Biodiversity BC

CONSERVING THE VARIETY OF LIFE

Preliminary Analysis of BC Climate Trends for Biodiversity

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PACIFIC CLIMATE IMPACTS CONSORTIUM

FOR: THE BIODIVERSITY BC TECHNICAL SUBCOMMITTEE

FOR THE REPORT ON THE STATUS OF BIODIVERSITY IN BC

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7 September 2007

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Preface

The assessment and protection of biodiversity is now acknowledged as an important responsibility for human life. The concept of biodiversity is maintained by a complex balance of competing influences. An understanding of this balance is now complicated by the knowledge that the global climate is changing.

What are the impacts of global climate change on the regional climate system and biodiversity? Is biodiversity sensitive to the traditional measures of climate change such as trends in temperature and precipitation?

This study documents the technical details of a new approach to historical climate trends for use in the study of biodiversity.

The analysis described in this report was funded by two separate contribution agreements from the Biodiversity BC Steering Committee. Supplemental funding was provided to synthesize the findings into this report by the Climate Change Section, Environmental Protection Division, BC Ministry of Environment. This project was carried out by Pacific Climate Impacts Consortium (PCIC) staff. PCIC is a multi-disciplinary consortium that includes researchers and climate specialists who address climate variability and change, extreme weather events and their impacts on natural ecosystems and commercial enterprise.

Dave Rodenhuis, Acting Director
Pacific Climate Impacts Consortium
7 September 2007

Executive Summary

This report summarizes the development of techniques for analysing historical climate trends to use in understanding impacts of biodiversity and some preliminary results. The primary objective of this investigation was to create an index of climate change for biodiversity at as high resolution as possible. Final results are at a 0.5° spatial resolution. Additionally, an attempt was made to combine trends into a single index. However, the combined index was found to be less meaningful than separate trends in temperature and precipitation.

Methods were developed to show total change throughout the year by summing the trends in each month and to normalize the amount of change by the natural historical variability. Because many aspects of biodiversity depend on changes that occur in specific times of year, summing trends in each month provides only limited additional information than annual averages. Further interpretation may be possible in future by analysing the monthly trends (computed but not shown in this report).

Analysis of these annual 1971-2000 trends provides some results not evident from longer trends. For example, during this recent period much of BC exhibits trends toward drier annual conditions, in contrast to 50 and 100 year trends. Furthermore, temperature trends during the past 30 years are typically larger than those measured over 50 or 100 years. Trends normalized by variability also provide some additional information. For example, although precipitation trends in the southern central interior of BC are smaller than neighbouring areas in terms of amount (mm per year), these small trends are relatively larger than other areas of BC in comparison to historical variability. Similarly, absolute trends (°C per year) in maximum temperature are smaller along the coast of BC but these increases may have a larger impact on biodiversity than they would in other areas of the province because the trends are much larger on the coast than other areas relative to historical variability.

The main difference between the trends shown here and other analyses of historical trends for BC is the use of the 1971-2000 time period. Interpretation of the trend in this short recent period may be misleading unless accompanied by strong caution regarding climate variability and extrapolation of trends. However, these trends do reflect the actual change in conditions that occurred over this recent 30-year period, and it can be argued that this is precisely what will influence biodiversity.

1. Background

The Biodiversity BC Steering Committee, a body consisting of several governmental and non-governmental agencies and organizations, is preparing a *Biodiversity Atlas for BC.* The Atlas is intended to be the spatial analysis component of a *Status Report on Biodiversity.* The Atlas will provide a province-wide overview of elements of biodiversity, including pressures affecting it at both ecosystem and species levels.

Providing climate trends in a form useful for comparison with other indices in the Atlas required novel map-based indices of climate trends. This report documents the methods used and briefly describes the results.

Biodiversity is defined, for the purposes of climate impacts analysis, by the Intergovernmental Panel on Climate Change (IPCC) as "the numbers and relative abundance of different genes (genetic diversity), species, and ecosystems (communities) in a particular area" (IPCC, 2002). Climate trends have an important effect on biodiversity on timescales ranging from years to decades. Parmesan, for example, cites one estimate that 59% of 1598 species have changed their dates of occurrence and/or distributions the past 20 to 140 years (Parmesan, 2006). A meta-analysis of the Northern Hemisphere suggests latitudinal and elevational shifts for species range of 6.1 km/decade northward and 6.1 m/decade upward. Projected responses to climate change also include significant changes to biodiversity (Williams *et al.*, 2007).

Changes in biodiversity can in turn affect climate (IPCC, 2002); in fact, the system is highly complex. For example, the interactions among changes in land use, atmospheric greenhouse gas concentrations, nitrogen deposition and acid rain, climate, and biotic exchanges (deliberate or accidental introduction of plants and animals to an ecosystem) are among the largest uncertainties in projections of future biodiversity change (Sala *et al.*, 2000). Identifying the relative influence of a changing climate independently of other factors may not be possible, especially as changes in biodiversity due to climate can occur slowly, making them hard to distinguish from other stressors that influence over shorter time scales (Kappelle *et al.*, 1999).

An analysis of climate change and variability in BC as measured by trends in temperature and precipitation shows that changes are already occurring across BC (Rodenhuis *et al.*, 2007), with the following findings:

- positive trends in annual average daily minimum temperature (+1.0 to 2.5°C), and in average daily maximum temperature (+0.5 to 1.5°C) have been documented. In northern BC the trends in minimum wintertime temperature were up to +3.5°C per century. For comparison, the global temperature trend of mean temperature is +0.7°C (between +0.6 and 0.9°C).
- trends in precipitation were also generally positive (+22%) and some observations of +50 % occurred in wintertime in the interior. However there were exceptions and some of the trends were reversed (negative) when a shorter record of 50 years was utilized.

Long-term climate change can stress some species and benefit others. For example, anecdotes of Garry Oak growing outside of its previous range are becoming ever more common, consistent with the projections at www.PacificClimate.org/impacts/rbcmuseum However, warming over the past century has also allowed some species to become more competitive; even, like the mountain pine beetle, to become epidemic. Decadal climate variability can stress some species with long life spans while others are more resilient, and quick-response species may even derive opportunity from variability. Similarly, short-lived species with many generations per decade have a greater probability of adaptation at the genetic level to climate change than do those with only a few generations per century. Coastal, high-latitude, and high-altitude ecosystems have been more directly affected than others (IPCC, 2002). Although this report focuses on air temperature trends over land only, the impact of climate on marine ecosystems will be different from terrestrial ones.

2. Methodology

In order to determine trends that would be more relevant or provide additional insight for presentation in the *Atlas* alongside other factors affecting biodiversity than the climate trends described above, several key assumptions about the influence of climate on biodiversity were made. These assumptions are listed in Table 1 along with the corresponding steps taken in development of the methodology for computing trends. Following a list of data sources, each of the trends and indices computed is defined. The section ends with short notes on downscaling and future scenarios.

Table 1: Assumptions and steps taken for definition of trend indices

Assumption	**Steps taken**
1. Biodiversity responds to changes regardless of when they occur throughout the year rather than to seasonal or annual averages.	1. Based indices on average magnitude (absolute value) of change in each month, not seasonal or annual averages. For example, a trend of equal magnitude toward wetter February and drier March does not cancel out but rather is twice as much change.
2. a) Biodiversity responds to conditions created by both the average climate and by climate variability. b) The standard deviation of climate over the historical period is an indication of variability.	2. a) Computed absolute trends as well as normalized by historical variability. b) Normalized the trend at each location by its standard deviation.
3. Most aspects of biodiversity included in the *Atlas* depend mainly on the most recent trends.	3. Used 30-year 1971-2000 trends and standard deviation instead of longer-term trends.
4. Biodiversity (ignoring effects of migration) at a location responds to temperature and precipitation change at a fine spatial scale.	4. Used gridded 0.5^{o}x0.5^{o} data; attempted downscaling to ~4km.

2.1 Selection of Data Sets

CRU

The CRU (Climatic Research Unit, University of East Anglia; Mitchell and Jones, 2005) data is included with the ClimateBC software package that is freely available (Wang *et al.*, 2006). The historical dataset in ClimateBC version 3.1 is at 1 degree and is averaged from the original 0.5° (roughly 50 km x 50 km over much of BC) dataset. ClimateBC version 3.1 was used in the first phase of development, but final results use the original dataset from Mitchell and Jones (2005) at 0.5° resolution. The dataset covers the 101 years from 1901-2001 with a total of 175 grid boxes over BC.

PRISM

The PRISM (Parameter-elevation Regressions on Independent Slopes Model; Daly *et al.*, 2002) dataset is at a resolution of 2.5 x 2.5 arcmin (roughly 4km x 4km over much of BC) for the reference period (1961-1990). The dataset is based on interpolated station data plus higher resolution information that influences temperature and precipitation, particularly elevation and aspect. PRISM data was used to investigate the possibility of downscaling to high resolution.

Other

A comprehensive comparison of results from different high-resolution historical datasets was not performed, but would yield useful guidance to the level of uncertainty present in the historical dataset. Examples of other datasets available include McKenney *et al.* (2006), Zhang *et al.* (2000), Kalnay *et al.* (1996) and Hijmans *et al.* (2005).

2.2 Definition of indices

Trends were computed from the historical data in the CRU data set for nighttime low and daytime high temperatures (T_{min} and T_{max}) as well as precipitation (Prec) by taking both the trend and standard deviation over the 1971-2000 period and dividing the magnitude of the trend by the standard deviation.

The climate change trend index was developed independently for each of three parameters and each of two ways of normalizing (by the historical variability of the location or by the average variability for the province). In addition, data were provided for the actual trend itself, absolute trend index and the historical variability trend index described below.

Trend

The trend, m_{Pi} is the slope of a least-squares linear fit to time series P where P is the parameter (T_{min},T_{max}, or Prec) and i is the time of year (1-12 from January…December, 13-16 = DJF, MAM, JJA, or SON seasonal averages, 17 = ANN annual average).

The 1971-2000 time period was used to compute the trend for all results in the *Atlas*. Indices were also computed for the 1951-2000, 1901-2000, 1961-1990, and 1941-1970 periods for comparison to other published trend results. A small subset of these results is shown in the discussion.

Note that it was considered adequate for these illustrative purposes to use simple trend calculations for computation of these indices, which require cautious interpretation due to the subjective nature of their definition. However, it must be noted that no steps have been taken to remove outliers or to test trends for statistical significance. Subsequent updates to this preliminary work should incorporate the commonly used peer-reviewed methods for ensuring robustness in computations of historical trends such as Sen's slope estimator, the Mann-Kendall test for significance of trend, and pre-whitening the time series to remove auto-correlation (Mann, 1945; Sen, 1968; Kendall 1975; Zhang *et al.*, 2000).

Absolute trend index

The absolute trend index, *ATI,* measures the average trend in each month of the year. The main difference between *ATI* and regular trends is that the absolute value of the trend from individual months is averaged; i.e., changes of opposite sign in different months reinforce rather than canceling out as they would in a standard annual average trend. *ATI* is defined as:

$$ATI_P = \frac{\sum_{i=1}^{12} \left| m_{P_i} \right| d_i}{365} \tag{1}$$

where m_{Pi} is the trend (slope of linear fit; per year) over 1971-2000 where P is the parameter (T_{min},T_{max}, or Prec) and i is the time of year (1-12 from January…December, 13-16 = DJF, MAM, JJA, or SON seasonal average, 17 = annual average), and d_i is the number of days per in the time period i. Here, the absolute value of the trend is summed for all months weighted by the number of days per month and divided by 365 to provide an average index per month; leap years are not taken into account. All months were treated equally, but if some months were considered more influential, this index could be modified to weight months according to their importance.

Historical variability trend index

The historical variability trend index, *HVI*, was computed in order to normalize results by a measure of historical variability; the standard deviation over the 1971-2000 period was used for this purpose. Two different methods of normalizing were performed: the first method used the standard deviation at each grid point (by location), the second method used the same standard deviation at all locations (average over the Province). Multiplying by 100 results in a unit of trend per century rather than per year for *ATI*. Note that the use of per century as a unit of measurement does not imply that the trend based on 1971-2000 has been occurring for the past century. The *HVI* is defined as follows:

$$HVI_{P,i}^{N} = 100 * \frac{m_{P_i}}{\sigma_{P_{i71-00}}^{N}} \tag{2}$$

where N denotes the type of normalization (L: by location or BC: provincial average), and $\sigma_{P_{i71-00}}$ is the standard deviation during 1971-2000 for time of year i (1 – 17 as above).

Climate change trend index

Finally, the climate change trend index, *CCI*, was computed by summing the absolute values of the historical variability trend index *HVI* for each month following the method used for expressing the monthly trends in terms of the trend index *ATI*:

$$CCI_{P}^{N} = \frac{\sum_{i=1}^{12} \left| HVI_{P,i}^{N} \right| d_i}{365} = 100 * \frac{\sum_{i=1}^{12} \frac{\left| m_{P_i} \right| d_i}{\sigma_{P_{i71-00}}^{N}}}{365} \tag{3}$$

where d_i is the number of days in the time period *i*. Here, the absolute value of the trend is summed for all months weighted by the number of days per month and divided by 365 to provide an average index per month; leap years are not taken into account.

2.3 Downscaling

Considerable effort was made towards downscaling to higher resolution. The first attempt, to use ClimateBC (Wang *et al.*, 2006), revealed the difficulty in using a downscaling technique based on combining a high resolution historical climatology with a coarse resolution historical time series: for any parameter that measures a change with time, the high resolution climatology cancels out. Although several attempts were made to work around this problem, downscaling was not feasible and final results are available at 0.5° only.

3. Results

Trends and each of the trend indices were computed for all time periods. Annual, seasonal, and monthly values were computed in all cases. A subset of selected maps is shown here as well as maps from the *Atlas* that were prepared based on the same data. First, a sample map from the *Atlas* is shown.

Maps in the *Atlas* are displayed as percentiles of the quantity shown. Fig. 1 shows species richness of freshwater fish across BC as a percentile of all values. The deepest red colour indicates the 91-100th percentile, which corresponds to 26-30 species observed since

1961 (of 71 species total), yellow indicates the 51-60th percentiles (20 species), and the deepest green indicates the 0-10th percentile (the fewest number of species: 11 or less). Subsequent maps from the *Atlas* have percentile ranges corresponding to the same colours, although actual values shown in the legend depend on the distribution and may not be visible as shown here.

Trends (*m*)

Maps of annual trends are shown below (Fig. 2). In comparison to other analyses of trends since 1951 or earlier, these trends will generally be larger (see *length of record* sub-section). Minimum temperature trends are larger in magnitude than maximum temperatures, particularly in much of the northern portion of the province (cf. Fig. 2a and 2b). The precipitation trends in the short 1971-2000 period are negative over most of BC, particularly the north coast; positive annual trends are present for the south coast, lower mainland, and some portions of the southern interior (Fig. 2c).

Absolute trend index (*ATI*)

The absolute trend index, in which the magnitudes of trends from each month are averaged, is shown in Fig. 3. Temperature results are consistent with Fig. 2, because temperature trends are of the same sign (warming) in almost all cases. Presentation as percentiles allows for the areas with relatively large trends in maximum temperature to stand out (the north coast and some areas of northern BC; Fig 3b). In this case, the legend shows that maximum temperature changes are smaller than minimum temperature (e.g., 90th percentile changes of .56°C and .68°C per decade respectively). *ATI for* precipitation differs from *m* due to averaging the magnitude of wet and dry trends from different months. In this sense, most ATI_{Prec} change is occurring on the coast and in the Kootenays.

Relative trend index (CCI^L)

The effects of normalization by location and summing over trends in each month of the year are shown by comparing absolute trend index *ATI* (Fig. 3) to the CCI^L index (Fig. 4). Along the coast, large CCI^L_{Tmax} occurs despite small absolute trends because the historical variability (Fig. 6) is also small at these locations.

CCI^L is also shown on a standard scale (0 to 4 standard deviations per century) below in addition to as percentiles. Fig. 5 demonstrates that CCI^L_{Tmin} is larger than CCI^L_{Tmax} at most locations and that for precipitation, most of the province exhibits a similar level of change (~1.5 to 2 standard deviations per century), regardless of location (i.e., large precipitation trends tend to occur in the same locations that have large variability).

Historical variability

The standard deviation during the 1971-2000 period (used in HVI^L and CCI^L) to normalize by location, is shown below. High historical variability reduces CCI^L and vice versa, as discussed in the previous section. The variability has been relatively constant in time for each of the three parameters and was computed also for all time periods (not shown).

Length of record

Length of record used for computation of trends can be extremely influential. Generally the longest record possible is preferred for determining climate trends. However, in this case the recent record was used intentionally because of the assumption (see section 2) that for most aspects of biodiversity shown in the *Atlas*, it is the recent trend that will be most important. Although it is beyond the scope of this report to analyse the underlying climate variability over the past century, it is important to note that the Pacific Decadal Oscillation, global warming trends, and drought near the early part of the 20th century all play a significant part in the differences between the results shown below.

Trends for each parameter are shown for several time periods in Table 2. Values shown are median of all values in the region. Results were also computed for 1941-1970 and 1961-1990 (not shown). Minimum temperature *CCI* (Fig. 7, Table 3) results show that the recent *CCI* is larger for periods of record that begin earlier. Because the historical variability is quite constant (Fig. 6), this result is attributable to larger temperature trends for the shorter period of record (Table 2).

Table 2: Median trend (m) for each parameter over different periods of record

	1901-2000	1951-2000	1971-2000
T_{min} (^{o}C per decade)	+.2	+.3	+.5
T_{max} (^{o}C per decade)	0	+.2	+.4
Prec (mm/month per decade)	+.7	+.3	-.7

Table 3: Median climate change trend index (CCI) for each parameter over different periods of record (standard deviations per century)

	1901-2000	1951-2000	1971-2000
T_{min}	1.0	1.9	3.0
T_{max}	0.4	1.1	2.0
Prec	0.4	0.9	1.7

Precipitation trends are influenced so much by the starting point of the record that the median change actually reverses sign depending (Table 2). Not only are precipitation trends variable, though, the total amount of change, as reflected by *CCI* is also increasing in the recent period (Table 3).

Seasonal, monthly and other results

In order to examine the separate effects of averaging the absolute value of changes for each month and that of normalizing trends by historical variability, a comprehensive comparison of the absolute trend *m* to *ATI*, *HVI,* CCI^L, and CCI^{BC} is required, including monthly and seasonal results as well as additional periods of record.

Such a comparison is beyond the scope of this paper. A preliminary inspection of seasonal results indicates that much of the temperature trend index is influenced by the trends in the winter months, as might be expected. Normalizing by location also appears to emphasize small changes in months with small variability (typically summer months for both temperature and precipitation). Monthly changes show some large differences between adjacent months. The variability in trends from one month to the next is relatively large because of the short 1971-2000 time period. This underscores the importance of extending this analysis of results to monthly and seasonal trends.

4. Summary

One step toward quantifying the impact of climate change on biodiversity is to provide maps that illustrate how rapidly climate has been changing in the past relative to historical variability. In this preliminary analysis, trends have been normalized by the amount of variability to provide an index of historical climate change, with an intentional focus on the recent 1971-2000 period. Visual comparison of the index to changes in aspects of biodiversity displayed in the *Status Report on Biodiversity* will facilitate the posing of useful hypotheses about quantifying the impact of climate change on biodiversity in BC. Several indices were created at 0.5° resolution for comparison to other elements in the *Status Report on Biodiversity.*

The climate change index was compared to absolute trends as discussed above. For temperature, the effect of normalizing by location dominates the differences between the *Climate Change Index (normalized by local historical variability)* CCI^L and *annual absolute trend* (m_{ANN}.) Some locations (and months) with small variability display large changes in the relative index CCI^L that are not apparent in the trend maps m_{ANN} (cf. Fig. 2 and 4). Coastal areas show this effect most prominently, and increases in summer temperatures become relatively more important. For precipitation, the effect of summing the magnitude of monthly trends is compounded with the normalization by location but generally large trends appear to occur in areas with large variability.

An analysis of length of record indicates that the use of a recent, short record amplifies the magnitude of trends as compared to the long-term trends. For temperature, the effect is a fairly geographically coherent amplification of the magnitude of the trends. For precipitation, the period of record can reverse the sign of trends in many locations. This indicates that a 30-year period is not suitably long for determining long-term trends, particularly for precipitation – which has relatively more variability (in space and time) than does temperature – and underscores the caution that these results only be used with the caveat that they represent only the trend during the 1971-2000 period. If the assumption turns out to be false that the trend during this period is relevant, care must be taken not to generalize these trends but rather to use the trends from the appropriate (usually the longest) period of record available.

Several opportunities for further work exist (see below). Further progress towards assessing the impact of climate change on biodiversity will require significant amounts of historical climate and biodiversity data as well as an understanding of the (most likely non-linear and complex) relationships between climate and different aspects of biodiversity.

Recommendations for further study include:

- Conduct thorough analysis of monthly and seasonal trend results in collaboration with biodiversity experts, in order to maximize the value of the trends computed and to prioritize the other next steps listed below
- Consult literature review currently in preparation by BC MOE on biodiversity and climate change to investigate other methods or approaches
- Investigate relationships between *CCI* and temperature and precipitation trends, or other methods of linking temperature and precipitation impacts on biodiversity
- Investigate the possibility of quantitative relationships of climate to aspects of biodiversity by
    - assembling and analysing climate and biodiversity datasets, and
    - designing and conducting case studies
- Compute (revised) *CCI* using GCM and/or RCM scenarios of future climate over the next century
- Investigate the effects on (revised) *CCI* of different time slices from 1971-2000
- Conduct more sophisticated trends analysis (remove outliers, examine statistical significance of trends, etc.)

Acknowledgements

This analysis described in this report was made possible through funding by two separate contribution agreements from the Biodiversity BC Steering Committee. Supplemental funding was provided to synthesize the findings into this report by the Climate Change Section, Environmental Protection Division, BC Ministry of Environment.

The authors would also like to thank Nancy Turner, Bob Peart, Richard Hebda, and Harry Swain for valuable review.

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Figures

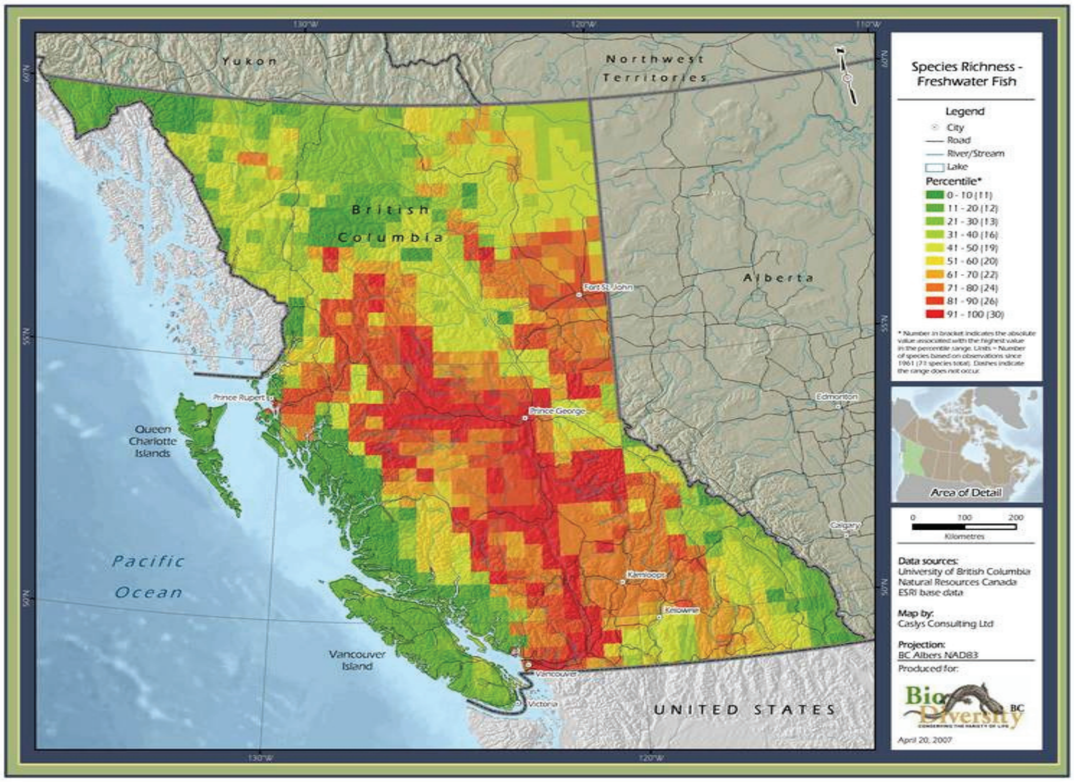


Figure 1: Sample map from Atlas: Species richness freshwater fish

Fig. 2a

Fig. 2b

Fig. 2c

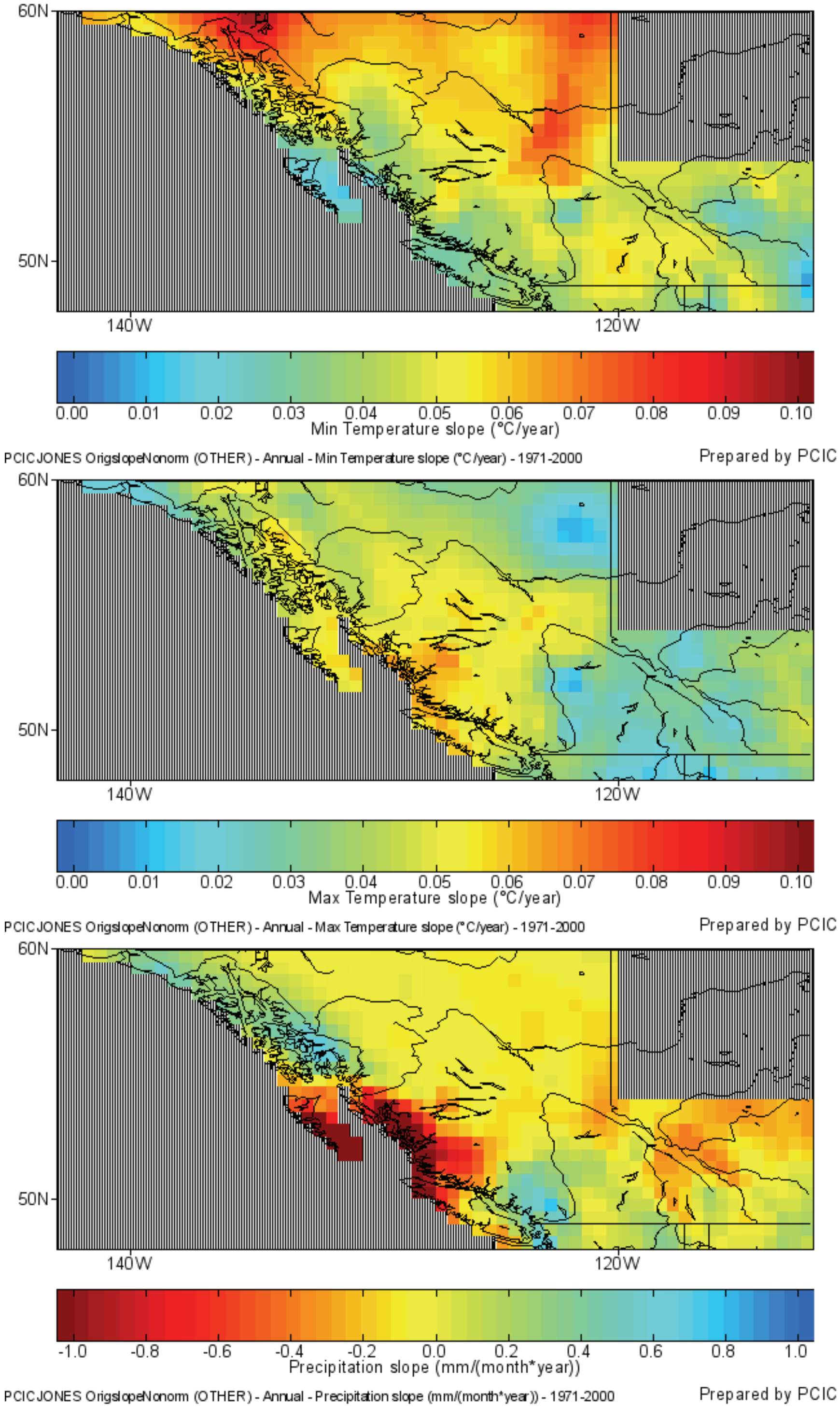
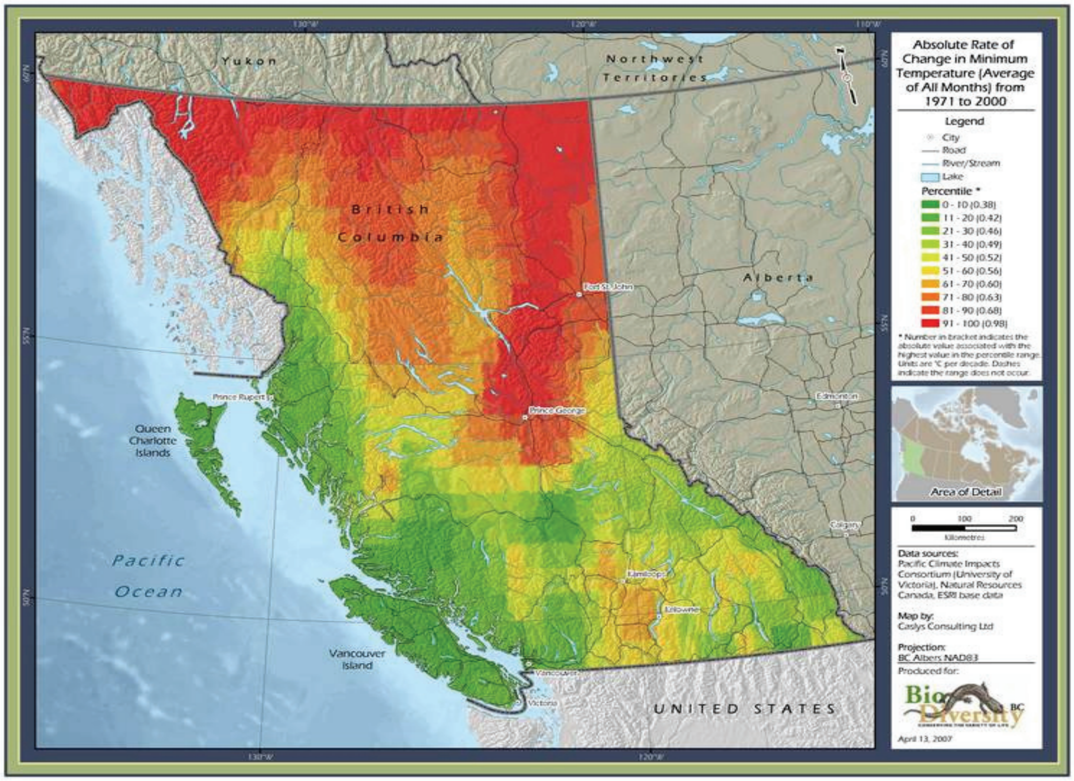


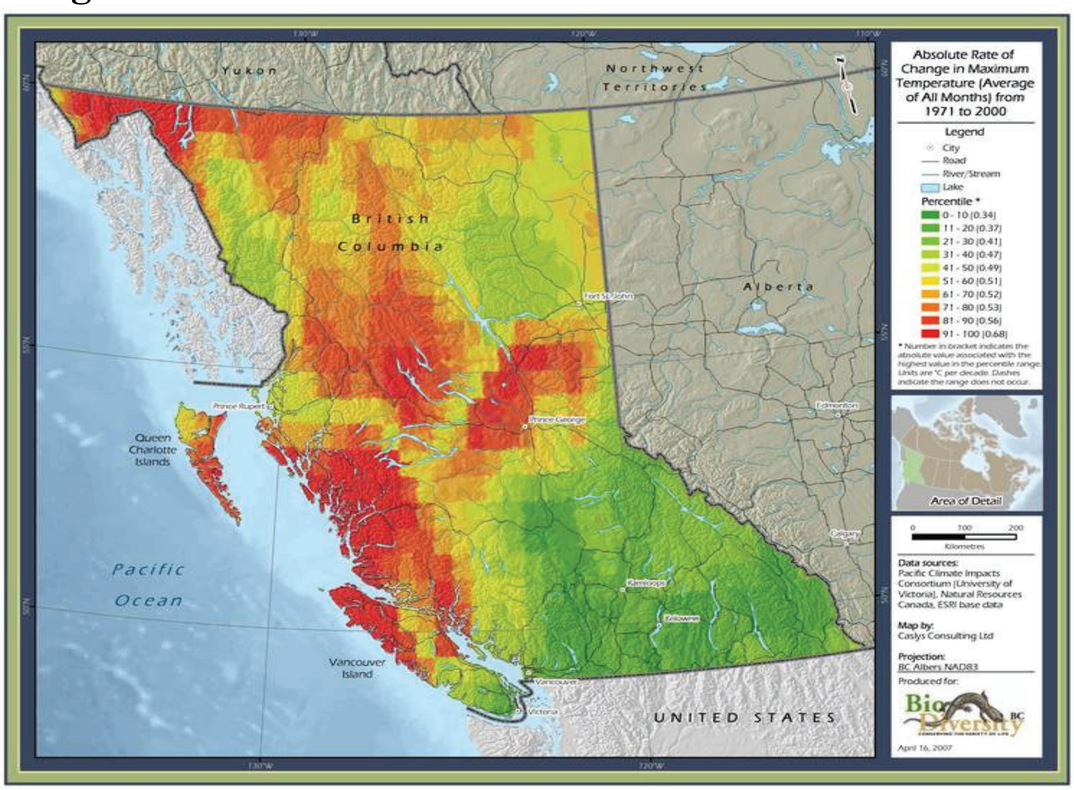
Figure 2: Trend in (a) minimum temperature (^{o}C per year) $m_{Tmin,ANN}$, (b) maximum temperature (^{o}C per year) $m_{Tmax,ANN}$, and (c) precipitation (mm/month per year) $m_{Prec,ANN}$

Fig. 3a



Absolute Rate of Change in Minimum Temperature (Average of All Months) from 1971 to 2000
Legend
City
Road
River/Stream
Lake
Percentile *
0 - 10 (0.38)
11 - 20 (0.42)
21 - 30 (0.46)
31 - 40 (0.49)
41 - 50 (0.52)
51 - 60 (0.56)
61 - 70 (0.60)
71 - 80 (0.63)
81 - 90 (0.68)
91 - 100 (0.98)
Area of Detail
Data sources:
Pacific Climate Impacts Consortium (University of Victoria), Natural Resources Canada, ESRI base data
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
April 13, 2007
Yukon
Northwest Territories
British Columbia
Alberta
Pacific Ocean
Queen Charlotte Islands
Vancouver Island
UNITED STATES

Fig. 3b



Absolute Rate of Change in Maximum Temperature (Average of All Months) from 1971 to 2000
Legend
City
Road
River/Stream
Lake
Percentile *
0 - 10 (0.34)
11 - 20 (0.37)
21 - 30 (0.41)
31 - 40 (0.47)
41 - 50 (0.49)
51 - 60 (0.51)
61 - 70 (0.52)
71 - 80 (0.53)
81 - 90 (0.56)
91 - 100 (0.68)
Area of Detail
Data sources:
Pacific Climate Impacts Consortium (University of Victoria), Natural Resources Canada, ESRI base data
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
April 16, 2007
Yukon
Northwest Territories
British Columbia
Alberta
Pacific Ocean
Queen Charlotte Islands
Vancouver Island
UNITED STATES

Fig. 3c

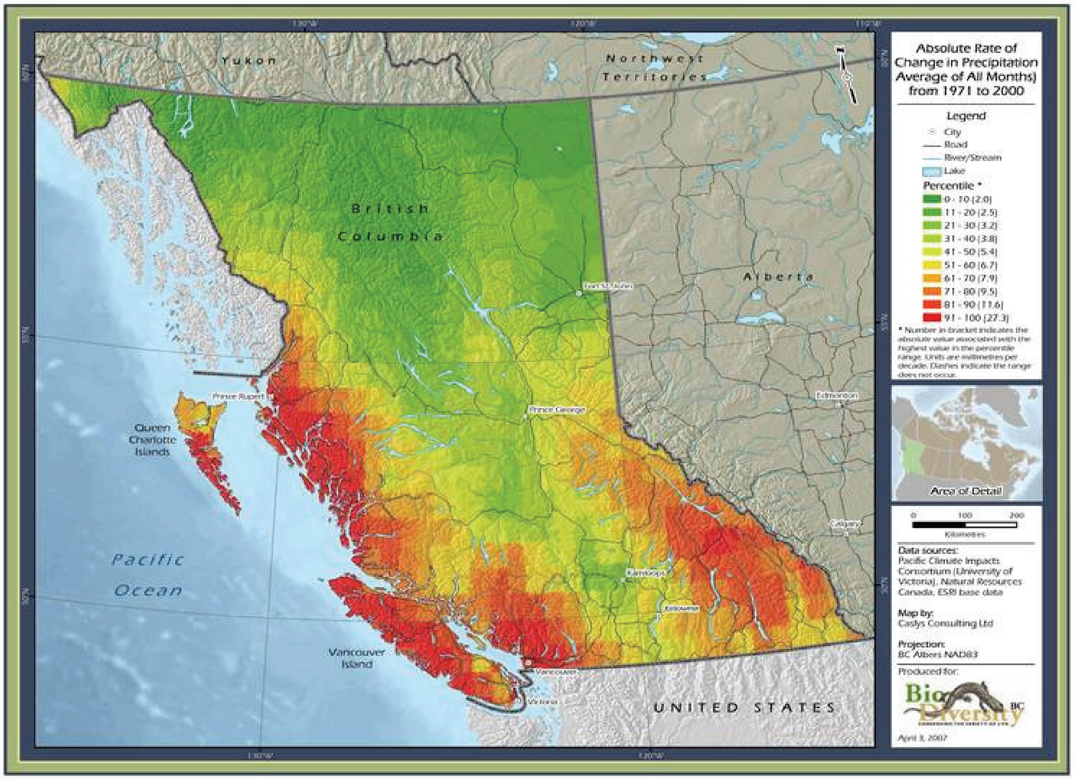


Figure 3: Percentiles of absolute trend in (a) minimum temperature ATI_{Tmin}, (b) maximum temperature ATI_{Tmax}, and (c) precipitation ATI_{Prec}

Fig. 4a

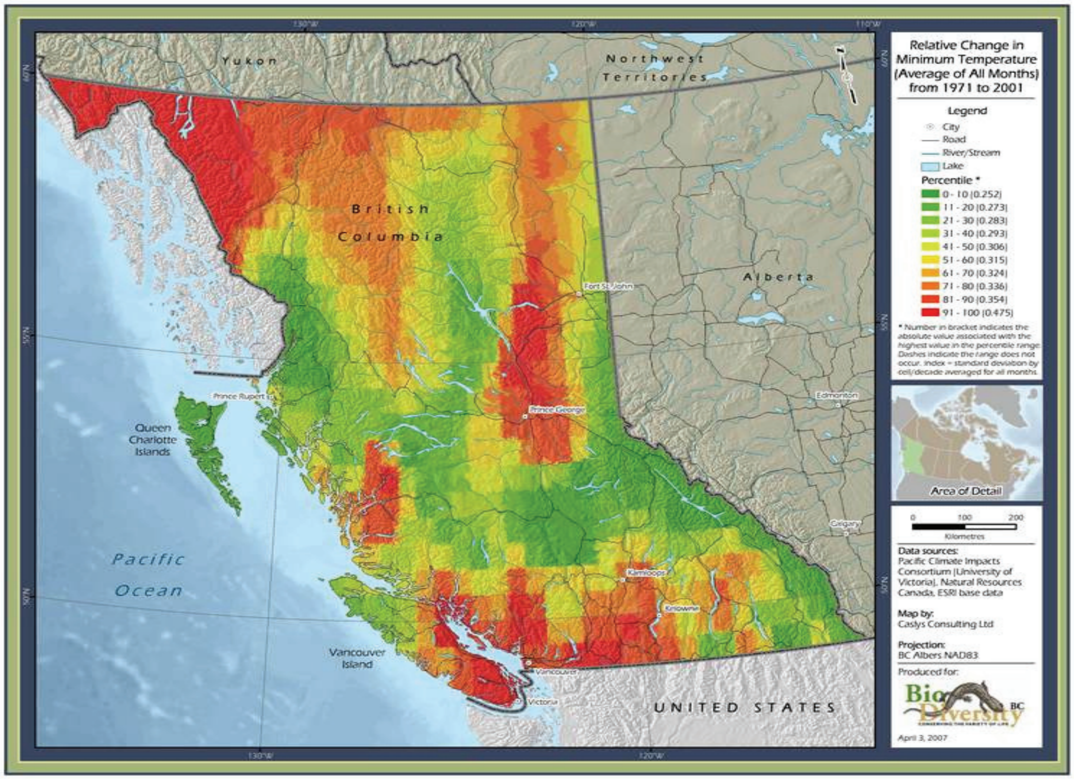
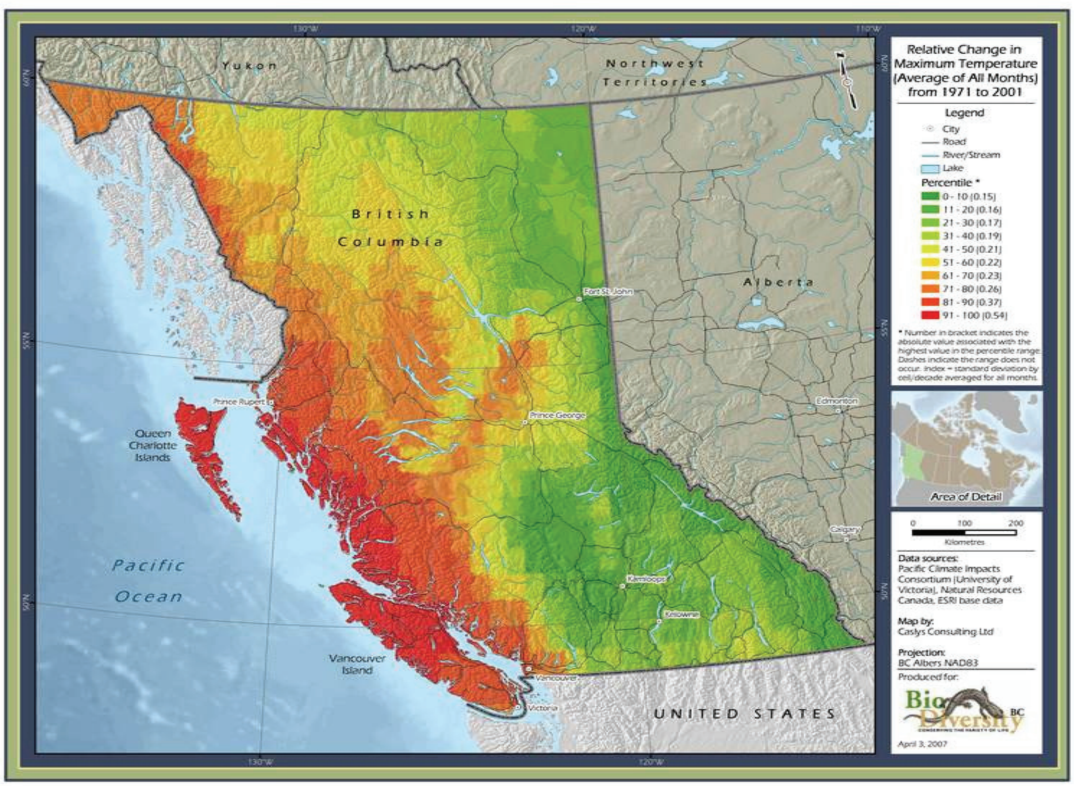

Relative Change in Minimum Temperature (Average of All Months) from 1971 to 2001
Legend
City
Road
River/Stream
Lake
Percentile *
0 - 10 (0.252)
11 - 20 (0.273)
21 - 30 (0.283)
31 - 40 (0.293)
41 - 50 (0.306)
51 - 60 (0.315)
61 - 70 (0.324)
71 - 80 (0.336)
81 - 90 (0.354)
91 - 100 (0.475)
* Number in bracket indicates the absolute value associated with the highest value in the percentile range. Dashes indicate the range does not occur. Index = standard deviation by cell/decade averaged for all months.
Area of Detail
Kilometres
Data sources:
Pacific Climate Impacts Consortium (University of Victoria), Natural Resources Canada, ESRI base data
Map by:
Caslys Consulting Ltd
Projection:
BC Albers NAD83
Produced for:
April 3, 2007
Yukon
Northwest Territories
British Columbia
Alberta
Fort St. John
Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Pacific Ocean
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES

Fig. 4b


Relative Change in Maximum Temperature (Average of All Months) from 1971 to 2001
Legend
City
Road
River/Stream
Lake
Percentile *
0 - 10 (0.15)
11 - 20 (0.16)
21 - 30 (0.17)
31 - 40 (0.19)
41 - 50 (0.21)
51 - 60 (0.22)
61 - 70 (0.23)
71 - 80 (0.26)
81 - 90 (0.37)
91 - 100 (0.54)
* Number in bracket indicates the absolute value associated with the highest value in the percentile range. Dashes indicate the range does not occur. Index = standard deviation by cell/decade averaged for all months.
Area of Detail
Kilometres
Data sources:
Pacific Climate Impacts Consortium (University of Victoria), Natural Resources Canada, ESRI base data
Map by:
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Projection:
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Produced for:
April 3, 2007
Yukon
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Prince Rupert
Prince George
Edmonton
Queen Charlotte Islands
Calgary
Pacific Ocean
Kamloops
Kelowna
Vancouver Island
Vancouver
Victoria
UNITED STATES

Fig. 4c

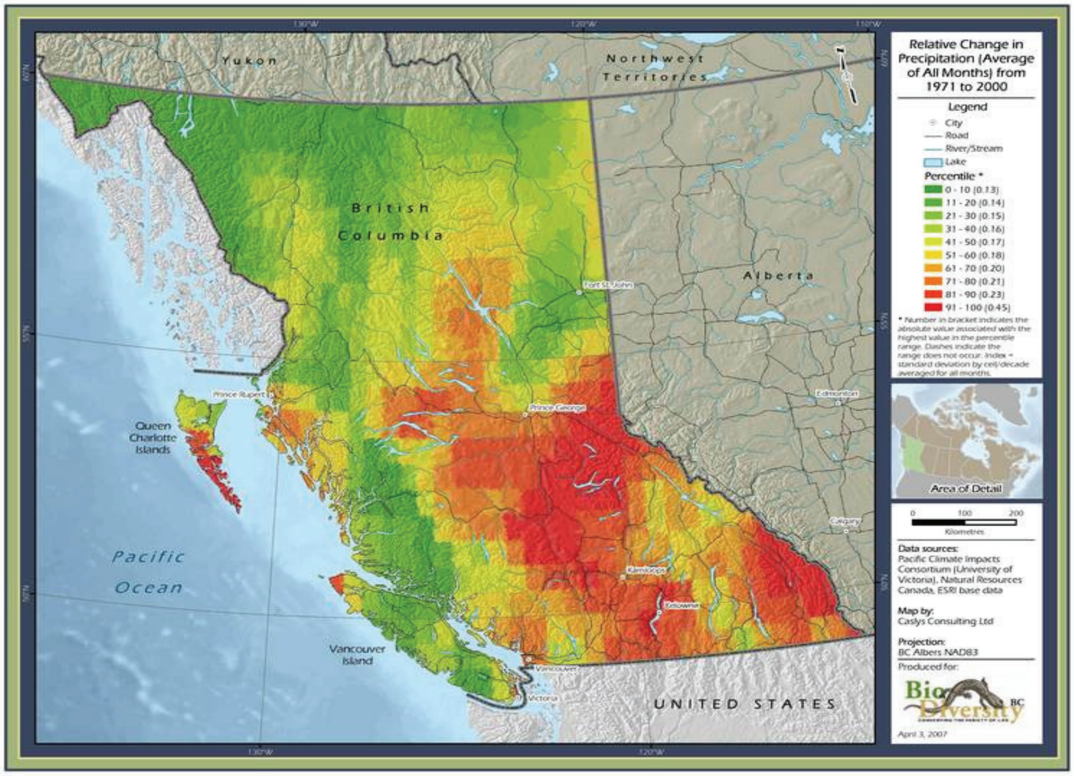

Figure 4: Percentiles of climate change index normalized by location in (a) minimum temperature CCI^{L}_{Tmin}, (b) maximum temperature CCI^{L}_{Tmax}, and (c) precipitation CCI^{L}_{Prec}

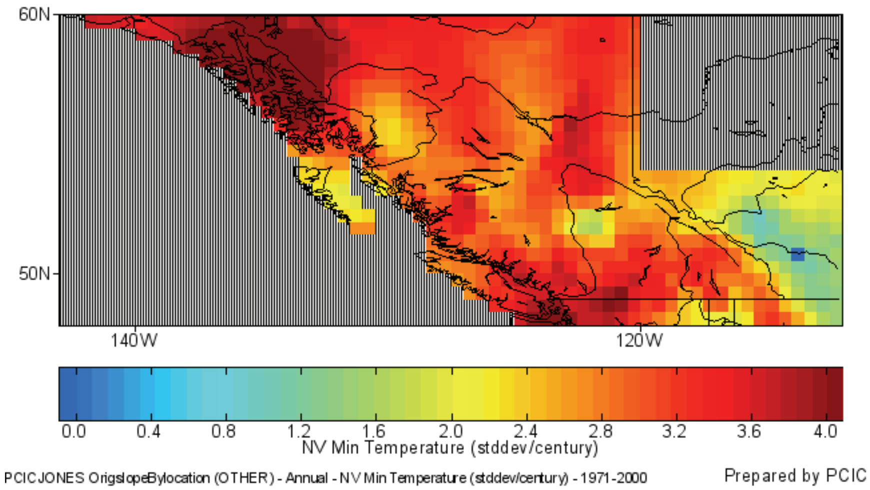

Fig. 5a

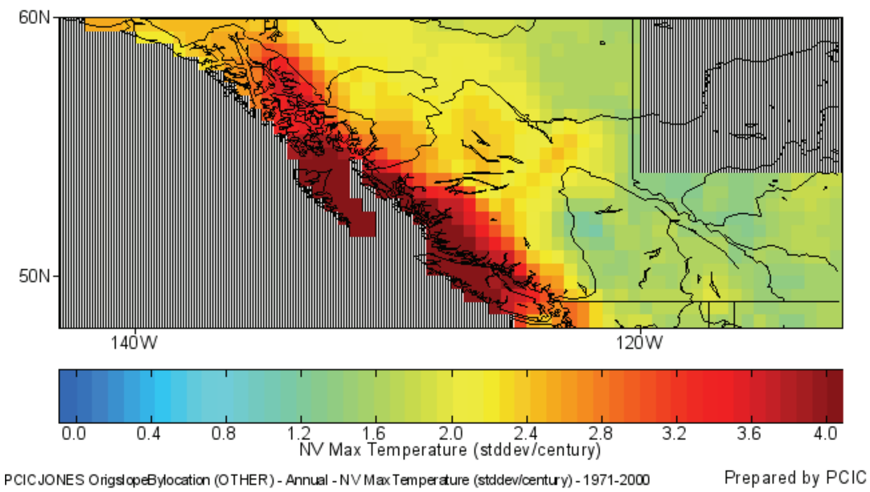

Fig. 5b

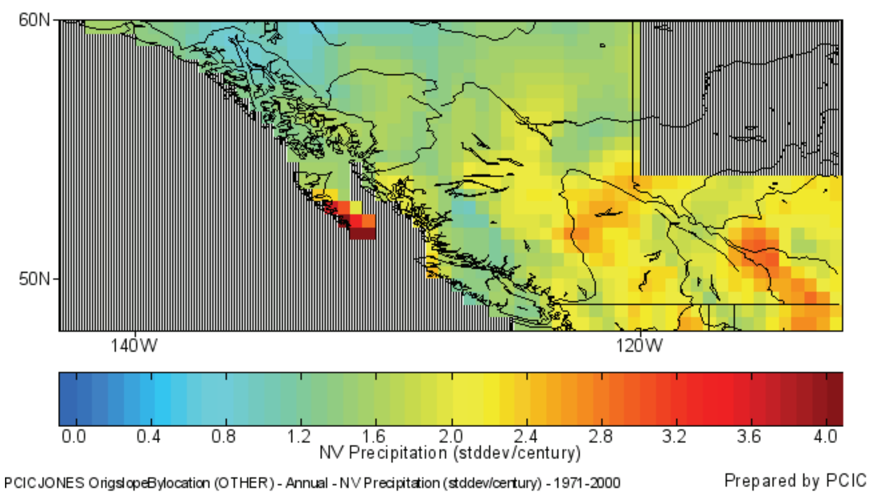

Fig. 5c

Figure 5: Climate change trend index normalized by location (average change per month; standard deviations per century) in (a) minimum temperature CCI^{L}_{Tmin}, (b) maximum temperature CCI^{L}_{Tmax}, and (c) precipitation CCI^{L}_{Prec}

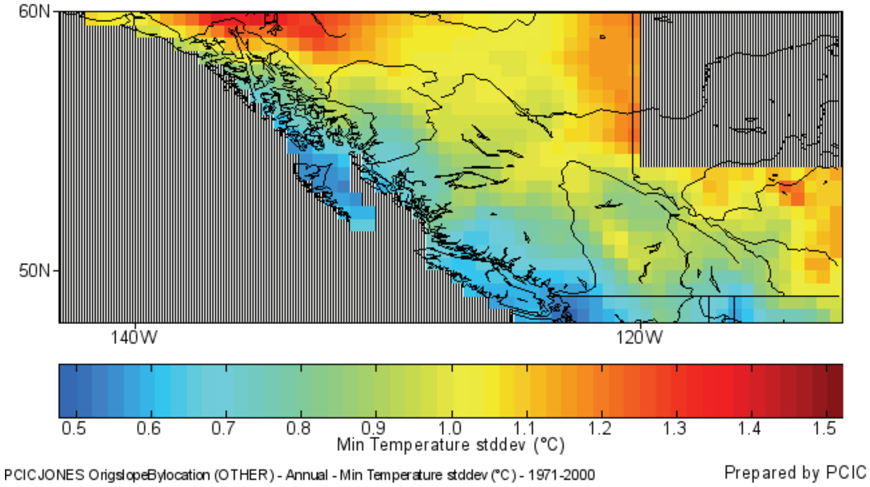

Fig. 6a

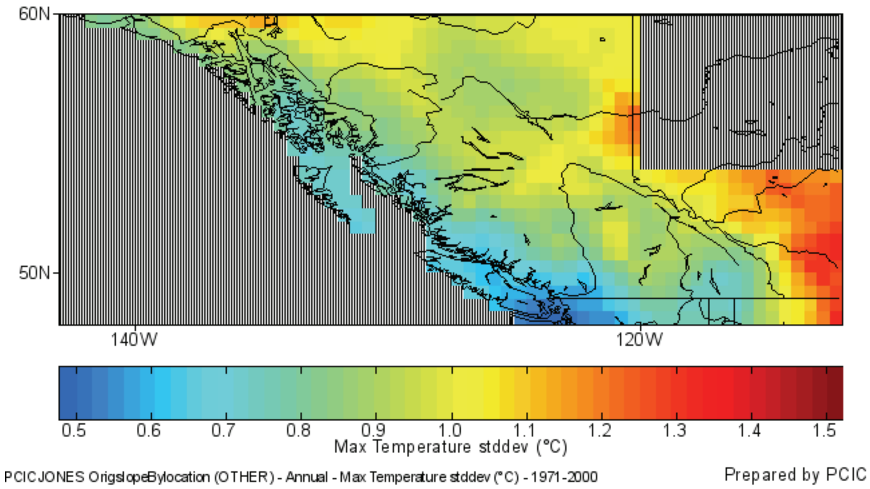

Fig. 6b

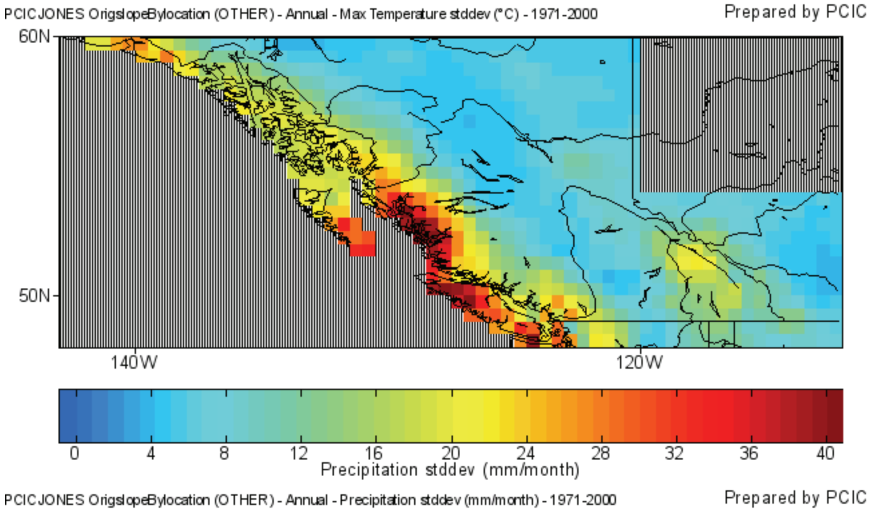

Fig. 6c

Figure 6: Historical variability $\sigma_{P_{ANN,71-00}}$ in (a) minimum temperature (^{o}C), (b) maximum temperature (^{o}C), and (c) precipitation (mm/month)

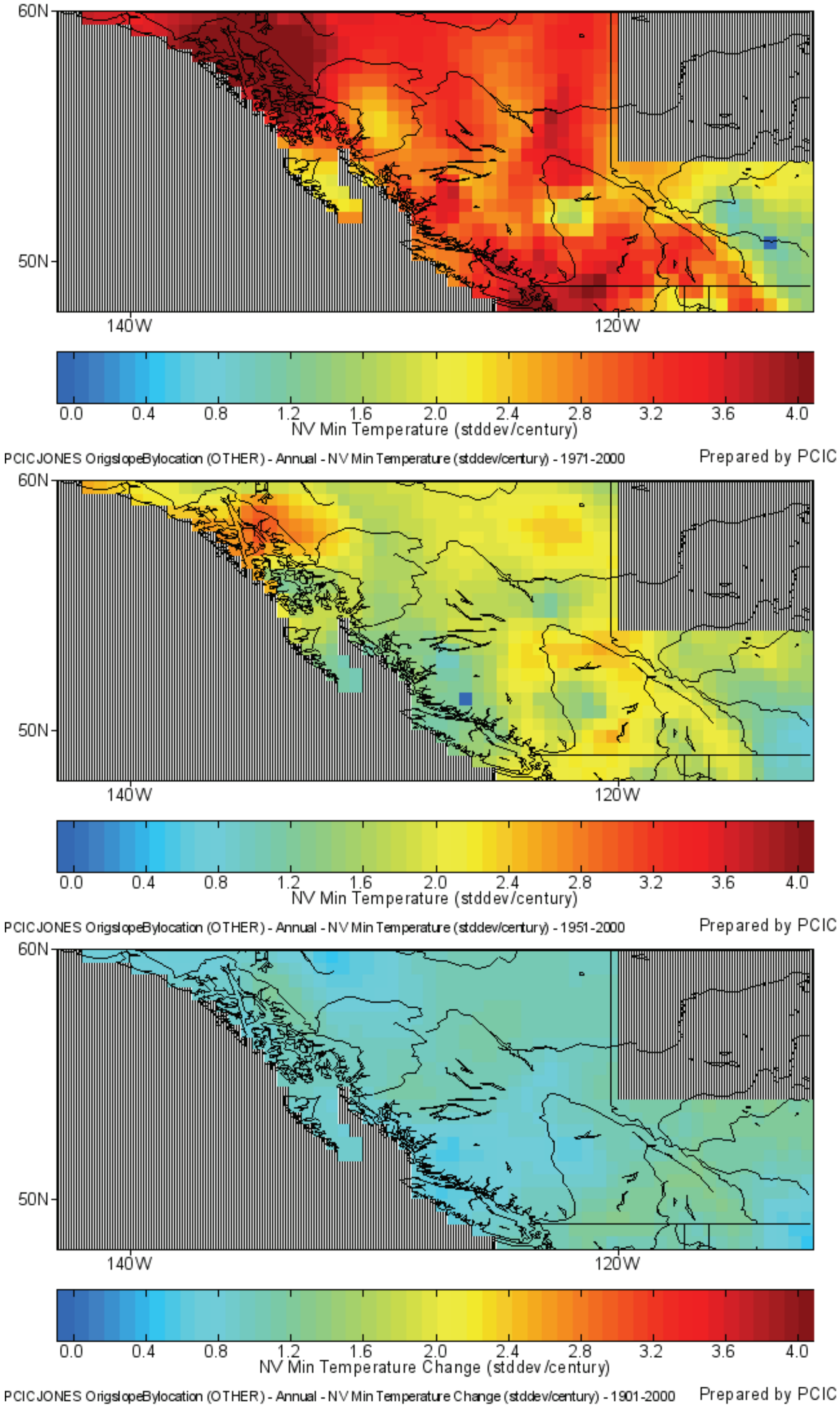

Fig. 7a

Fig. 7b

Fig. 7c

Figure 7: Minimum temperature climate change trend index normalized by location CCILTmin (average change per month; standard deviations per century) for (a) 1971-2000, (b) 1951-2000, and (c) 1901-2000

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Appendix 1: Perl Code

Perl scripts were developed to conduct the work detailed in this report. This section gives an overview of the scripts, terminology used, and a list of the scripts. The code itself is not attached to this document but is available from Pacific Climate Impacts Consortium.

Overview

The following provides a conceptual overview of what the perl code does:

```
variables = tmax, tmin, prec
months = 1-12
timesofyear=1-17 (12 months, 4 seasons, annual average)

time slices = 1961-1990, 1971-2000

grid boxes = boxes within chosen window

Load months into times of year

For each variable
    For each grid box
        For each year
            Do daily averaging for months 12,1,2 (DJF), add to times of year
            Do daily averaging for months 3-5 (MAM), add to times of year
            Do daily averaging for months 6-8 (JJA), add to times of year
            Do daily averaging for months 9-11 (SON), add to times of year
            Do daily averaging for annual, add to times of year

    // At this point there is a timeseries for each grid box, for each
time of year (including seasons and annual)

    For each time of year
        For each grid box
             Compute mean, stddev, slope, intercept, correlation
coefficient, and hv (100 * slope / stddev) for each time slice

    For 71-2000
        For each grid box
           For each time of year
              Compute alt_slope: ((1971-2000 mean) - (1941-2000 mean)) / 30

    For each time slice
        For each time of year
            Compute mean stddev of all grid boxes
```

For each time slice
    For each grid box
        For each time of year
            Compute hv without normalization: (100 * slope / mean stddev)

For 1971-2000
    Add absolute trend index as 18th timeofyear: Sum (days per month)*(absolute value of data for month) for months 1-12, divide by sum for months 1-12 of days per month

Terminology

Within the code, references are made to the following terminology, used slightly differently in the report above:

Original slope – m_P in equation (1) above; simple linear trend (this is the trend that has been chosen for use).

New slope – difference between 30-year means as slope (calculated but not used in final results).

Absolute trend index – *ATI* for *m* and *CCI* for *HVI* – this is computed as the 18th "time of year" after the months, seasons, and annual.

HV index – *HVI* – historical variability index, originally called "natural variability" index: the monthly, seasonal, or annual trend normalized by standard deviation.

BD index – originally referred to as the biodiversity index, this is the inverse of *HVI* (no longer used but included here as it remains in the code).

List of scripts

do_run.pl -- Does the run to generate the output files (runs trend_dev.pl, clip2window.pl, calc_slope.pl, do_bd.pl, do_bd_nonorm.pl)

create_outputs.pl -- Creates the output files (runs add_abslope.pl)

add_abslope -- Adds the final column (absolute trend slope) to the slope files for each variable, for both the least squares fit and the difference between means method (old and new methods)

calc_slope.pl -- Calculates the new slope.

clip2window.pl -- Clips georeferenced data to a rectangular window.

do_bd.pl -- Computes the hv and bd indices for the given data do_bd_nonorm.pl -- Computes the not-normalized-by-location hv and bd indices for the given data

trend_dev.pl -- Does averaging of the input data to generate a new time series for each of the seasons and annual, then computes the mean, slope, stddev, hv, bd, intercept, and correlation coefficients for the input CRU data, outputting one file for each data variable/derived variable/timeslice combination.

Appendix 2: Data files

The data files listed below were delivered to the Biodiversity BC Technical Subcommittee as part of this project. Files were sent email to Matt Austin, Co-Chair of the Technical Subcommittee on 05-Feb-2007 1:58 pm and 12-Feb-2007 12:28 pm, and are available from Pacific Climate Impacts Consortium.

Naming convention is (timeslice)_(variable)_(slopetype)_(index).csv where

- timeslice is always 7100 for 1971-2000
- variable is tmin for Minimum Temperature, tmax for Maximum Temperature, or prec for Precipitation
- slopetype is either newslope (difference of means between 1941-1970 and 1971-2000) or origslope (slope of least squares linear fit to 1971-2000)
- index is either trend: *m* and *ATI* or hv: *HVI* and *CCI*

Units are as follows:

- *m*: ^{o}C/year or mm/year for the given month, season, or the annual average
- *ATI*: ^{o}C/year or mm/year; average change per month
- *HVI*: standard deviations per century
- *CCI*: standard deviations per century; average change per month

All files include latitude and longitude as columns A and B respectively. Columns C through S are January through December, DJF, MAM, JJA, SON, and Annual averages. Column T is as listed in the table below. See equations 1 through 3 for definitions.

Table 4: File details

File name	Columns C-S	Column T
7100_tmin_origslope_trend.csv	$m_{Tmax,i}$	TI_{Tmax}
7100_tmax_origslope_trend.csv	$m_{Tmin,i}$	TI_{Tmin}
7100_prec_origslope_trend.csv	$m_{Prec,i}$	TI_{Prec}
7100_tmin_origslope_nv_nonorm.csv	$HVI^{BC}{}_{Tmin,\ i}$	$CCI^{BC}{}_{Tmin}$
7100_tmax_origslope_nv_nonorm.csv	$HVI^{BC}{}_{Tmax,\ I}$	$CCI^{BC}{}_{Tmax}$
7100_prec_origslope_nv_nonorm.csv	$HVI^{BC}{}_{Prec,\ i}$	$CCI^{BC}{}_{Prec}$
7100_tmin_origslope_nv.csv	$HVI^{L}{}_{Tmin,\ i}$	$CCI^{L}{}_{Tmin}$
7100_tmax_origslope_nv.csv	$HVI^{L}{}_{Tmax,\ I}$	$CCI^{L}{}_{Tmax}$
7100_prec_origslope_nv.csv	$HVI^{L}{}_{Prec,\ i}$	$CCI^{L}{}_{Prec}$

Also, stddev.csv contains $\sigma^{BC}_{P_{i71-00}}$ from equation (2) in columns B-R for each time period.

All files except stddev.csv were also produced for "newslope" which was computed in order to facilitate updating the index using climate scenarios from global or regional climate models. In this case, each index was re-computed by subtracting two thirty-year average periods from each other. For example, the 1941-1970 average was subtracted from the 1971-2000 average. This difference in means was divided by 30 years in order to be comparable to the original slope. This most simplistic version of the slope is thus a line between the means of the two thirty-year periods at their respective midpoints.