

# **Vulnerability of wetlands in the Central Interior Ecoprovince to climate change<sup>1</sup>**

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## **ABSTRACT**

As well as numerous ecosystem services, small lakes and wetlands provide important habitat for many waterfowl and other species. They also are vulnerable to the continuing effects to climate change, particularly drying trends.

We evaluated potential future consequences for wetlands in the Central Interior Ecoprovince (CIE) for two climate variables (precipitation as snow and summer heat-moisture index) that are expected to influence small lake and wetland persistence. Climate variables were projected for the study area using ClimateWNA software for two IPCC (Intergovernmental Panel on Climate Change) scenarios representing plausible futures.

We evaluated accuracy of the projection methodology against a series of measured water depths for 33 wetlands in the Riske Creek area. Efforts were informative for the sample area, but the small range in climate variables prohibited credible scaling up over the entire Central Interior Ecoprovince.

Small lakes and wetlands in the CIE will experience drying trends due to declining snow levels and increased summer drying. Further, increased and possibly accelerating, drying trends occurred in the scenario without CO<sub>2</sub> mitigation, illustrating that the fate of wetlands in the study area will be influenced by the success of international policies to mitigate CO<sub>2</sub>. The methodology credibly estimates the relative vulnerability of specific wetlands and can be applied elsewhere in the province, so can be used to guide efforts to adapt to climate impacts.

## INTRODUCTION

British Columbia is experiencing climate warming trends similar to those documented elsewhere in western North America (Mote 2003; Taylor 2005) and more globally (IPCC 2007). Some waterbirds already have responded to changing climate by altering their arrival times inland, their duration inland, the northward extension of their range and shifting their relative abundance northward (Bunnell and Squires 2005; Bunnell et al. 2005; Bunnell et al. 2008). Current warming trends are expected continue into the future (BCWLAP 2002; Taylor 2005; IPCC 2007; Bunnell et al. 2008).

Small, shallow wetlands and lakes are expected to be highly vulnerable to drying trends simply because they contain the least water. Actual losses will be subject to water inputs through precipitation, rivers and ground water. In the central interior region, warming trends have been documented and are anticipated to continue (Dawson et al. 2008). That is cause for concern for the waterfowl populations that depend on these wetlands.

The lakes and wetlands of the central interior of British Columbia provide important habitat supporting substantial numbers of many waterfowl species (Breault et al. 2007). The smallest of these wetlands and lakes in the region are the most productive for waterfowl (Figure 3). Small wetlands may also be the most vulnerable to drying, particularly if size and depth are correlated.

This study has 3 objectives: 1) to create a drying index from selected climate variables that expresses vulnerability of wetlands to climate change, 2) to project trends in climate variables expected to influence small wetlands and lakes in the central interior of British Columbia, and 3) to provide maps of the projected risk.

## STUDY AREA

The study area is the Central Interior Ecoprovince (CIE), an 11.1 million hectare region found in central British Columbia (Figure 1). It is a large and ecologically diverse region, incorporating ten of the province's biogeoclimatic zones (Meidinger and Pojar 1991). Of these, five forested zones predominate in the region: Engelmann Spruce Subalpine Fir, Sub-boreal Pine Spruce, Sub-boreal Spruce, Montane Spruce, Interior Douglas-fir and Interior Cedar Hemlock.

The region is rich in small lakes and wetlands (Figure 2), which provide significant support to populations of many waterfowl species (Breault et al. 2007).

## METHODS

Assessment was facilitated by the availability of ClimateWNA software that can downscale available historical and future global circulation model (GCM) data and generate a range of climate variables for application at regional or sub-regional scales (Wang et al. 2006). ClimateWNA software<sup>2</sup> was used to generate climate variables used. ClimateWNA extracts and downscales historical monthly data using PRISM (parameter-elevation regressions on independent slopes model; Daly et al. 2002). It also integrates future climate datasets (2020s, 2050s and 2080s) generated by various global circulation models (Wang et al. 2006). The model calculates seasonal and annual climate variables for specific locations in British Columbia based on latitude, longitude and elevation. For the CIE study area, climate variables were downscaled for latitude, longitude and elevation at centroids of a pre-generated 16-ha grid.

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<sup>2</sup> <http://www.genetics.forestry.ubc.ca/cfcg/ClimateWNA/ClimateWNA.html>

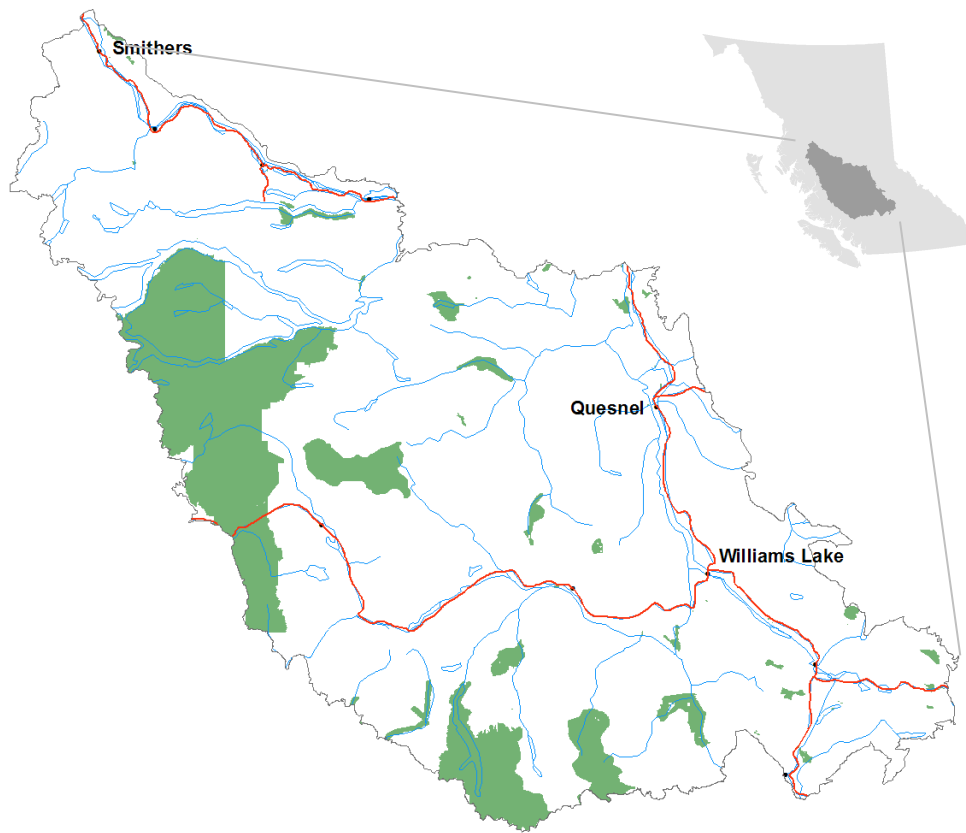


Figure 1. Central Interior Ecoprovince study area (protected areas in green).

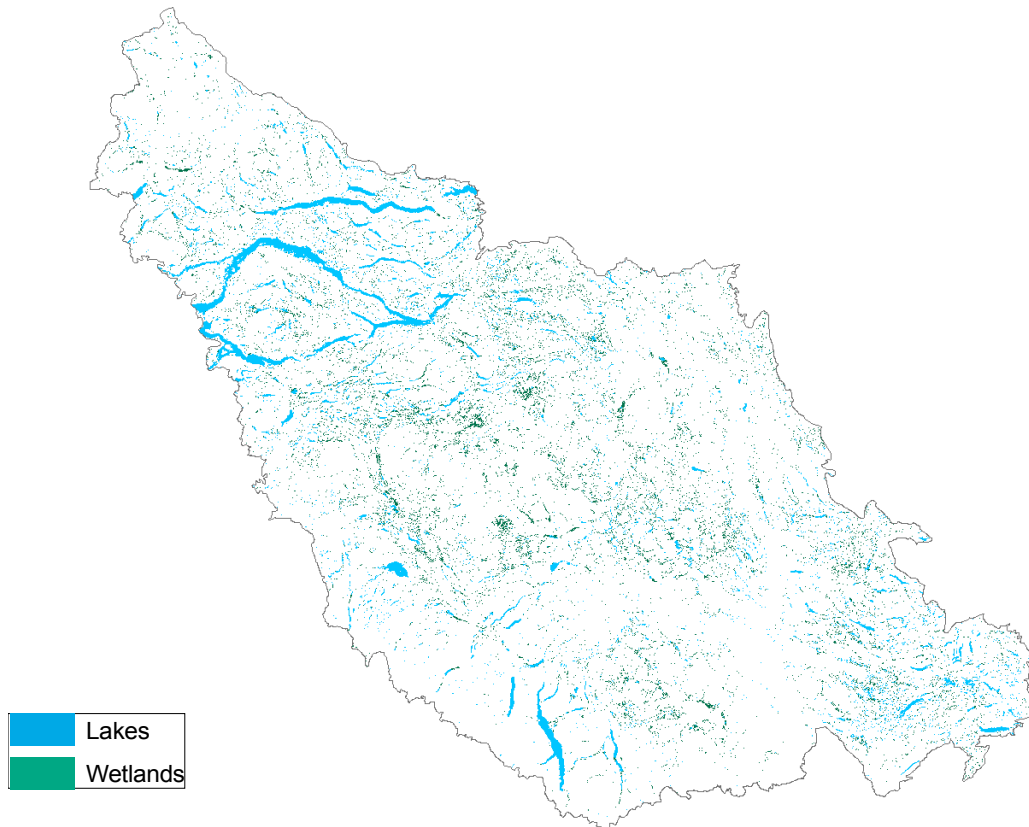
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Two climate variables were selected for evaluation: annual precipitation as snow (PAS) and summer heat-moisture index (SHM index). These variables were chosen from available variables because they were expected to have the greatest effect on the water balance of wetlands in the study area. PAS was expected to provide a primary water source (input) for wetlands, while SHM was expected to provide an indication of drying trends (output) for wetlands.

- PAS is a direct measure of snow precipitation (mm). It is provided on a calendar year (as opposed to preceding fall and current winter). That hinders evaluating individual year responses, but has little effect when merged over longer periods. Higher values represent greater water input.
- SHM is generated by ClimateWNA using the equation:  $(MWMT * 1000)/MSP$ , where MWMT is the Mean Warmest Month Temperature (°C) and MSP is Mean Summer (May – Sept) Precipitation (mm). SHM index is a derived variable, used as a proxy for direct measures of humidity or evaporation and transpiration that usually are unavailable

(Tuhkanen 1980). Higher values of the SHM index represent a stronger drying tendency relative to lower values (due to less precipitation and/or higher temperature).



**Figure 2. Lakes and wetlands in the Central Interior Ecoprovince.**

For use as a qualitative drying index, PAS and SHM data were normalized on a 0 – 1 scale, with higher values representing a higher risk of drying (PAS was normalized on an inverse scale, because higher PAS confers lower risk). Before normalizing, PAS data were log-transformed because limited amounts of very high snow levels (e.g., upper elevation areas) resulted in a highly skewed distribution of PAS data. These 2 normalized values were then combined multiplicatively (PAS x SHM) to yield a single (itself normalized) representing a measure of the risk of drying, ranging from 0 to 1. Multiplicative combination permits either drying or lack of snowpack to have a dominating effect. For example, an area with almost no snowpack or very high heat moisture index may be under much greater drying stress than an area with average levels of both variables. Wells et al. (2009) presented an identical approach to evaluation except the two normalized indices were combined as an additive index. An additive index does not distinguish between extremes of snowpack or the heat moisture index and averages values of the two. Elsewhere (Bunnell et al. 2010), we evaluated which approach was most predictive of measured water levels. When deciles are presented for either combined index they are calculated for all time periods within a particular climate scenario.

Any projection must have a reference baseline period from which to calculate changes. IPCC (the Intergovernmental Panel on Climate Change, employs the period recommended by the World Meteorological Organization – 1961-1990, which IPCC terms the “normal” period. To assess vulnerability PAS and SHM variables were projected for a baseline, ‘climate normal’

period (1961-1990), using downscaled climate data, and for two future scenario's representing differing levels of future global CO<sub>2</sub> production (mapped results for SHM and PAS are found in Appendices 3 and 4). Future scenarios selected for projection were the Intergovernmental Panel on Climate Change (IPCC) 'A2' scenario, representing continued economic growth with limited global coordination or cooperation and the 'B1' scenario, representing coordinated global efforts towards a non-carbon intensive economy (IPCC 2007). Of all IPCC scenarios, these represented the largest (A2) and lowest (B1) future CO<sub>2</sub> production and climate change outcomes (IPCC 2007).

A2 and B1 scenario data were available from ClimateWNA for three time periods: 2020 (representing the period 2010-2039), 2050 (representing 2040-2069) and 2080 (representing 2070-2099). Projections used here were downscaled by ClimateWNA from Coupled Global Circulation Model 3 (CGCM3) output, one of a suite of 23 models used for IPCC (2007) scenario projections. The CGCM3 model was developed by the Canadian Centre for Climate Modelling and Analysis (Flato 2005).

Lake and wetland spatial data used in this study were derived from British Columbia Corporate Watershed Base (CWB) data<sup>3</sup>, provided for the project by the Canadian Wildlife Service (CWS) of Environment Canada. CWB lake and wetland data were combined into a single layer for this study. Wetlands that were contiguous with lakes were removed, based on discussion with CWS (A. Breault pers. comm.) and remaining contiguous polygons were merged to form single polygons. For this study, only wetlands and lakes 10 ha or smaller are considered and they are collectively referred to as wetlands for the remainder of this report.

Climate data from the 16-ha grid were overlaid with wetland polygons and values were assigned to wetland polygons based on a 'biggest wins' rule: where more than one climate grid polygon intersected with a wetland, the value for the largest intersecting climate polygon was assigned to the wetland polygon.

Attempted calibration of the drying index used published data provided by A. Breault that measured water levels at three times of year for 33 wetlands in the Riske Creek area (24 with complete measurements over a 10-year period; 1997-2006). Climate for each wetland was downscaled for each year of measurement and comparisons made between the components of the drying index and measured water levels. Statistical analyses were restricted to simple regression and one-way ANOVAs. For details see Bunnell et al. (2010).

## RESULTS

### Current wetlands

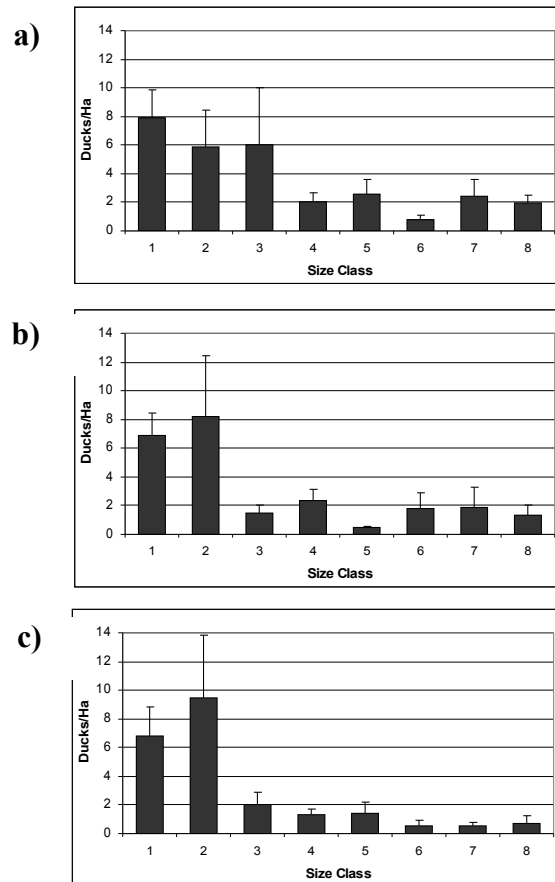
In total, we found 131,866 small wetlands (which we defined as 10 ha or smaller) representing 145,756 ha in total area in the study area. Wetlands were stratified by size class because impacts of climate were expected to vary with size as a correlate of depth. A substantial majority (70.7%) of wetlands were found in the smallest size class, though this accounts for only 22.9% of wetland area in the study area (Table 1). Conversely, the largest two size classes account for more than half of wetland area (59.4%) in only 15.5% of wetlands found in the study area (Table 1).

**Table 1.** Area and number of small wetlands for four size classes of wetlands found in the CEI study area.

<sup>3</sup> [http://www.ilmb.gov.bc.ca/bmgs/products/mapdata/corporate\\_watershed\\_base\\_products.htm](http://www.ilmb.gov.bc.ca/bmgs/products/mapdata/corporate_watershed_base_products.htm)

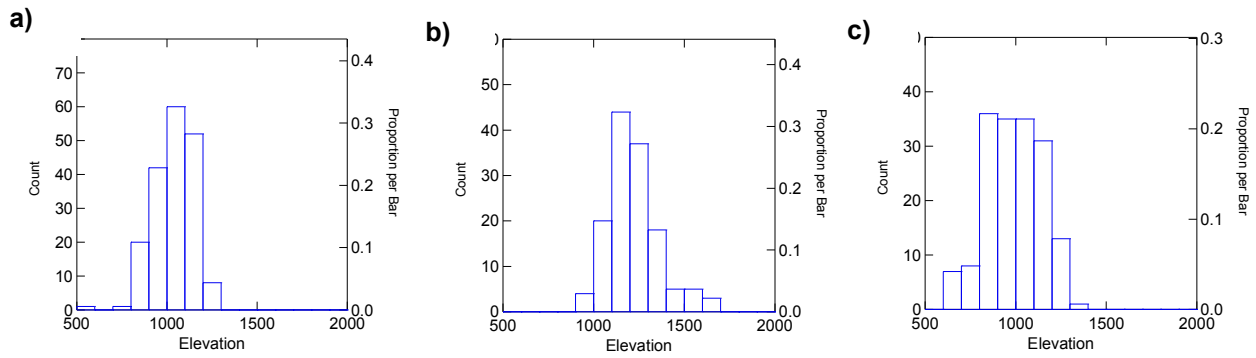
Size Class	Size Range	Area (ha)	Number
1	0 - 1ha	33,358	93,227
2	1 - 2ha	25,758	18,183
3	2 - 5 ha	45,689	14,607
4	5 - 10 ha	40,951	5,849
<b>Total:</b>		145,756	131,866

The smallest size class is not only the most abundant, but also the most productive. We evaluated productivity (ducks/ha) for three separate Ecosessions of the CIE (Figure 3).

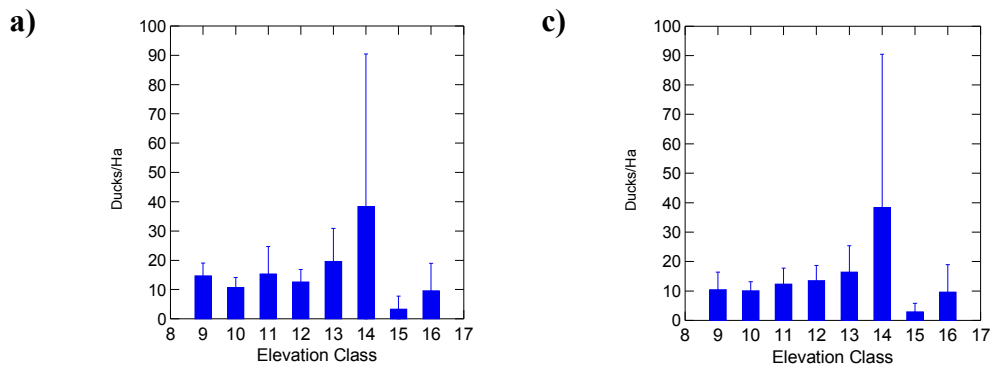


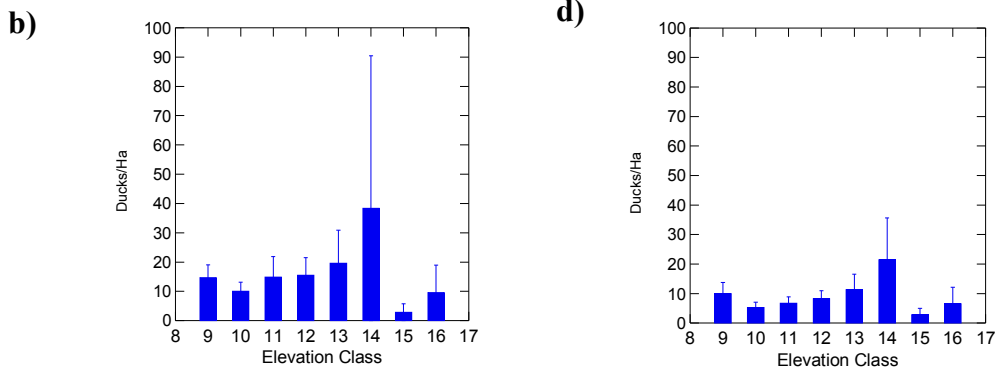
**Figure 3.** Relative density of waterfowl on wetlands of different size classes in the Central Interior Ecoprovince. **a)** Cariboo Basin **b)** Chilcotin Plateau **c)** Nazko upland. Relative density as ducks / ha. Size Classes: 1 = 0-1ha; 2 = 1-2ha; 3 = 2-3ha; 4 = 3-5ha; 5 = 5-10ha; 6 = 10-20ha; 7 = 20-50ha; 8 = 50+ha (transect survey data for 2008 provided by Canadian Wildlife Service; see Breault et al. (2007) for approach).

Across all three ecosessions, wetlands of >2 ha were consistently the most productive. The distribution of wetlands over different elevation bands differs for each ecosession, with the Chilcotin Plateau showing the least clumped distribution (Figure 4).



**Figure 4.** Distribution of all wetlands by elevation class. **a)** Cariboo Basin (n = 184) **b)** Chilcotin Plateau (n = 136) **c)** Nazko upland (n = 166). Transect survey data for 2008 provided by Canadian Wildlife Service; see Breault et al. (2007) for approach. Count = ducks/ha.





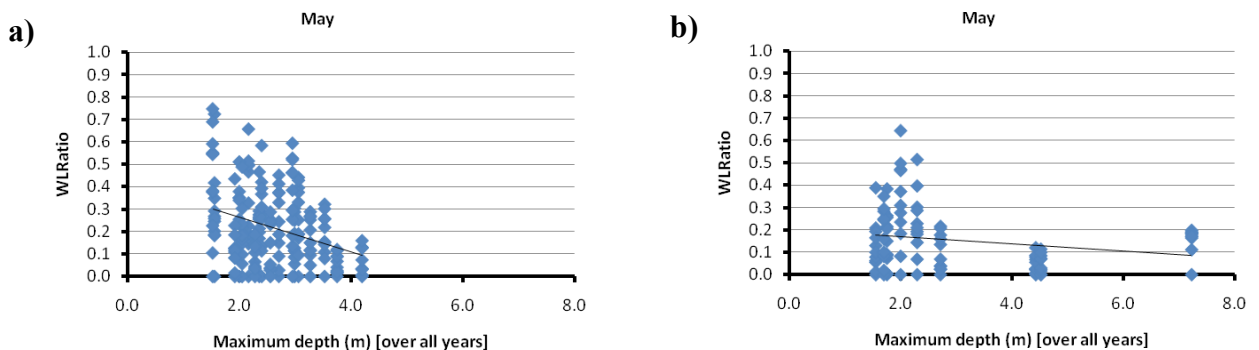
**Figure 5.** Productivity of wetlands (ducks / ha; mean  $\pm$  SE) as a function of elevation class in the Chilcotin Plateau. **a)** = wetlands <1 ha, **b)** = wetlands <2 ha **c)** = wetlands < 3 ha, **d)** = all wetlands. Elevation classes are: 9 = 900 to 999 m, 10 = 1000 to 1099 m, 1100 to 1199, etc.

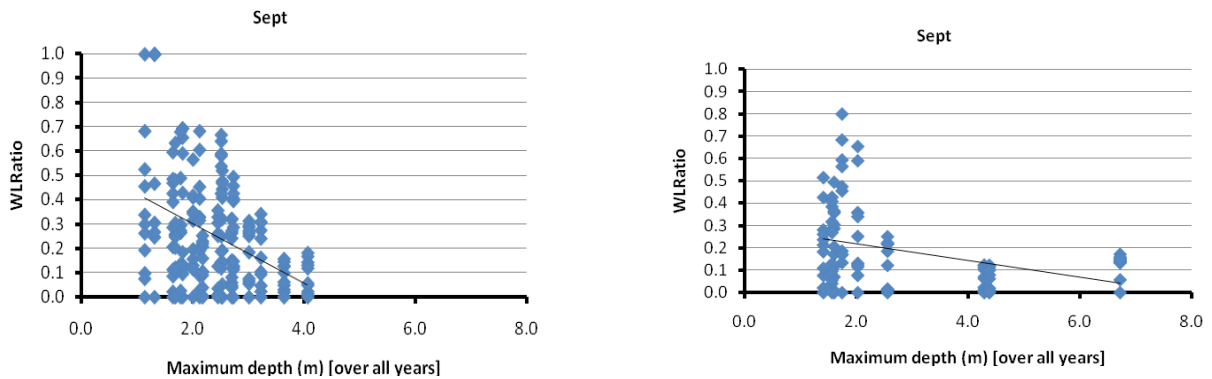
Elevation itself could have an influence on productivity of wetlands through temperature, surficial geology or other covariate. We evaluated relations of current productivity with elevation for the Chilcotin plateau (Figure 5).

Because the large majority of wetlands are <1 ha (Table 1), the depictions of Figure 5 expands the range of wetland sizes, rather than evaluating relationships over small groups of larger wetlands. The interpretation would remain the same in either depiction – from about 1000 m to 1500 m, there is a gradual increase in wetland productivity with elevation, after which productivity declines abruptly. The lowest wetlands (900 to 999 m) show somewhat higher productivity on average than those a few 100 m higher.

### Evaluating the drying index

Bunnell et al. (2010) report on efforts to evaluate the drying index. Unpublished depth measurements for 33 wetlands over the period 1997-2007 were obtained from CWS. Most wetlands were measured 3 times a year for the study period. Key points are summarized here.





**Figure 6.** Proportionate decline in water level as a function of maximum depth (WLRatio) of the wetlands during May and September of 1997-2007. **a)** elevation up to 975 m (measurements = 160 for May and September). **b)** elevation 975 m plus (measurements = 99 for May, 100 for September). Source: Bunnell et al. (2010: Figure 1).

No matter what causes a decline in water level, for the same decrease in water level, a greater portion of the water will be removed in more shallow wetlands. Given that most wetlands have relatively shallow gradients, the area of wetland will decrease disproportionately with decreasing water depth. The measure of wetland depth was the maximum recorded water depth for the specific wetland over the 11-year measurement period (1997-2007). The proportionate decline in water level (WLRatio) was expressed as (maximum water depth – measured depth / maximum water depth). Larger values indicate a greater decline in depth below the maximum for that wetland. In Figure 6, patterns are illustrated for two elevation classes of wetlands. Data points in the figure include all years for a wetland aligned with a single maximum depth of that wetland. That creates considerable scatter, because weather between years is highly variable.

As anticipated, a greater proportion of maximum depth is lost in shallower wetlands, which has implications for the effective size of wetland. Although there is considerable scatter as a function of annual weather differences, the direction of the change is robust (usually  $p < 0.001$ ; Bunnell et al. 2010: Table 1).

The maximum recorded depths of wetlands was significantly related to size of wetlands in the 33 wetlands evaluated in Bunnell et al. (2010). The resultant relationship was:

$$\text{Maximum depth (m)} = 1.85 + 0.11 \text{ Size (ha)} \quad \text{adjusted } r^2 = 0.63; p < 0.001$$

Size represents a useful surrogate for wetland depth, at least within the measured wetlands. The relationship has important implications. Over all wetlands in the Central Interior Ecoprovince, 84.5% of wetlands are  $\leq 2$  ha. Because these small wetlands are more shallow, they lose a greater portion of their water during drying (Figure 6) and a larger portion of favourable habitat. It is precisely the most productive wetlands that are most vulnerable (Figure 3).

Evaluation of the influence of the summer heat-moisture index (Bunnell et al. 2010) yielded two major findings. First, there is a general downward trend in water level with increasing SHM, as expected. Second, although the expected downward trend is generally apparent, it was strong only for shallow wetlands. Measured wetlands spanned only 50 m in elevation. Over that range, effects of wetland depth on drying overshadowed potential effects of elevation and differences in snowpack.

The range in climate variables of measured wetlands did not permit effective evaluation of the effects of snowfall. Based on their analyses, Bunnell et al. (2010) made recommendations for a more readily generalized water level index that extended beyond the sample of measured depths. They addressed a measured 'water level index' or depth of water; the 'drying index' used here is the inverse of that. We have modified their recommendations to accommodate that. They recognized 7 general principles:

- wetland depth has a large effect on the proportion of water lost from the wetland;
- wetland size is a useful correlate of wetland depth;
- as the SHM index increases, water output increases and empirical water levels decline;
- as PAS increases water input increases and empirical water levels should increase as effects of drying are compensated (not evident in the measured samples that were dominated by the SHM, because of very low annual snowfalls (< 10 cm);
- maximum summer temperature (a component of SHM index) does not have any apparent influence on its own – it is the combined effect of summer heat and moisture that shows relationships with water level;
- assessing the relative impacts of inputs and outputs on resultant water depth (PAS and SHM) would help to focus potential adaptive measures effectively; and
- normalizing climate variables permits a generalized index.

The indices of major inputs and outputs of water level have opposing effects on the resultant water level. To have the lowest empirical water levels associated with the highest levels of the drying index, the effect of PAS must be inverted so that greatest drying is associated with the lowest levels of PAS or least water input. The most flexible index would allow extremes of either PAS or SHM to have strong effects. That suggests a multiplicative form to the index rather than additive, which simply averages the two effects. The simplest combination, in the absence of data to the contrary, would allow inputs and outputs of moisture to have equal effect. The most appropriate form of the index is simple and multiplicative, but inverts the rank of PAS:

$$\text{Drying index} = (\text{normalized SHM} \times \text{inverted normalized PAS})$$

The index itself is normalized to increase generality.

Key findings when evaluating this form of the index against other forms using the same climate variables across the measured wetlands were:

- The multiplicative form consistently performed better than the additive form (lower standard errors of regression). That suggests that extreme values of either PAS or SHM do have a stronger effect than is evident when these are added or averaged.
- The multiplicative form offered a wider range of predictor values than did the additive index, even when normalized – again revealing the role of extremes of either contributor in the combined index and providing a wider range of applicability.
- When the elevation range is low, log transformation of snowfall data is unnecessary and actually increased the standard error of regression in most instances tested.

We expect the first two points not only to be general, but to be more pronounced when climate variables span a larger range than in the sampled wetlands. The third point is unlikely to hold when the range in snowfall and elevation is larger than that within the measured wetlands (50 m). When applied to the entire Central Interior Ecoprovince, we employed a log transform of snowfall data.

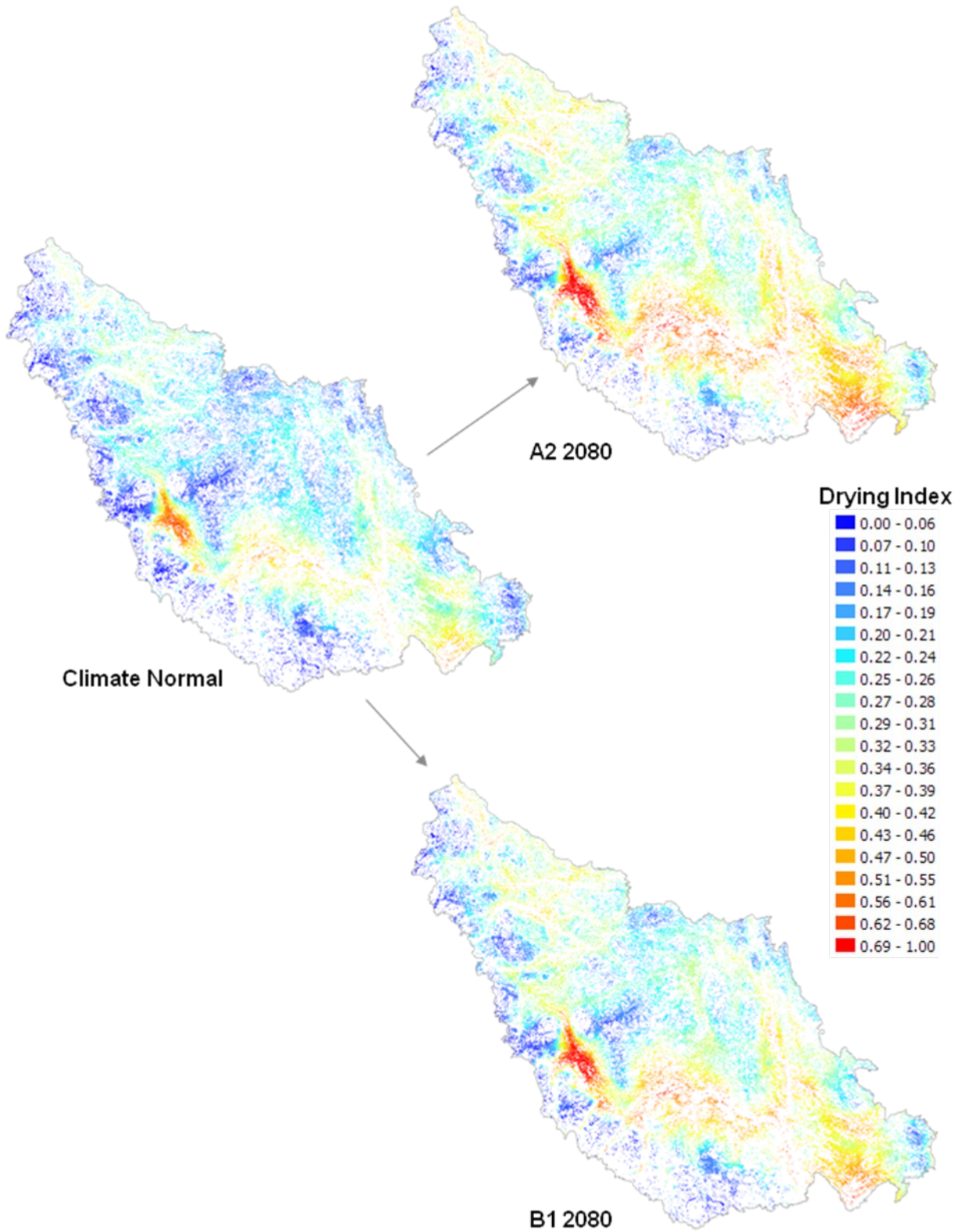
## Projected climate

Maps of the projected climatic effects are illustrated in Figures 7. A halo of 250 m is placed around each wetland to permit visualization of otherwise tiny dots. The Figure illustrates projection under each climate scenario (A2 and B1) projected to 2080 (see methods) and 'climate normal' (1960 to 1990). Note that 'climate normal' is a convention used by ClimateWNA to establish a base line. There was nothing normal about species' responses to climate change during that period. Bunnell et al. (2008) documented that for bird species there were significant, and sometimes dramatic, shifts in range, relative density, arrival and departure times, amount of overwintering and reproductive measures.

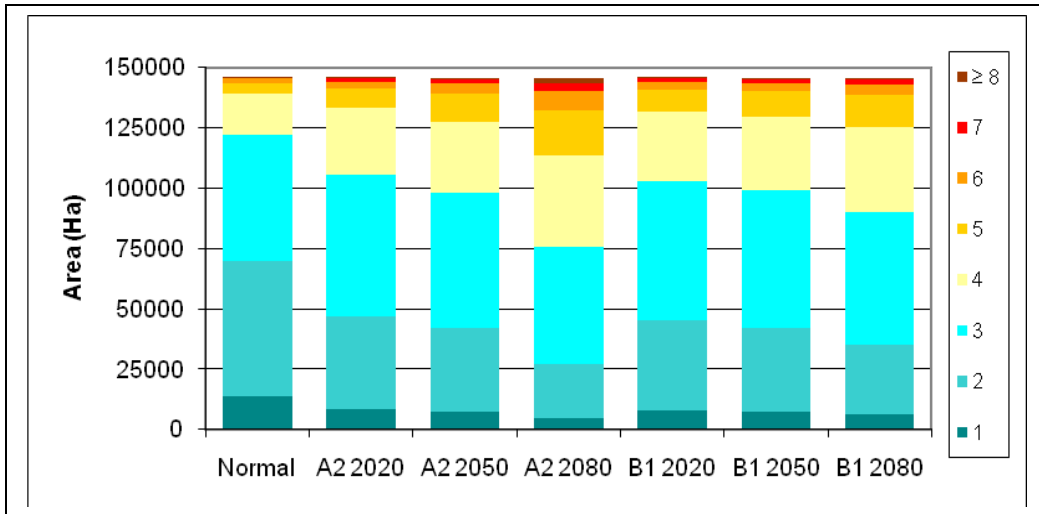
Broadly, the climate drying index increased substantially for portions of the landscape under both A2 and B1 scenarios (Figure 7), primarily in areas of low elevation in the study area. Climate drying index results were summarized by deciles to discern temporal trends for the A2 and B1 climate scenarios. To illustrate trends, deciles divide the range of observations over all projections within both scenarios into 10 equal parts. Trends in drying indices for number and area of small wetlands are illustrated in Figures 8 and 9. Generally, index values shift from lower to higher deciles for future time periods, with more extreme shifts for the A2 scenario (Figures 8 and 9). Under the A2 scenario, the majority of the wetland area and a larger proportion of wetland numbers occur in deciles 1 through 5. By 2080, the projections indicate most wetlands (number and area) are in deciles 6 and higher. Projected changes are less dramatic under the B1 scenario. Note that values in deciles 9 and 10 occur only under projected climates, not during the climate normal, indicating that wetlands will be experiencing novel and extreme drying conditions.

There was no obvious difference in decile patterns among wetland size classes, suggesting that the different size classes have similar spatial distributions in the study area; that is, they are experiencing similar frequencies of current and projected climate variables across the range of size classes. Note that this does not imply the same impact on wetlands of different size classes. Smaller wetlands also tend to be more shallow and will dry out faster when exposed to the same drying index.

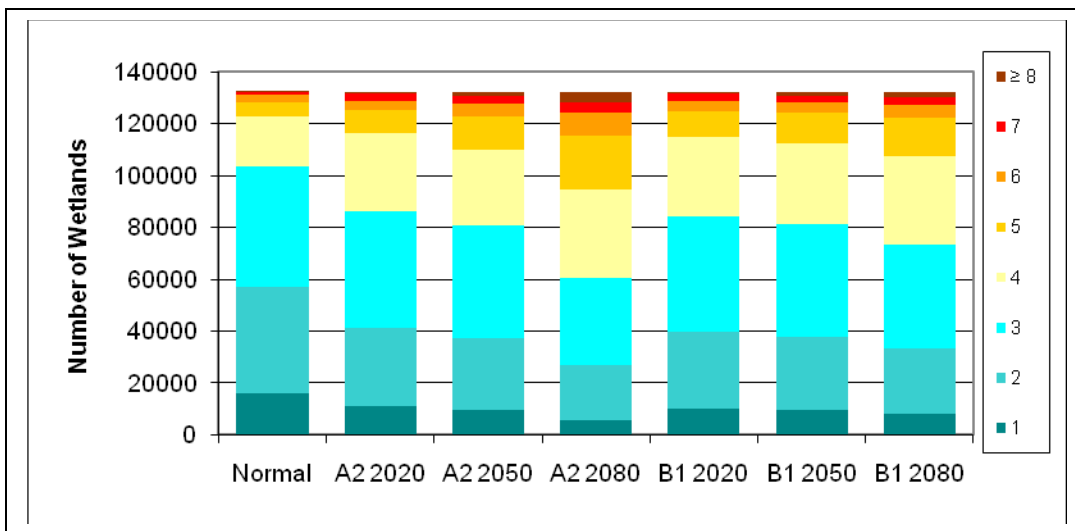
**Figure 7.** Climate drying index maps for wetlands (10 ha or smaller) for climate scenarios A2 and B1. Wetlands have a 250 m buffer to allow visualization of results. **True about halo?**



**Figure 7.** Climate drying index maps for wetlands (10 ha or smaller) for climate scenarios A2 and B1. Wetlands have a 250m buffer to allow visualization of results.



**Figure 8.** Area of small Central Interior wetlands (0 – 10 ha) by drying index decile (1 = lowest risk; 10 = highest). Deciles calculated over all years of all scenarios.



**Figure 9.** Number of small Central Interior wetlands (0 – 10 ha) by drying index decile (1 = lowest risk; 10 = highest). Deciles calculated over all years of a scenario.

During ‘climate normal’ for the smaller wetlands ( $\leq 10$  ha), about 83% of the area is in deciles 1 through 3 (Figure 8). Under the A2 projection to 2080 that proportion declines to <52%. Over the same period, the number of small wetlands in deciles 1 through 3 declines from about 78% to 46% (Figure 9). By 2080, under the A2 scenario, the majority or near majority of both number and area of small wetlands are projected to experience drying indices in the 4<sup>th</sup> decile or higher. Representation in decile 1 has fallen from 9.5% to 3% for area and from 12.2% to 4.4% for number. The pattern is similar within the B1 scenario, but is less pronounced. Comparison of 2080 values for the A2 and B1 scenarios illustrates that the effect of mitigation is not as strong as is desirable.

Effects are stronger for the smallest wetlands. During 'climate normal' for wetlands ( $\leq 1$  ha), about 98% of the area is in deciles 1 through 4 (Figure 8). Under the A2 projection to 2080 that proportion declines to  $<40\%$ . Over the same period, the number of small wetlands in deciles 1 through 4 declines from about 91% to 39% (Figure 8). By 2080, under the A2 scenario, the majority of both number and area of small wetlands are projected to experience drying indices in the 5<sup>th</sup> decile or higher; there is no longer any representation in decile 1. The pattern is similar within the B1 scenario, but is less pronounced. Comparison of 2080 values for the A2 and B1 scenarios illustrates the strong effect of mitigation.

The most noteworthy feature of the projection is that the most extreme drying indices (8<sup>th</sup> through 10<sup>th</sup> deciles) do not occur during the climate normal period, but are attained by 2050, expanding considerably by 2080. This pattern is general across all wetland size classes suggesting that the different size classes have similar spatial distributions in the study area. That is, they are experiencing similar frequencies of current and projected climate variables across the range of size classes.

Realized consequences of these projections are not clear, and very much dependent on depth of the wetlands. We expect, however, that wetlands in deciles 8 through 10 will vanish and those in decile 7 are extremely threatened.

Two broad natural features are known to, or likely to, influence the magnitude of the drying index – elevation and adjacent vegetation. Both temperature and snowpack are strongly covariate with elevation and have a strong effect on the drying index (Figure 10).

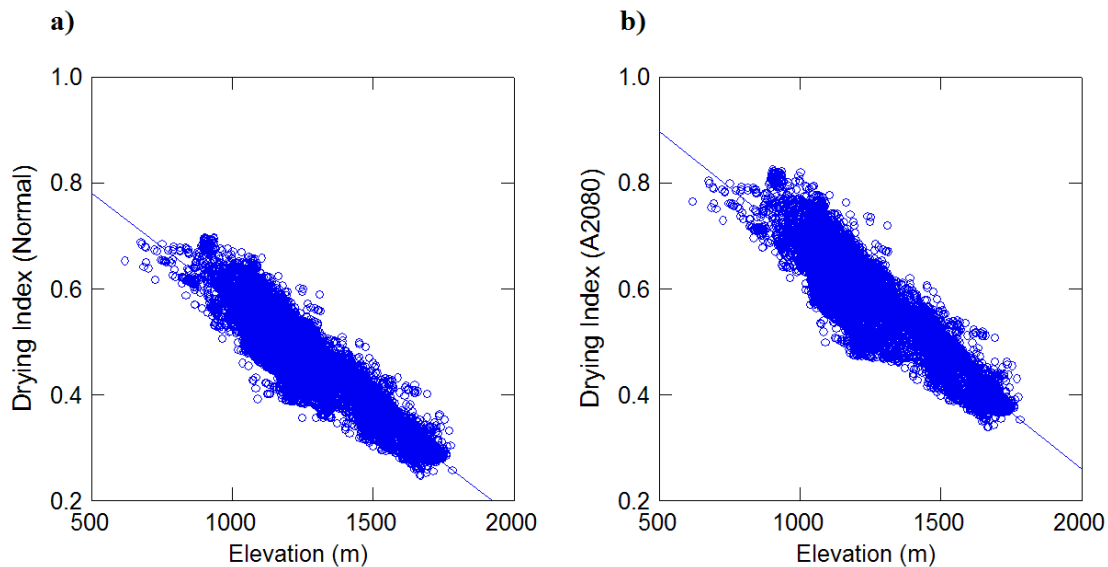


Figure 10. Normalized drying indices for (A) the climate normal period (1960 to 1990) and (B) climate to 2080 under the A2 scenario of the IPCC (2007) as a function of elevation for wetlands on the Chilcotin Plateau Ecosection. Both adjusted  $R^2$  values are  $>0.78$   $p < 0.0001$ .

Note, that between the scenarios, the decile values for the regression line have shifted up one decile class, but the form of the relation remains nearly identical.

## DISCUSSION

Based on CGCM3 projections of climate there will be a considerable increase in both area and number of wetlands receiving lower snow fall and greater summer drying (Figure 7). Those findings indicate that many small or shallow wetlands will experience significant drying trends in the future. That in turn will impact waterfowl populations in the region, because the smallest wetlands, many of which are the most vulnerable to drying trends, have been shown to provide some of the most productive waterfowl habitat (Figure 3).

The findings demonstrate the utility of available tools for projecting climate variables and assessing potential impacts on a regional basis, using methodologies that can be applied elsewhere in the province. The downscaling algorithm of ClimateWNA provided localized climate variables from much coarser historical data and GCM models, which allowed assessment at a scale relevant to wetland distribution in the study area. We caution that while downscaling has been shown to be accurate where climate data are available, the accuracy of downscaled results have not been assessed for many areas of the province and topographic strata (i.e., high elevation sites) where historical climate data are limited (Hamann and Wang 2005).

Examination of the spatial distribution of drying trends due to declining snow levels and increased summer drying suggest that these trends vary with elevation and latitude. The predictive ability of the summer heat-moisture index was documented (details in Bunnell et al. 2010), but the influence of snowpack is inferred. The inference is strong (more snowpack means more water), but the measured wetland depths spanned to small an elevation range for it to be validated. Series of measured water depths in small wetlands are rare, so work towards more general relations may be limited to known effects (snowfall increases with elevation) and exploration of geographic variables to assess factors most strongly influence climate variables that affecting the water balance of wetlands. Examination of the amount of change (absolute and relative) in climate variables may prove informative, particularly for areas already experiencing a precarious water balance. Although normalizing relations and using deciles assist generalizations, they are derived from a specific pool of climate data which restricts their applicability to that data. Bunnell et al. (2010) noted that decile 7 derived for the Southern Interior Ecoprovince may be the equivalent of decile 10 for the Central Interior Ecoprovince.

The findings also have important implications to climate change policy: the CO<sub>2</sub> intensive scenario (A2) showed a more substantial drying trend than did the scenario that was based on global efforts to mitigate CO<sub>2</sub> production (B1), particular over longer time frames (Figures, 7, 8 and 9). Further the rate of drying trends appears to accelerate with time under the A2 scenario (Figures 8 and 9). That pattern is consistent with IPCC scenarios of all 23 model projections, suggesting that the use of a particular global circulation does little to obscure broad patterns. The overall implication is that the success of national and international policies designed to reduce CO<sub>2</sub> emissions will be critical to determining the long term fate of small wetlands in the central interior of BC, and undoubtedly elsewhere.

We suggest that further work should seek opportunities (temporal series of depth measures) for evaluating projections of drying and increasing understanding of water inputs to wetlands from surrounding landscape. Because input is often from ground water, it is likely that local hydrological processes are too complex or poorly known to model effectively. However, it may be possible to determine generalized hydrological trends that broadly influence wetland persistence. This is expected to be driven in a large part by topography, but may also be influenced by forest management activities in the region, including widespread tree mortality due to the wide mountain pine beetle outbreak currently effecting much of the provinces lodgepole pine forests.

An obvious refinement is to link waterbirds and other species to simple classes of wetlands (size and elevation). We have begun that work, but results are very preliminary as more organism data are accumulated. Those linkages are expected to be broad when simple, easily mapped classes are employed, but should allow evaluation of how individual species and groups of species may be impacted by loss of small wetlands due to the influence of climate change impacts.

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Appendix 1: Climate drying index decile values

Table 1. Climate drying index deciles for area and number of Class 1 wetlands (< 1 ha).

Scenario		Decile									
		1	2	3	4	5	6	7	8	9	10
Normal	Area (ha)	97	829	3,613	8,092	13,255	5,639	1,521	245	0	0
	Number	385	3,396	12,275	21,494	35,665	14,916	4,463	802	2	0
A2 2020	Area (ha)	50	580	2,031	6,510	12,269	8,794	2,128	929	1	0
	Number	190	2,281	7,824	18,035	32,518	23,828	5,866	2,853	3	0
A2 2050	Area (ha)	20	460	1,822	6,012	11,696	9,023	3,105	1,152	1	0
	Number	76	1,789	7,130	16,992	30,883	24,714	8,294	3,516	2	2
A2 2080	Area (ha)	7	254	1,176	4,349	9,100	10,806	5,396	1,601	602	1
	Number	26	1,031	4,850	13,475	23,891	29,414	14,259	4,582	1,867	3
B1 2020	Area (ha)	30	530	1,944	6,356	12,043	9,059	2,368	961	1	0
	Number	108	2,037	7,627	17,720	31,848	24,637	6,460	2,958	3	0
B1 2050	Area (ha)	27	482	1,820	6,051	11,659	9,545	2,618	1,090	1	0
	Number	98	1,879	7,165	17,106	30,831	25,891	7,086	3,339	3	0
B1 2080	Area (ha)	12	370	1,533	5,392	10,832	10,537	3,278	1,310	27	0
	Number	44	1,449	6,262	15,783	28,574	28,518	8,701	3,984	83	0

Table 2. Climate drying index deciles for area and number of Class 2 wetlands (1 – 2 ha).

Scenario		Decile									
		1	2	3	4	5	6	7	8	9	10
Normal	Area (ha)	50	473	2,255	6,827	10,744	4,393	947	108	0	0
	Number	36	339	1,629	4,840	7,569	3,111	674	80	0	0
A2 2020	Area (ha)	34	279	1,240	4,924	10,369	6,801	1,644	506	0	0
	Number	24	200	894	3,518	7,314	4,804	1,157	367	0	0
A2 2050	Area (ha)	13	199	1,112	4,523	9,876	6,998	2,401	676	0	0
	Number	9	143	802	3,232	6,967	4,940	1,700	485	0	0
A2 2080	Area (ha)	2	112	697	2,969	7,785	8,696	4,116	1,122	299	0
	Number	2	80	498	2,126	5,506	6,134	2,922	795	215	0
B1 2020	Area (ha)	16	253	1,191	4,816	10,127	7,021	1,833	542	0	0
	Number	11	181	859	3,439	7,148	4,955	1,293	392	0	0
B1 2050	Area (ha)	13	235	1,108	4,531	9,875	7,381	2,049	606	0	0
	Number	9	168	800	3,236	6,971	5,212	1,445	437	0	0
B1 2080	Area (ha)	5	166	963	3,851	9,167	8,330	2,555	748	14	0
	Number	4	118	692	2,755	6,472	5,881	1,810	535	11	0

Appendix 1 cont.

Table 3. Climate drying index deciles for area and number of Class 3 wetlands (2 – 5 ha).

Scenario		Decile									
		1	2	3	4	5	6	7	8	9	10
Normal	Area (ha)	126	725	3,268	12,518	20,088	7,539	1,356	198	0	0
	Number	40	233	1,054	4,000	6,415	2,434	440	65	0	0
A2 2020	Area (ha)	61	521	1,830	8,521	19,395	12,082	2,720	689	0	0
	Number	20	169	580	2,750	6,178	3,887	871	226	0	0
A2 2050	Area (ha)	26	369	1,634	7,690	18,634	12,545	3,960	953	8	0
	Number	7	123	516	2,484	5,936	4,024	1,279	310	2	0
A2 2080	Area (ha)	4	240	1,009	4,621	14,565	16,121	7,094	1,751	414	0
	Number	1	78	320	1,495	4,647	5,149	2,290	563	138	0
B1 2020	Area (ha)	34	463	1,740	8,295	19,024	12,524	3,011	727	0	0
	Number	10	151	552	2,678	6,057	4,027	966	240	0	0
B1 2050	Area (ha)	29	424	1,609	7,733	18,516	13,298	3,360	849	0	0
	Number	8	140	510	2,494	5,898	4,271	1,081	279	0	0
B1 2080	Area (ha)	10	334	1,415	6,332	17,333	14,894	4,433	1,024	45	0
	Number	3	109	445	2,048	5,520	4,781	1,424	338	13	0

Table 4. Climate riskdrying index deciles for area and number of Class 4 wetlands (5 – 10 ha).

Scenario		Decile									
		1	2	3	4	5	6	7	8	9	10
Normal	Area (ha)	101	785	2,491	11,159	18,495	6,488	1,144	162	0	0
	Number	14	111	361	1,594	2,646	925	164	24	0	0
A2 2020	Area (ha)	42	621	1,560	6,837	18,218	10,854	2,078	590	26	0
	Number	6	87	224	986	2,604	1,545	299	84	4	0
A2 2050	Area (ha)	28	420	1,498	5,942	17,523	11,356	3,201	833	26	0
	Number	4	61	210	862	2,504	1,616	460	118	4	0
A2 2080	Area (ha)	19	218	1,028	3,464	13,653	14,578	6,106	1,353	380	26
	Number	3	31	145	506	1,938	2,089	874	195	54	4
B1 2020	Area (ha)	36	507	1,536	6,520	17,816	11,400	2,341	644	26	0
	Number	5	72	219	940	2,550	1,621	337	91	4	0
B1 2050	Area (ha)	36	470	1,488	5,970	17,348	12,105	2,632	750	26	0
	Number	5	67	211	864	2,481	1,722	379	106	4	0
B1 2080	Area (ha)	19	354	1,352	4,803	16,027	13,753	3,564	915	38	0
	Number	3	51	189	698	2,281	1,972	509	130	6	0