence of climate change and variability on the hydrology of BC. Often, the influence of climate variability cannot be distinguished from that of climate change because some modes of climate variability such as the Pacific Decadal Oscillation (PDO) operate on multi-decadal time scales. Therefore, a considerably long record is required to adequately distinguish between trends created by the PDO as it switches from one phase to another (cool to warm), from trends occurring due to climate change.

Applying data to the South Selkirks : Data and analyses most applicable to the South Selkirks were completed by PCIC (Rodenhuis et al. 2009). They used data from the Water Survey of Canada to examine changes in historic streamflows across B.C. They restricted their data to Canadian Reference Hydrometric Basin Network (RHBN), which are watersheds relatively undisturbed by human activity (although those watersheds were sometimes affected by natural disturbances such as Mountain Pine Beetle). They divided streams into runoff categories (pluvial, hybrid, nival and nival/glacial)[2]. Their

[2] Classification of seasonal runoff regimes has recently been carried out for BC and in the past was carried out specifically for the Georgia and the Fraser Basins. Runoff was classified into one of four categories: rain-fall dominated (pluvial), a mixture of rain-fall and snow-melt (hybrid), snow-melt dominated (nival), and snow-melt

analysis calculated trends for 1976-2005. Annual mean, minimum and maximum streamflows were investigated, as were effects of ENSO and PDO. Comparison of streamflow results to trends in temperature, precipitation, and snowpack results was hindered by the lack of overlapping periods. Trends in streamflow were investigated for the latest 30 year period 1976-2005 to update a previous study and to allow the analysis of the largest number of stations. However, this period is not directly comparable with other trend estimates in their report such as with snowpack or temperature and precipitation. Trends in snowpack were carried out for 1950-2007. Temperature and precipitation were analyzed from 1900-2004. Thus, some generalizations had to be made to compare the different variables. Over the 1976-2005 study period, the warm PDO (1977-1998) likely influenced trends in streamflow.

Rodenhuis et al. (2009) reported that, in general, annual mean streamflow decreased in the southern parts of the Province, increased in the central and Fraser Plateau regions, and decreased in northwestern areas. Trends in the South Selkirks were generally not significant. Patterns were different for different types of runoff systems (pluvial (rain dominated) or nival (snow dominated)). For watersheds at low elevations and southern latitudes that have lost their glacier influence, the annual mean streamflow decreased and the minimum daily average streamflow decreased. This result was consistent with the impacts of warmer temperatures in mixed snow/glacial runoff regimes. They reported that the onset of spring-melt advanced by 10-30 days over the 1948-2002 period in runoff regimes dominated by snowmelt. Rodenhuis et al.'s (2009) investigation of ENSO and PDO phases on streamflow revealed that they have important modulating effects that should be considered for the purposes of planning and management. Impacts of ENSO and PDO were greatest in southern BC.

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combined with glacier-melt (nival/glacial). Due to lower temperatures in high latitudes and altitudes, areas outside the Georgia Basin are likely to have either nival or nival/glacial runoff regimes. However, it has been shown that some areas display unique characteristics such as having summer peak flows resulting from summer rains. Yet, classifying rivers within these regimes helps to identify how they are vulnerable in the face of climate change and allows results to be grouped in a way that facilitates discussion.

The timing of peak and low flows is different in each regime. *Pluvial* tends to peak in November and December, with lowest flows occurring in July and August. *Hybrid* can have high flows from October to January and then again in April to June and have low flows in July and August. The proportion of rainfall versus snow-melt in the runoff of the hybrid regime is determined by temperature. Moving inland from the coast, or northwards up the coast, increases the predominance of snow-melt, as would increases in the mean basin elevation. Nival tends to peak in May, June, or July, and has lowest flows in the winter months of December to March when incoming precipitation is stored as snow. Nival/glacial has high flows that extend from May to August or September. Again, from December to March, flows are low as precipitation is stored as snowpack.

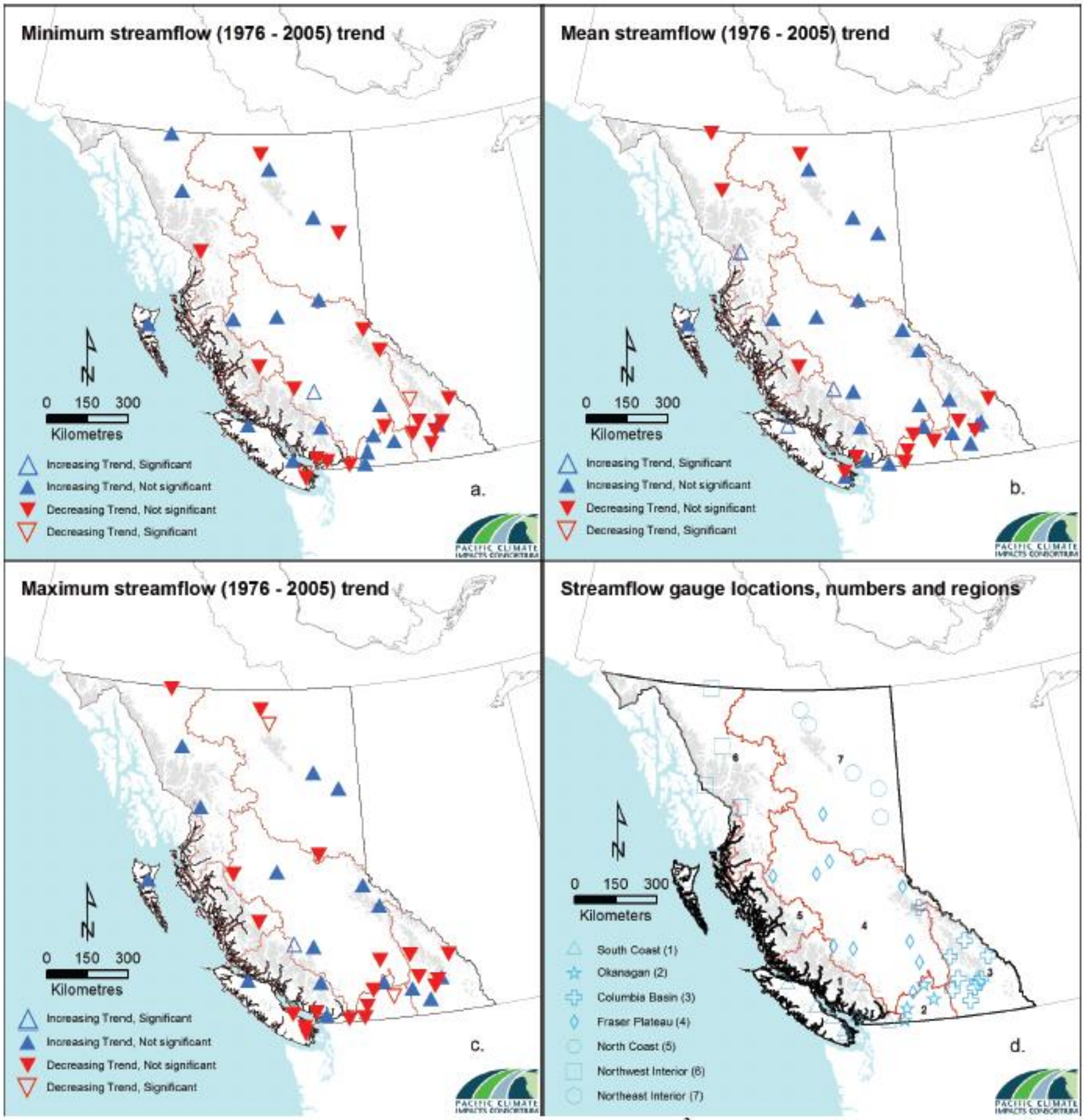


Figure 10. a) Annual minimum streamflow 1976-2005 trend (m3/s per day) b) annual mean streamflow 1976-2005 trend (m3/s per day), c) annual maximum streamflow 1976-2005 trend (m3/s per day) and d) streamflow gauge locations, numbers, and regions. Grey areas indicate snow and glacier cover zones. From RHBN data, Baseline Thematic Mapping (BTM). (Source: Rodenhius et al. 2009)

Other streamflow data exist for specific areas of the South Selkirks. The US Geological Survey has data for some Rivers crossing the border that were not included in PCIC's analyses and would be applicable to particular sites (e.g., the Flathead River, http://waterdata.usgs.gov/MT/nwis/current/?type=flow). We examined those stations, but have not added that information to the report as they do not add substantially to the PCIC analyses, nor change their findings – changes in flow do not appear significant.

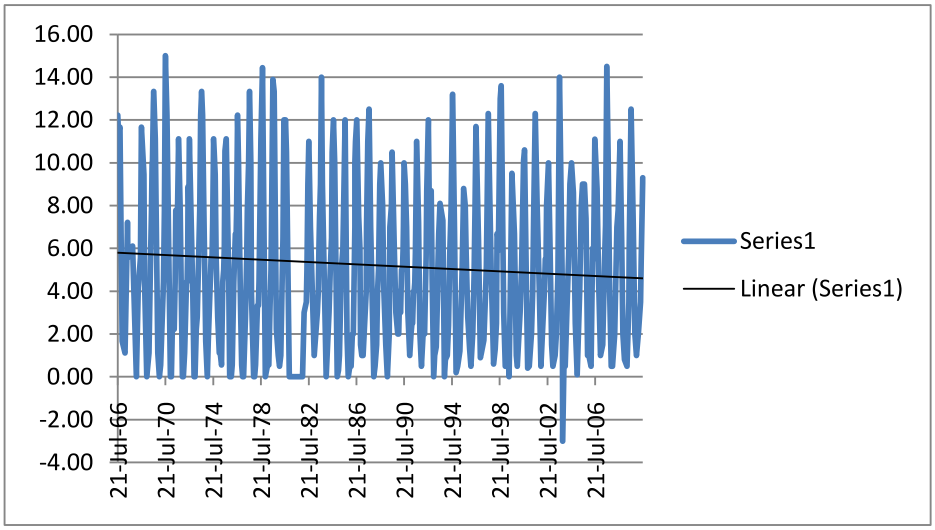
5. Water temperature

Rationale: Increased water temperatures are predicted as a result of climate changes especially in northern areas. Warmer temperatures are expected to affect the fitness, survival, and reproductive success of certain fish and other aquatic species. Over the long term, higher temperatures may result in a shift in the distribution of cold-water species to higher latitudes and elevations. However, if other factors such as habitat discontinuities were to limit these range shifts, an overall reduction in the distribution of certain species would result. By contrast, river warming may have positive consequences for aquatic species that prefer (or can tolerate) warmer water temperatures. Native warm-water species may be able to expand their range into higher-altitude lakes and more northerly regions. Warmer temperatures may also allow invasive or exotic species to expand in range.

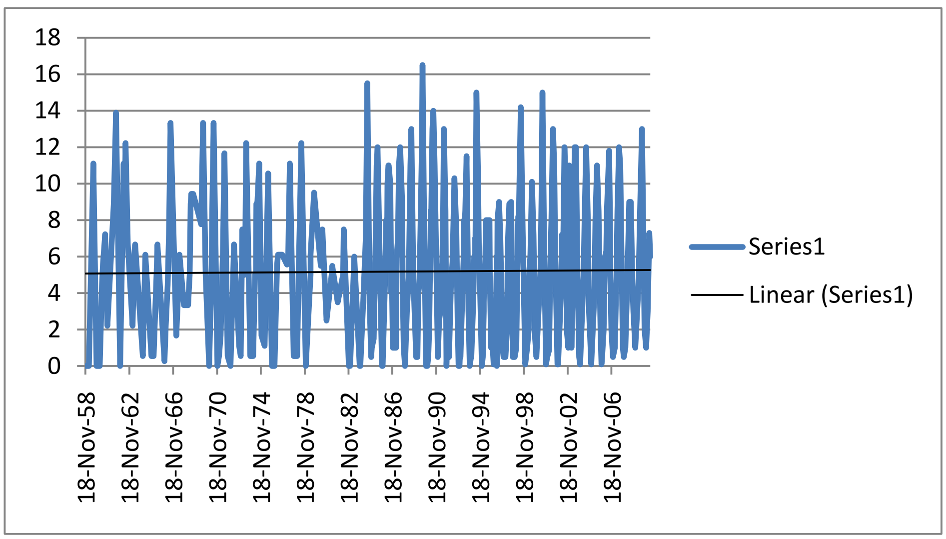
Applying data to the South Selkirks: The most systematic water temperature data is held by Environment Canada's Water Survey of Canada. The B.C. Ministry of Environment has some measures of water temperature but only for selected streams and these are scattered and not recorded provincially but may be known by regional staff. Eddington et al. (2009) reported that *MOE Water Stewardship Division* Sciences and Information Branch is currently conducting research into how water temperature monitoring can be improved, but at this point in time it seems those plans have been put aside and none are in place to monitor water temperature (Leonne Gaber pers. comm., Robert Gibson pers. comm.).

B.C. MoE staff in Victoria (Leonne Gaber pers. comm., Robert Gibson pers. comm.) and Nelson Region (Tracy Henderson pers. comm.) indicated the best and most comprehensive water temperature data are held by Environment Canada's Water Survey. Tracy indicated that there are also data from a limnological study of Kootenay Lake and that some companies in the region likely have data from contract work. We elected to use just the Environment Canada data; their network of sites includes BC Hydro data, but does not seem to have other provincial information (perhaps because of the scattered nature of that information). The locations of water survey sites are noted on an interactive web-based map. The map does not indicate which stations have water temperature information, or if the temperature data are gathered by temperature probes or are surface measurements made when technicians are in the field. A request to Water Survey Canada (Lynne Campo) resulted in clarification on which sties had water temperature information, which she then provided (quickly and free of cost).

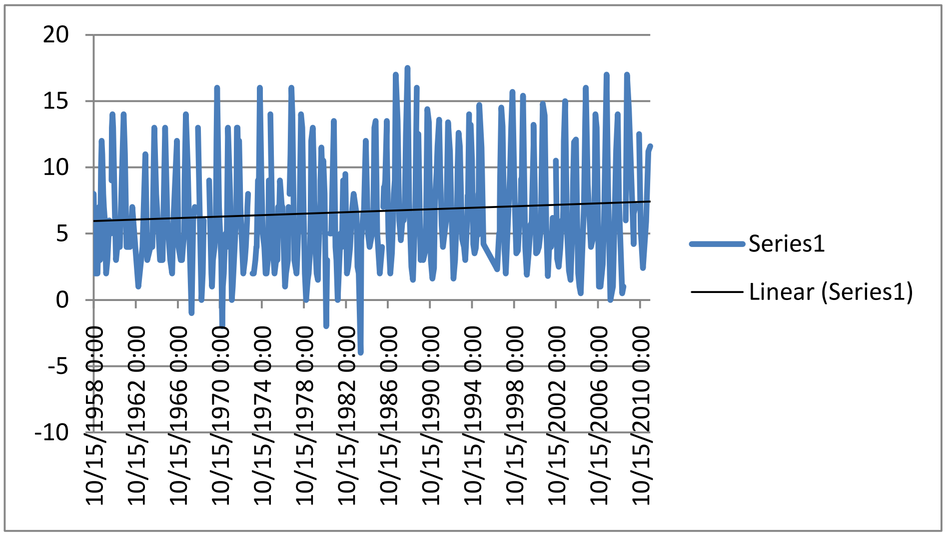
For the South Selkirks area, we selected 38 water survey stations. None had temperature probe information, but 31 stations had spot surface water temperature measurements (taken by technicians when they are at the station). Four of the 38 stations were run by the USGS (i.e., 35 of the 38 stations had temperature information) and those data are not held by Water Survey Canada. Data from the 31 Canadian stations with water temperature information showed no clear trend over time. All showed very slight changes (12 increased more than 0.5^{o}C; 7 decreased; 9 showed no trend). Stations had different lengths of record but no differences were apparent between stations with long versus short data histories. Measurements were taken at different times and different conditions and again were just surface water measurements. Examples are provided below.



a) decreasing water temperature trend (Station nh064).



b) Example of neutral water temperature trend (Station ng002).



c) Example of increasing water temperature trend (Station ne007).

Figure 11. a) Example of decreasing water temperature trend (Station nh064); b) Example of neutral water temperature trend (Station ng002); c) Example of increasing water temperature trend (Station ne007).

THE USGS website allows similar information to be downloaded (see Figure 12), but does not provide raw data. The user interface can provide daily trends or monthly or yearly data. The monthly and yearly trends seem to edit the data for gaps, thus resulting in short time series. The daily data series is the longest, but cumbersome to view.

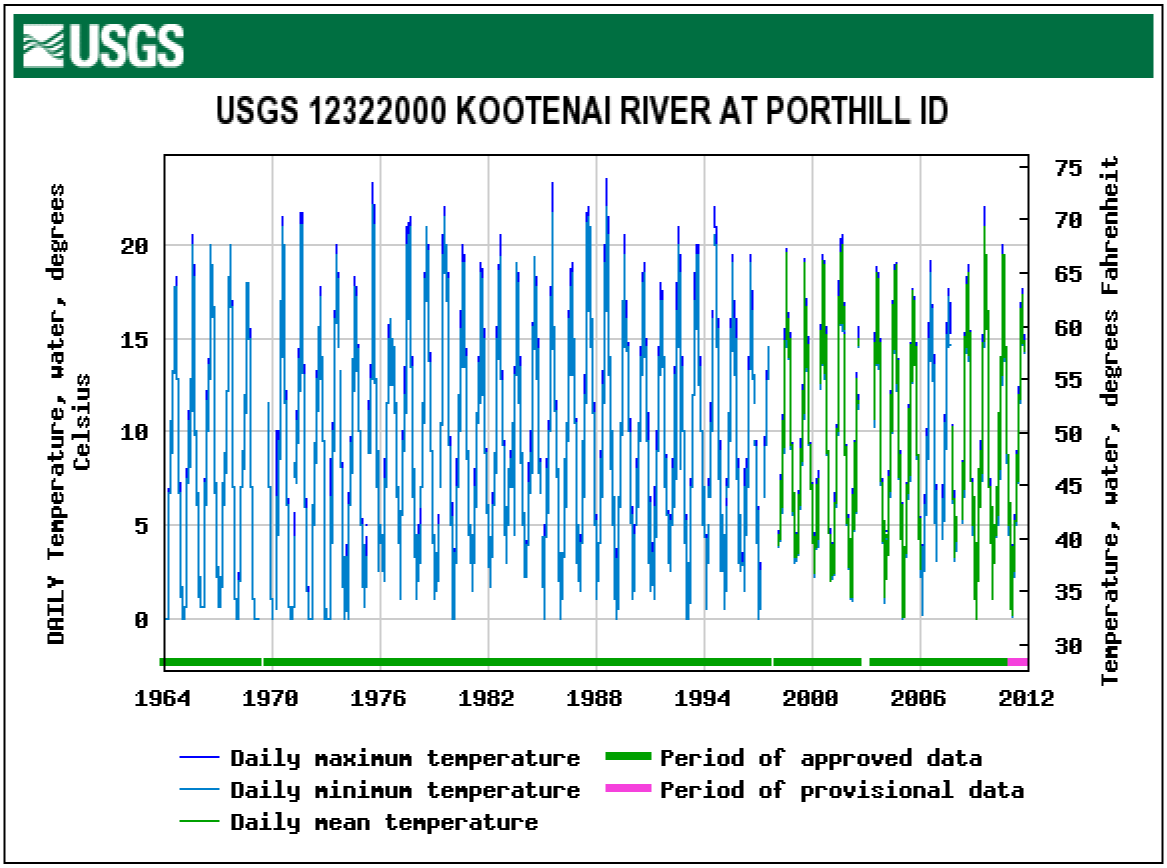


Figure 12. Example water temperature graph for a USGS station in the South Selkirks area.

There would be utility in the Province developing a more systematic survey or at least a common repository for both water temperature and water quality information (see next section). Without an easier means of finding and accessing provincial information, we are limited (by reasonable time and effort) to the Water Survey Canada sites.

6. Water quality

Rationale: Climate driven changes to hydrological systems are likely to cause changes in the physical, chemical and biological characteristics of water in forest and rangeland streams and lakes. Such changes may impact on freshwater and estuarine ecosystems and aquatic species found within forests and rangelands and may also have some impact on the quality of water available for human use.

Applying data to the South Selkirks: In a similar manner as for water temperature date, data on water quality for the South Selkirks were available with reasonable effort only from Environment Canada. Environment Canada partners with both the BC and Yukon governments in the BC Yukon monitoring project. Although the BC Ministry of Environment conducts water quality sampling outside of the BC Yukon monitoring project, and they have an "Environmental Management System" website which allows retrieval and subsequent analyses of water quality information, that information is difficult to find or access. (Getting an ID to access the system is simple, but finding information is not). The EMS system has water quality information from a variety of sources and for a variety of purposes, but there appears to be no systematic sampling of water quality of streams, rivers, lakes or aquifers. The Ministry of Environment apparently has 3500 sites where water quality is measured; talking with many people, including those noted in the section above on temperature, did not result in finding those data.

The Ministry of Environment also has jurisdiction over ground aquifers. At this time information on aquifers is extremely difficult to find or access. MoE holds no systematic reports. Consultants hold some information on some aquifers. 'Well' records are not linked to the aquifers delineated through the Aquifer Classification System. It is not possible to query the well records or the aquifers for all the well records that are found in the area of any given aquifer. Changes in aquifers are likely with climate change, but no system is in place to track those changes.

Eventually, for the South Selkirks, we opted to simply use the Environment Canada Information. Philip Chau of Environment Canada provided water quality files for the stations within the study area. Most sites are sampled on a bi-weekly basis for a wide range of water quality variables, including trace metals, nutrients, major ions, fecal coliforms, and other parameters of site-specific importance (e.g. dissolved oxygen, pesticides, etc.). The primary objective of their water quality monitoring program is to look at the long term changes in water quality to assess trends. The program has been in operation since 1975, but the present format of the network (i.e. long-term, routine monitoring), was formalized under the Canada-B.C. Water Quality Monitoring Agreement in 1985. The map below shows station locations:

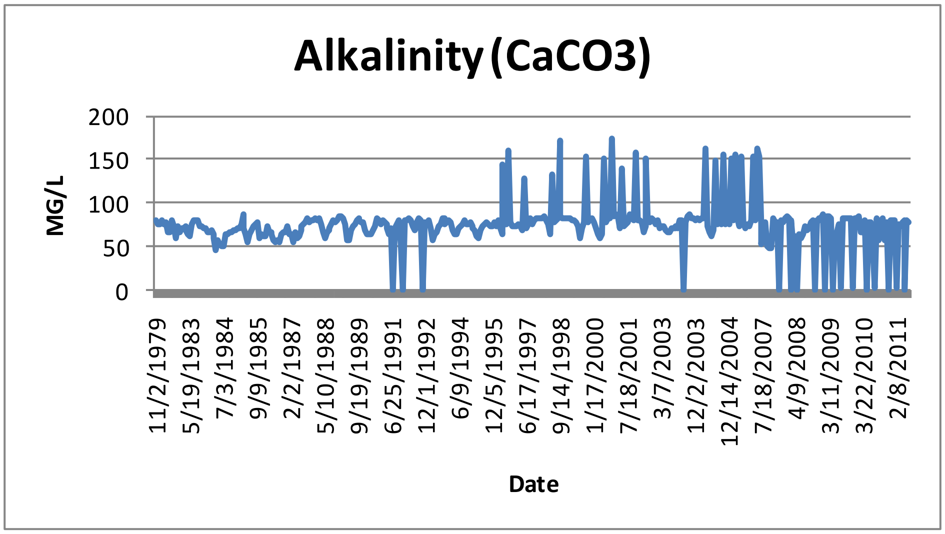
Figure 13: Locations of water quality stations

We requested water quality information from Environment Canada for 10 stations in or near the study area. For each of those stations several water quality indices were measured, usually from 1979, but sometimes only from 2000 to present. Andrea Ryan, head of the water quality group, recommended dissolved sulphate, dissolved NO3 and NO2, water hardness, turbidity, and alkalinity as indices that may best reflect effects of climate change. Monique DeJong of Environment Canada warned that some stations have considerable influence of human activity. For example, nitrogen readings along the Elk River stations are influenced by the activity in the coal beds nearby. Examination of the 5 indices at each of the 10 stations revealed little information (see Table3). Of the potential 50 combinations (station by index), less than 10 showed any trends at all and none are obvious.

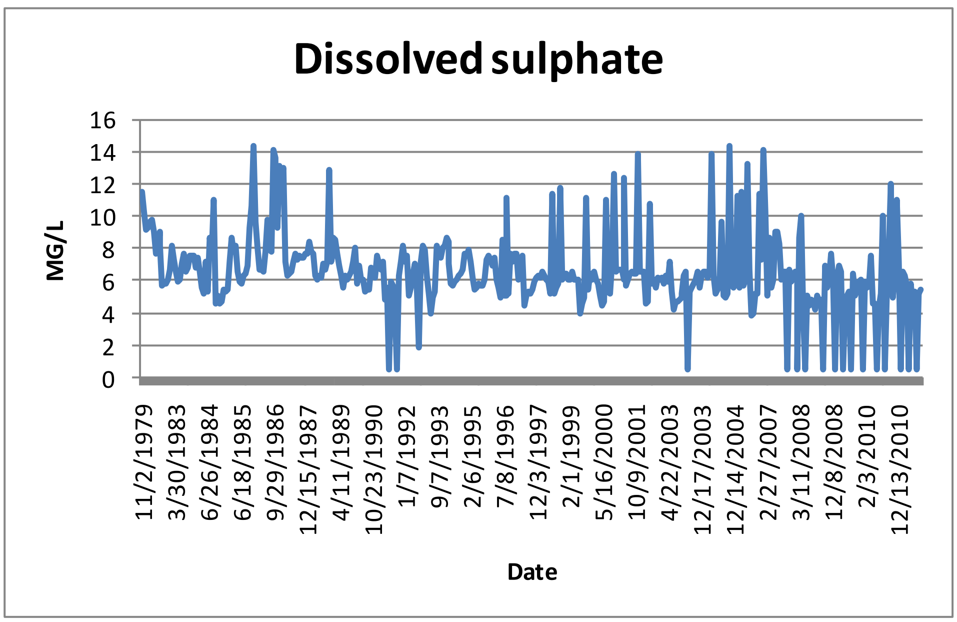
Table 3: Water quality trends in the South Selkirks

Station (length of records for most indices)	Alkalinity total (CaCO3) MG/L	Hardness CaCO3 (MG/L)	Dissolved NO3 and NO2 (MG/L)	Dissolved sulphate (MG/L)	Turbidity (NTU)
Columbia River at Birchbank (1983-)	No trend	No trend	Slight decrease	No trend	No trend
Columbia River at Waneta (1979 -)	No trend	No trend	Slight decrease	No trend (but more low values)	No trend
Elk River at Highway 93 near Elko (1984-)	No trend	No trend	No trend	Rising trend but many low values	No trend
Elk River below Sparwood (2002-)	No data	No data	Rising and more variable	No trend	No trend
Kettle River at Caron Road Bridge (1979-)	No trend	No trend	No trend	No trend	No trend
Kettle River at Midway (1979-)	No trend	No trend	No trend	No trend	No trend
Kootenay River at Creston (1979-)	More records with low values	No trend	Less variable and very slight decrease	No trend, very variable	More variable over time
Kootenay River at Fenwick Station (1984-)	Slight rise; more low values	No trend (almost cyclic)	Decreasing	No trend	No trend
Pend D'Oreille River at Waneta (1979-)	More zero values	Slight decrease	Slight decrease (to almost zero)	More zero values	No trend
St. Mary River at Wycliffe (1999-)	No data	No data	No trend	No trend	No trend

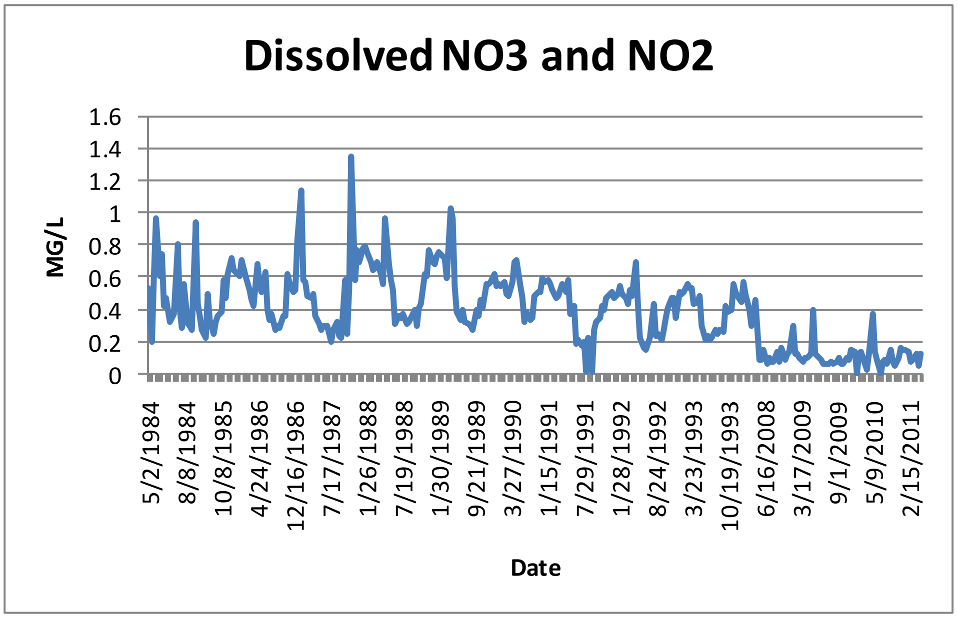
It is interesting that some of those trends seem to be contrary to what would be expected if CO2 was being deposited (e.g., variable but decreasing alkalinity; decreasing NO3 and NO2; more zero readings for sulphates).



a) Trends in alkalinity at Pend D'Oreille River at Waneta



b) Trends in dissolved sulphate at Pend D'Oreille River at Waneta



c) Trends in dO3 and NO2 at Pend D'Oreille River at Waneta

Figure 14: Examples of water quality information for the South Selkirks area available from Water Survey Canada. a) Trends in alkalinity at Pend D'Oreille River at Waneta; b) Trends in dissolved sulphate at Pend D'Oreille River at Waneta; c) . Trends in dO3 and NO2 at Pend D'Oreille River at Waneta

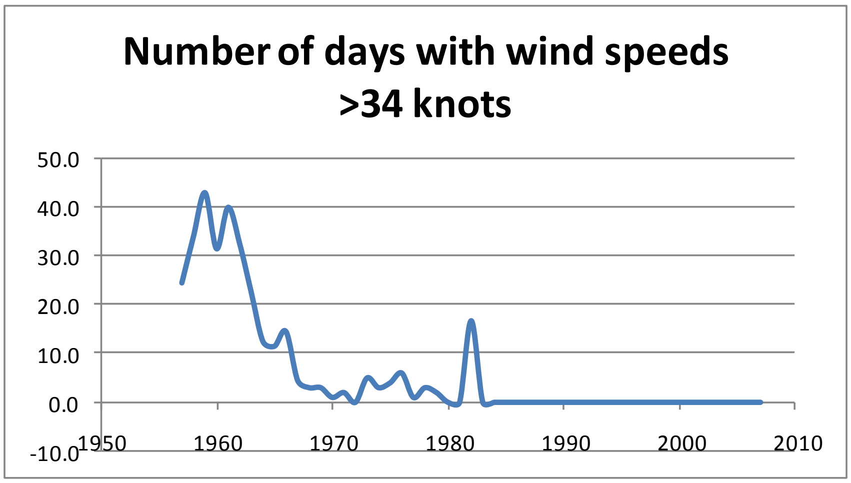
7. Unseasonable or unexpected weather conditions

Rationale: During periods of climate adjustment there is a strong likelihood of unseasonable or unexpected weather. This may include late or early frosts, extreme snowfalls, ice storms, hail, droughts and other weather-related events. Many of these can have major impacts on forests and rangelands. In addition to changes in temperature and precipitation, global climate change has the potential to increase the intensity of Pacific storms. Increasing sea surface temperatures of the Pacific Ocean and changes in climate variability can also contribute to this effect. The Province lies directly in the path of Pacific storms, and changes in intensity are an important concern for hydroclimatology and water management in the future.

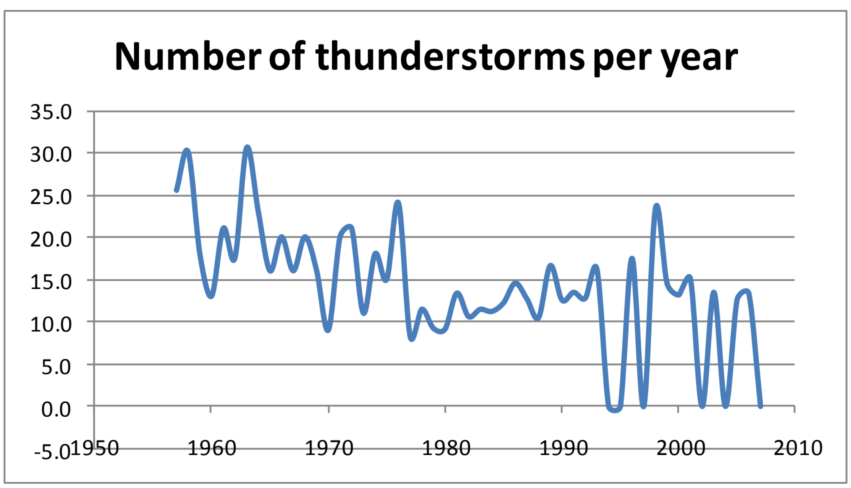
Applying data to the South Selkirks: Ideally, reporting under this indicator should include an examination of the frequency and intensity of unseasonable or unexpected weather events over long time periods to see how the current decade compares with those of the past. In reality, very little information exists on extreme weather events. Environment Canada's Meteorological Service of Canada (MSC) monitors and collects data on severe weather conditions, such as hurricanes, tornadoes, severe thunderstorms, storm surges, strong winds, high heat or humidity, heavy rain or snow, blizzards, freezing rain and extreme cold. Environment Canada Climate Network for British Columbia and Yukon operates a network of approximately 500 climate stations in B.C. and the Yukon and maintains an associated archive of historical weather information. Information on extent of dry periods, frost free days, early and late frosts may be derived from measured climate information and soon will be examined by PCIC (Faron Anslow pers. comm.). Until PCIC includes extreme weather in their summaries, the option is to acquire raw data from Environment Canada. There is a cost to acquire data, and correspondence (they prefer email or a 1-900 number) to sort out the stations and data took much longer than did acquiring the water flow, temperature and quality information from the Water Survey branch.

Environment Canada weather information for sample of about 30 stations in the South Selkirks area indicates a possible decrease in days with high winds and decrease number of thunderstorms, but shows no pattern for number of days of freezing rain or days of frost (even in the shoulder months).

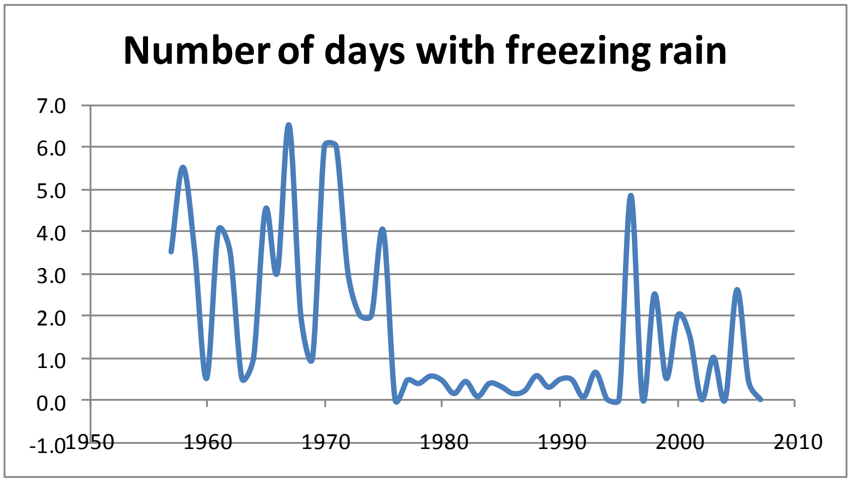
a)



b)



c)



d)

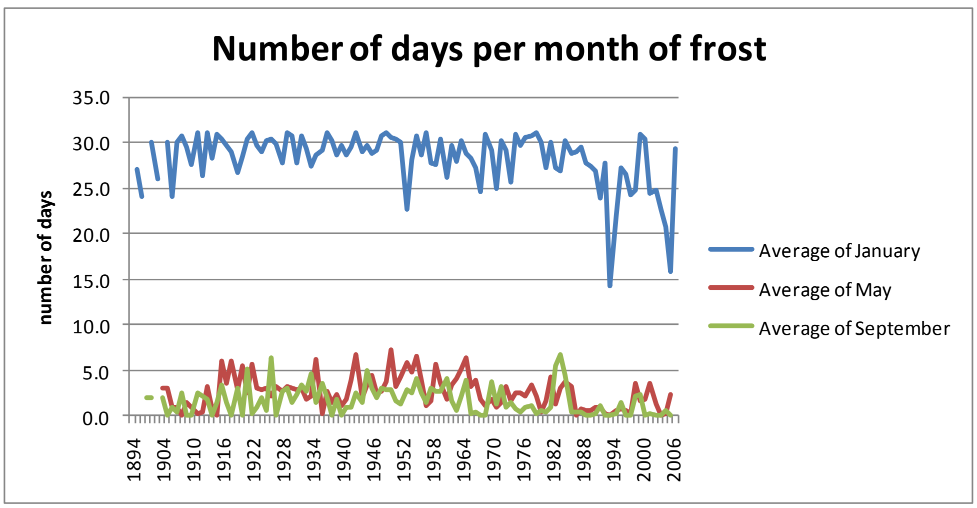
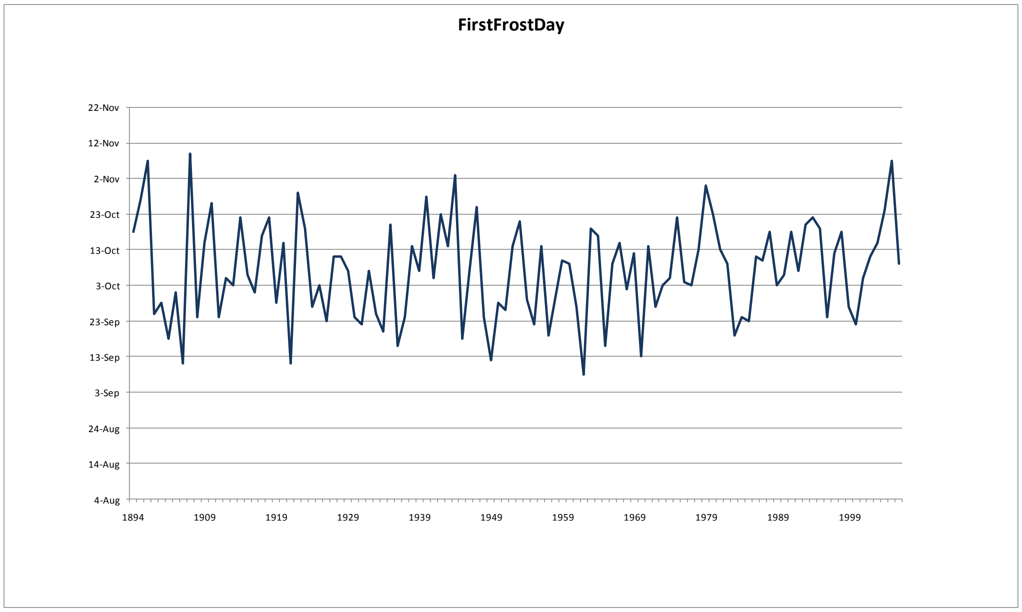


Figure 15: Trends in days per year of a) wind, b) thunderstorms, c) freezing rain and d) number of days of frost in January, May and September.

The date of first frost (when minimum temperatures were below zero) does not show much trend and is very variable. The date of last frost may be slightly later since the 1960's but again there is no strong signal and large variability (Figure 16).

a)



b)

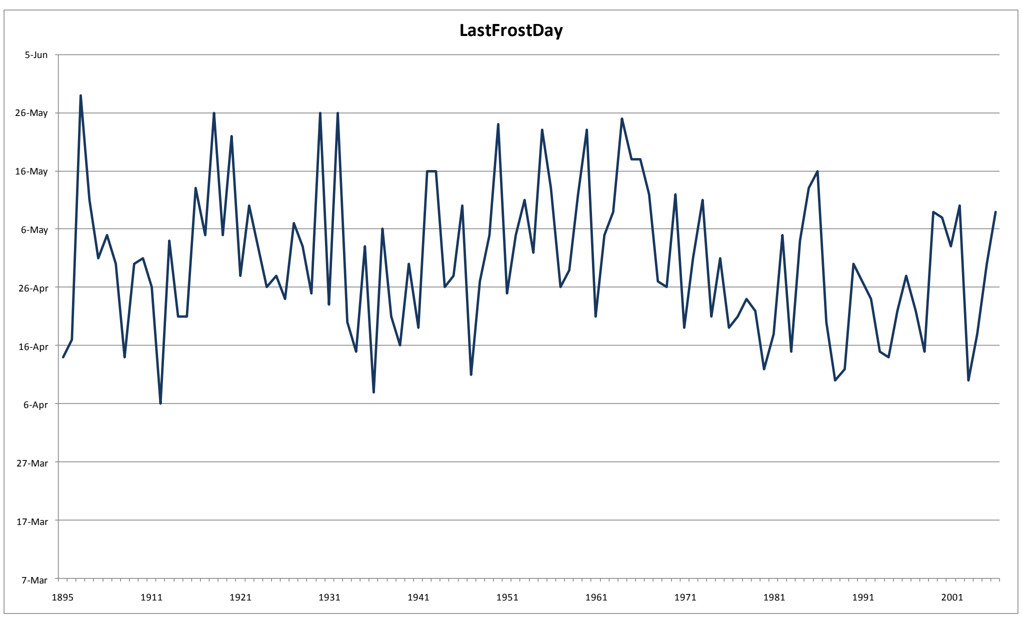
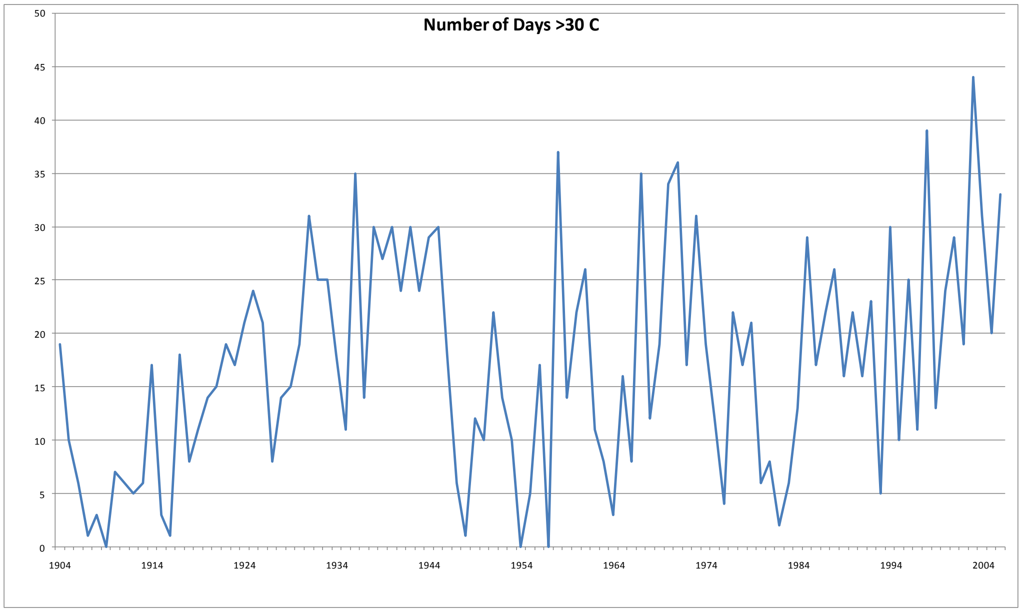


Figure 16. Date of a) first frost b) last frost from 1895 to present for the South Selkirks area.

The number of days with temperature above 30^{o}C is increasing, and the number of days with temperatures below -20^{o}C is decreasing (Figure 17).

a)



b)

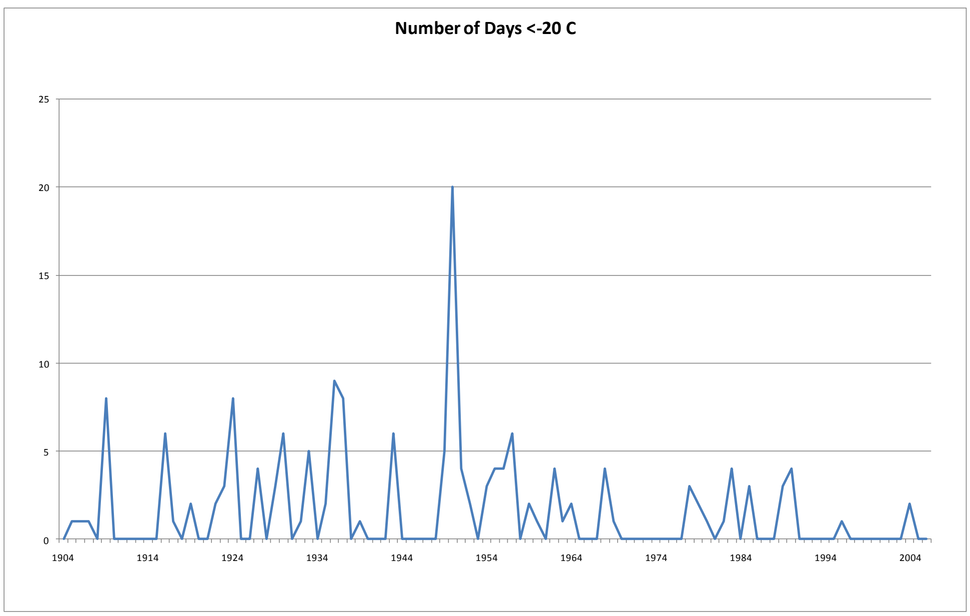


Figure 17 Number of days a) above 30°C and b) below -20°C since 1900s for the South Selkirks area.

Criterion 2: Natural Disturbances

8. Mass movements

Rationale: In the survey (Eddington and Innes 2008), mass movement was seen as highly important for monitoring in light of climate change. The number of confounding factors (effects of land use rather than climate) that would mask or mislead interpretation of effects of climate change, make this a difficult priority indicator to pursue. This indicator was meant to examine the scale and density of mass movements and erosion events (landslides, rockfalls, debris torrents, debris avalanches, debris flows, etc.) in relation to climate change. The frequency and extent of rapid mass movements are influenced by underlying geology, precipitation amount and intensity; snow accumulation, melt rate, and distribution; and land uses such as road construction or forest harvesting. Vegetation also influences the likelihood of mass movements through the soil-stabilizing effects of root systems and the effects of vegetation structure and composition on hydrology. Climate change may affect precipitation, snowmelt and vegetation to alter the frequency and/or magnitude of mass movements and erosion events. Although underlying geology is independent of climate, climate change may affect surficial geology and also affect mass movements.

Landslides in mountainous terrain are strongly influenced by climatic factors, including precipitation and temperature (Geertsema et al. 2006, Evans and Clague 1994). Catastrophic landslides at high elevations may be particularly responsive to increases in temperature. Researchers have suggested that recent melting of glaciers in British Columbia has debuttressed rock slopes adjacent to glaciers, causing deep-seated slope deformation and catastrophic failure (Clague and Evans 1994; Holm et al. 2004). Alpine permafrost may be degrading under the present warmer climate, decreasing the stability of slopes. Recent large rock avalanches in the European Alps have been attributed to melting of mountain permafrost (Gruber 2011) and this phenomenon may also play a role in initiating landslides in northern British Columbia.

Precipitation also affects landslides (Geertsema et al. 2006, 2009). In a simple sense, the occurrence of landslides will increase in relation to the amount and duration of precipitation; however, slope factors may be more complicated and thus preclude a simple analysis. Some landslides respond rapidly to rainfall, others have delayed responses. In any case, antecedent conditions have been shown to be very important. In general, soils must become saturated, allowing the build-up of pore pressures. Larger, and especially deeper, landslides tend to have delayed responses to precipitation. It takes time for water to infiltrate and saturate potential slide masses. Individual rainstorms, rain-snowmelt events, and outburst floods can indirectly trigger landslides by increasing peak flows in streams. High water flows are known to increase bank erosion, which can trigger landslides. Timing of precipitation and snowmelt is important. For example, the sudden and delayed melt of above-average snowpacks can lead to increased occurrence of landslide events caused by increases in pore pressure.

There is evidence that landslides are linked to overall climate as well as to specific weather events (Geertesma et al 2007). A warmer, wetter climate is likely to be accompanied by increased landslide activity. Climate change has indirect, as well as direct, effects on landslide frequency. Reduction of evapotranspiration, hydrophobic soil conditions following wildfires, and salvage harvesting predispose landscapes to increased slope failure.

Applying data to the South Selkirks: Ideally, Province-wide aerial surveys or remotely sensed data would be used to record mass movements and erosion events over a certain size. This information could be supplemented where possible with information collected on a regional basis in order to aid interpretation and gain some understanding of changes of mass movement with climate change. In reality no provincial-level or even regional level systematic surveys or tracking of mass wasting occurs.

We were unable to find evidence of systematic programs directed at monitoring mass movement frequency and extent in the South Selkirks area (Peter Jordan pers. comm.). Peter Jordan of the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), has inventoried mass wasting events on selected study areas in the South Selkirks area. The work was undertaken pre-2002 and since then there has been no funding to continue the projects. Jordan's approach (Jordan 2002) was to conduct an air photo inventory of all landslides, natural and development-related, on forest land in a study area (centred on the Slocan Valley) which covered roughly 1 million ha. Within the study area, eight small map areas were selected, covering 13 870 ha and including 210 landslides. Detailed terrain maps were prepared for these areas, and almost all landslides were inspected in the field. A set of random points was generated to provide a sample of non-landslide points. Using a geographic information system, several terrain and land use attributes were determined for each point, including bedrock geology, soil association, biogeoclimatic zone, land ownership, and grid-produced topographic attributes such as slope and aspect. A journal publication summarizing the work is anticipated for March 31, 2012. If such studies were repeated every decade or so, changes in frequency or extent of mass wasting possibly could be linked with changing climate. Mass wasting inventories usually involve examining events visible on air photos. Those photos give records of events over the previous 10 to 15 years. Air photos are repeated every 5 or so years, so on-going records could be established if funding was re-introduced. As indicated previously, the number of confounding factors (effects of land use rather than climate) that would mask or mislead interpretation of effects of climate change on mass wasting, make this a difficult indicator to pursue. As well, rare events, like large mass wasting, are difficult entities to sample to establish trends – by their very nature they are rare. Large areas and many repeated measures would be necessary to draw any correlations with any statistical significance.

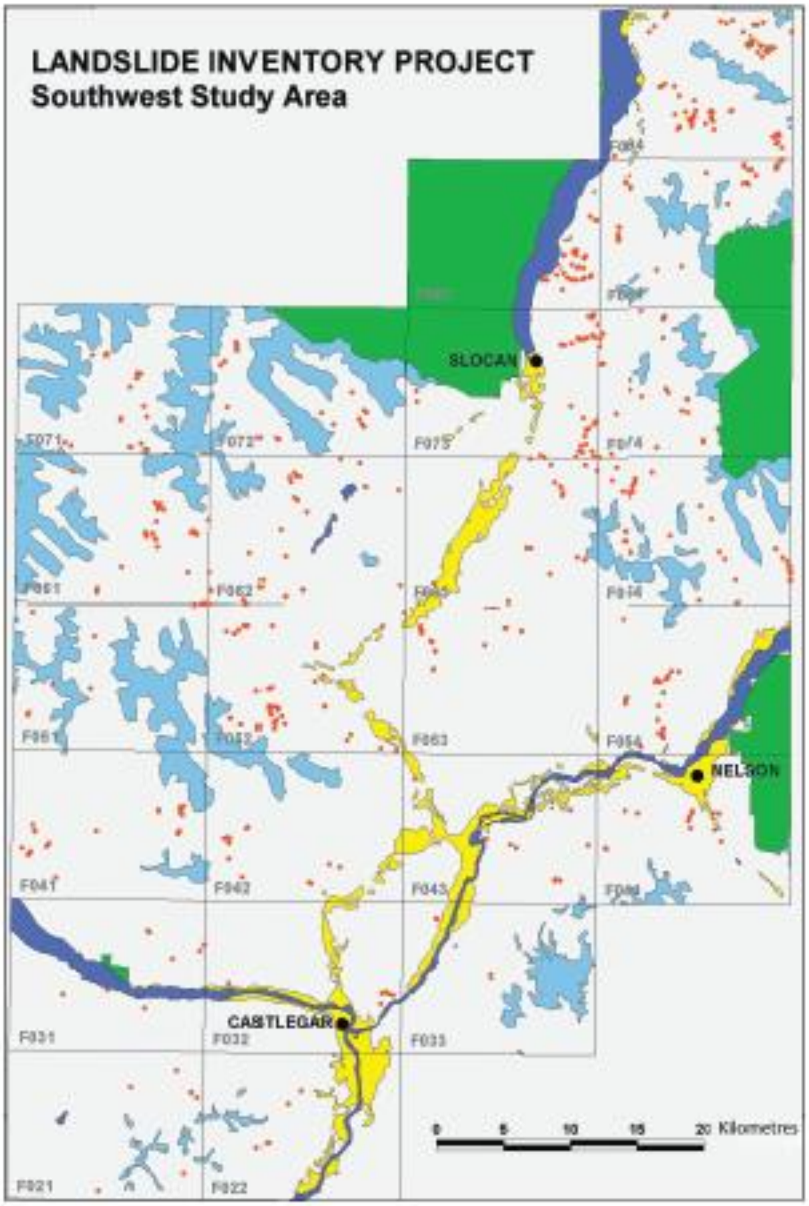


Figure 18. Jordan's (2002) southwest (Slocan Valley) study area. Landslides are red dots. Non-forest areas are lakes (dark blue), parks (green), alpine (light blue), and urban/agricultural (yellow).

Jordan (pers. comm.) indicated that some Forest Districts historically kept records of any mass wasting events reported to them. Licensees, Ministry of Forests personnel, and others, would note mass wasting events and a record was kept at the Forest District Office. This record has not been updated since 2004 when the Forest Practices Act was repealed and licensees were not longer required to report events. As well, Districts were amalgamated and resources reduced, so record keeping became less formal (or non-existent). Some Forest Districts, and some licensees, continue to report mass wasting, but the information is not collected systematically across the region (or Province).

Some forest companies in the South Selkirks area have tracked mass wasting. Kari Stewart-Smith (pers. comm.) indicated that TEMBEC initiated tracking of mass wasting events 7 years ago. That program was halted then restarted, but will likely be stopped again because the person leading the program has been laid off. That program tracked mass wasting in TEMBECs tenures and included both human-caused and natural slides. Tembec does not have the information in a database and prefers to use it internally only.

Whereas linking *weather* to particular slides is quite possible (if slides were observed soon after they occurred), linking any changes in frequency to *climate change* would be more difficult and require many years of record, ideally for natural slides. For mass wasting to be linked to climate, regular landscape level inventories would be needed. If the samples were large enough some of the confounding factors would not matter, but for the most part, records of vegetation type, recent human disturbance, recent weather, and other factors affecting stability would need to also be recorded before any correlations to climate change would be possible.

9. Windthrow

Rationale: Increases in the intensity, frequency and severity of stormy weather predicted as a result of climate change is likely to result in increased scale and severity of wind throw damage to forests. Forests may also become increasingly susceptible to wind damage through the effects of other climate-related factors. For example, increased precipitation could destabilize soils or increased pests could reduce vigour of tree roots.

This indicator is meant to report on the scale and severity of wind throw damage affecting forests. This indicator is currently seen as of moderate importance to the monitoring framework. It should be monitored using Province wide aerial surveys to record medium to large scale damage resulting from wind throw. This information should be supplemented where possible with information collected on a regional basis especially for those areas expected to experience increases in the intensity, frequency and severity of storms or suffering from other stressors thought to be climate related. As discussed below, stand-level monitoring of windthrow is difficult to relate to changes in climate or weather but is important information for management; landscape-level information has greater applicability to tracking effects of climate change.

Applying data to the South Selkirks: When all of BC is considered, there are many studies of stand-level windthrow, but none of these are within the South Selkirks study area. TEMBEC surveys for windthrow, then looks for opportunity to salvage the downed timber, but no data base is kept with windthrow records. MFLNRO (Deb MacKillop pers. comm.) is unaware of any windthrow studies in the Kootenay Region.

Forest and Range Evaluation Program (FREP) does not yet have landscape level studies on windthrow but does have cutblock level information on amounts of wind throw experienced by retention patches (Nancy Densmore pers.comm.). FREP's data is publicly available and our analyses showed that in the South Selkirks area (Arrow, Kootenay Lake, Columbia and Rocky Mountain Forest Districts), windthrow in retention patches varied from a high of 17% in the ESSFwm to lower levels in the IDFdm (5.8%) and MSdk (6.2%). Even if these samples are supplemented over time, it would be difficult to relate stand-level windthrow to changing climate. Much of the variance in windthrow can be attributed to design of cutblocks or retention patches, their layout as compared to the orientation of major winds, and attention to windfirm boundaries. As well, risk of windthrow will change with stand age, so examining changes over time would be confounded. Unless those factors were known, then any changes in levels of stand-level windthrow could not be easily attributed to changing climate and weather patterns. Even if the stand-level windthrow studies could be repeated in similar places in the future, the ability to say anything about effects of climate are minimal. Landscape-level studies have more potential to link to climate trends.

No landscape-level studies of windthrow relevant to the South Selkirks have been conducted with the exception of the province-wide forest health surveys completed yearly by the Ministry of Forests Lands and Natural Resources Operation (Westfall and Ebata 2010). The BC Forest Service has surveyed the majority of the forested land in the Province using aerial survey since 1999 resulting in the production of an annual report summarizing forest health conditions and digitized maps and tables by region and district. They have codes for windthrow, so if the windthrow can be seen while flying at 800m altitude at 80 knots, it will be recoded. Just as for mass wasting, occurrence of windthrow is not frequent and thus will be difficult to relate to changing climate. They estimated 301 ha of windthrow in the Kootenay Forest Region during 2010 (and 277 ha of landslides). Those values, repeated often enough could produce trends that may correlate with climate change, but the low levels and infrequent nature of both disturbances will make any detection of trends difficult.

Criterion 3: Biological Diversity

10. Genetic diversity

Rationale

Species are prone to increased risk of extinction when a significant proportion of their genetic diversity is lost. Such loss usually results from factors such as habitat reduction and fragmentation, reduced population levels, pests and disease infestations, and restrictions and/or shifts in former range. Changes anticipated with climate change can increase these threats for some species and potentially reduce genetic diversity, which may in turn result in decreased resilience and ability to adapt to future environmental changes. Although climate change may affect many species and populations and thus affect their genetics, in BC forests, little is known about the genetic diversity of any organisms besides trees, and even for trees it is difficult to track loss of genetic diversity (Sally Aiken pers. comm.).

To monitor genetic change, baseline data on genetic diversity and quantitative information from direct measures of changes (e.g., rate/ direction of loss) in genetic variation would be necessary. These elements are not known for many species or populations. In the absence of such detailed information, it is possible to monitor surrogates. For example, it would be possible to develop a list of forest and rangeland species and populations considered to be at risk from isolation and loss of genetic variation, then monitor shifts, expansions or contractions of their ranges. Shifts in range though, do not necessarily imply loss of genetic variability. A quite different measure, but a useful one given the actions anticipated by the province of BC, would be to monitor the application of formal measures to mitigate declines in genetic variation such as in situ and ex situ conservation programs and assisted migration (moving species/genetic provenances outside their range).

For phase 4 of the project, the treatment of the genetic diversity indicator was limited to considering the diversity of tree species and seed sources used in managed forests. Although changes in tree species in an area affect the genetic diversity present in that area, they do not indicate a change in the genetic diversity of the tree population itself. Although trees (and other species) may migrate in response to climate, this does not mean their genetics has changed. Part of migration is phenotypic plasticity that allows establishment and success in other sites, part may actually be genetic adaptation (e.g., Allendorf et al. in press).

Applying data to the South Selkirks: No data exists to allow examination of changes in tree species distribution or treeline shifts in the South Selkirks. BEC, VRI and TEM[3] plots provide information on tree species present; however, tracking change in species composition requires re-measurement, and this has not been done (Aiken pers. comm.). The National Forest Inventory (NFI) plots allow some tracking of change, but these plots also do not have a long period of re-measurement. None of those data sets presently allow tracking of shifts of conifer trees over time, but they do provide useful baselines for studies done in the future, provided, of course, they are re-measured. Serious thought should be given to establishing the BEC plots as permanent sample plots.

Three years ago, seed transfer guidelines were adjusted so that use of some seed could be extended upslope from past guidelines by 100 to 200 m (depending on seed and location, Greg O'Neill pers. comm.). Subsequently, guidelines were adjusted to allow the use of larch seed from historical area into the Bulkley Valley. Presently, the seed transfer guidelines are undergoing a large revision to facilitate assisted migration. At present there are no monitoring systems reporting how much the flexibility in the guidelines is being used (e.g., how often seed is planted at higher elevations or more northerly latitudes than before), nor are stands where assisted migration has been implemented monitored to assess stand development. However, data sent to "RESULTS" provincial database would allow investigation of those questions. Because the program is very young, trends in stand development for stands established using 'assisted migration seed guidelines' are not likely to be different from other stands. The BC Forest Service intends to include a monitoring component once the larger revision of seed transfer guidelines is complete and implemented (Greg O'Neill pers. comm.).

Once the seed transfer guidelines and rules are adjusted, then it would be useful to track how much seed or seedlings have been transferred and how those trees are developing compared to the usual regeneration on those sites. Until there are more entries in RESULTS, we deemed the indicator not yet useful to explore for the South Selkirks area.

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[3] BEC= Biogeoclimatic vegetation plots
VRI = Vegetation Resources Inventory plots
TEM = Terrestrial Ecosystems Mapping plots
NFI = National Forest Inventory plots

11. Ice cover on lakes

Rationale: L*ake* and river ice are an excellent indicator of climate change, especially because decadal and inter-decadal variation due to PDO and ENSO are integrated in melt response (break-up, freeze up and ice duration).

Applying data to the South Selkirks: Rodenhuis et al. (2009) computed trends in lake ice cover for 1976-2005 to provide updated results for the most recent 30 year period and trends for 1966-1995 were included to compare to a national study (Dugay et al. 2006). The BC data came primarily from volunteer efforts of the BC Lakes Stewardship Society (***http://www.bclss.org/***) that records dates of ice on and ice off for various lakes in B.C. Rodenhuis et al. (2009) reported decreased duration of lake ice in the most recent records (0 to 42 fewer days of ice). The spring break-up of lake ice also occurred up to 10 days earlier, although one station in the north-eastern portion of the Province showed a later break-up by 2 days. None of these lakes are in the South Selkirks area.

12. Summary

The Phase 4 indicators included temperature, precipitation, snowpack (including extents of glaciers), streamflow, water temperature, water quality, unexpected weather, mass wasting, windthrow and genetic diversity. We used the South Selkirks area as the location to pilot these indicators to see how readily the information theoretically available in BC (see Kremsater and Innes 2012) could be gathered and reported.

The abiotic indicators of ***temperature, precipitation, snowpack***, and ***stream flow*** are analysed and summarized well by PCIC. We used their information to present trends on these indicators for the South Selkirks. They intend their data to be soon publicly available via a user-friendly web interface. PCIC also reports on ***extent of glaciers*** but more recent work by members of the former Western Cryosphere Network presents even more useful information on extents of glaciers applicable to the South Selkirks.

The other abiotic indicators – ***water temperature, water qualit****y* and ***extreme weather*** – are not yet reported by PCIC. Water temperature data exist beyond those held by Environment Canada, but those data are very difficult to find or access. The same can be said for water quality data -- unless the Provincial Ministry of Environment recommences its efforts to compile water temperature and quality information, Environment Canada will continue to be the best option for that information. Both data sets (water temperature and water quality) are provided free of cost. Environment Canada also holds weather data that be used to evaluate extreme weather. That data comes at a cost and, at least in this case study, took more time to acquire. The Provincial government also holds weather data but again that data is not easy to access.

The PCIC and Environment Canada information allowed us to present trends in the abiotic indicators for the South Selkirks area. It is evident from PCIC's analyses that in the South Selkirks, temperatures are rising (those during winters more than those during summer); precipitation in increasing (more during spring and summer than during fall or winter); streamflow trends are variable; and glaciers are receding. Analyses of the Environment Canada's data showed no obvious trends in water temperature or quality. For extreme weather, the number of hot days has increased and the number of cold days has decreased slightly. Total number of days with frost had decreased slightly, but the date of first frost and last frost show no obvious change. The number of high wind events and thunderstorms has decreased.

For the natural disturbances indicators of ***mass wasting*** and ***windthrow***, little local information existed. As well, there is no systematic reporting of these indicators either provincially or regionally. Both these indicators would be difficult to relate to climate change even if substantial sampling was undertaken; we had little to report in the South Selkirks.

For the ***genetic diversity*** indicator, which was limited to considering ***changes in tree diversity***, it is too early in the assisted migration program to investigate amounts and locations of seed transfer. We did not report on that indicator.

Similarly, the indicator **of *ice on and off lakes*** is not tracked for any lake in the South Selkirks, so we were unable to report on that indicator.

13. Literature Cited:

Allendorf, F. W., G. Luikart and S. N. Aitken. (in press). "Conservation and the Genetics of Populations (second edition), Blackwell Publishing.

Bolch, T., B. Menounosm and R. Wheate. 2010. Landsat-based inventory of glaciers in western Canada, 1985–2005. Remote Sensing of Environment 114 (2010) 127–137.

Clague, J.J. and S. G. Evans. 1994. Historic retreat of Grand Pacific and Melbern Glaciers, Saint Elias Mountains, Canada: an analogue for decay of the Cordilleran ice sheet at the end of the Pleistocene? Journal of Glaciology 40 (134): 2005-210.

Duguay, C.R., T.D. Prowse, B.R. Bonsal, R.D. Brown, M.P. Lacroix, and P. Ménard. 2006. Recent trends in Canadian lake ice cover. Hydrological Processes, 20: 781-801

Eddington, M.M and J.L. Innes. 2008. Determining suitable biophysical indicators for anticipating and responding to climate change in British Columbia's forest and rangelands. Faculty of Forestry ,UBC.

Eddington, M.M., J. L. Innes, A.E. McHugh, A. C. Smith. 2009. Monitoring forest and rangeland species and ecological processes to anticipate and respond to climate change in British Columbia. FREP 20. B.C. Ministry of Forests.

Geertsema, M., J. J. Clague, J.W. Schwab, S. G. Evans. 2006. An overview of recent large catastrophic landslides in northern British Columbia, Canada. Engineering Geology 83: 120– 143

Geertsema, M., V.N. Egginton, J.W. Schwab, J.J. Clague. 2007. Landslides and historic climate in northern British Columbia Landslides and Climate Change. In McInnes, Jakeways, Fairbank & Mathie (eds). Taylor & Francis Group, London.

Geertsema, M., J. W. Schwab, A. Blais, M.-Stevens, and E. Sakals. 2009. Landslides impacting linear infrastructure in west central British Columbia. Nat Hazards 48:59–72.

Gruber, S. 2011. Landsides in cold regions: making a science that can be put into practice. Proceedings of the Second World Landslide Forum – 3-7 October 2011, Rome.

Holm, K., M. Bovis, and M. Jakob. 2004. The landslide response of alpine basins to post-Little Ice Age glacial thinning and retreat in southwestern British Columbia. Geomorphology 57 (2004) 201–216

Jordan, P. and J. Orban (editors). 2002. Terrain stability and forest management in the Interior of British Columbia: workshop proceedings, May 23–25, 2001 Nelson, British Columbia, Canada. Res. Br., B.C. Min. For., Victoria, B.C. Tech. Rep. 003.

Kremsater, L.L., and J. L. Innes. 2012. Monitoring forest and rangelands to anticipate and respond to climate change; information for phase 4 indicators. Report to UBC and MFLNRO (FREP).

Rodenhuis, D.R., K.E. Bennett, A.T. Werner, T.Q. Murdock, and D. Bronaugh. revised 2009. Hydro-climatology and future climate impacts in British Columbia. Pacific Climate Impacts Consortium, University of Victoria, Victoria BC, 132 pp.

Westfall, J. and T. Ebata. 2010. 2010 summary of forest health conditions in British Columbia. B.C. Forest Service, Ministry of Forests Lands and Mines.

Zhang, X., D.K. Harvey, W.D. Hogg, and T.D. Yuzyk. 2001. Trends in Canadian streamflow. Water Resources Research, 37(4): 987–998.

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