5.6 BUILDING HISTORIES OF CLIMATE EXTREMES AT CANADA'S BIOSPHERE RESERVES 1935-2005

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1. INTRODUCTION

Climate change will result in a set of diverse and regionally-specific impacts on natural ecosystems and human societies. A growing literature suggests that while climate mitigation strategies are necessary to reduce greenhouse gas emissions from anthropogenic sources, those alone are unlikely to be sufficient. As studies have shown, the impacts of climate change from previous emissions of greenhouse gases over the past 150 years will have to be confronted by all countries including Canada. Therefore, pursuing a complementary strategy of enabling countries to adapt to climate change and negate many of the expected adverse impacts is equally, if not more, urgent (Adger and Kelly, 1999; Burton et al., 2002).

To determine how communities such as Biosphere Reserves are equipped to deal with the inevitable impacts of climate change requires an understanding of each community's adaptive capacity. A community's adaptive capacity is its talent and willingness to take the initiative in making adjustments to reduce the negative impacts of climate change. Fundamentally, adaptive capacity is the ability to respond to climate changes and then to initiate responses to these climate changes.

In its *Third Assessment Report*, the IPCC (2001) listed a number of requirements for enhancing adaptive capacity including, *inter alia*, improved education and information. The purpose of this paper is to discuss how to build the adaptive capacity to climate change at Canada's Biosphere Reserves through improved education and information on past climate extremes.

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2. BIOSPHERE RESERVES

Biosphere Reserves are ecosystems around the world, regionally representative of the biosphere, and recognized internationally by UNESCO's Man and the Biosphere (MAB) Programme as part of a global network of 459 Biosphere Reserves in 97 countries (UNESCO, 2005). Biosphere Reserves are used to share knowledge on how to manage natural resources in a sustainable way; to co-operate in solving natural resource issues; to conserve biological diversity; to maintain healthy ecosystems; to learn about natural systems and how they are changing; and to learn about traditional forms of land-use. Biosphere reserves are test areas for demonstrating ideas, tools, concepts, knowledge, etc. of resource conservation, sustainable development as well as climate change. It is the role of the biosphere reserve to serve as a mechanism for enhancing local, regional, and multi-jurisdictional cooperation that is most needed in the area (Ravindra, 2001).

These objectives are met through each Biosphere Reserve's management structure, or "round table" of local communities (ranging from local indigenous communities to rural societies), farmers, foresters, fishermen, research scientists, government decision-makers, and other agency representatives. What make these "round tables" unique are their connection to a national network of Biosphere Reserve communities and the links to the World Network promoting areas where sustainable development is an applied concept.

Since 1972, UNESCO has designated 13 biosphere reserves in Canada (see Figure 1): Mont St. Hilaire (Quebec, 1978); Waterton (Alberta, 1979); Long Point (Ontario, 1986); Riding Mountain (Manitoba, 1986); Charlevoix (Quebec, 1989); Niagara Escarpment (Ontario, 1990); Clayoquot Sound (British Columbia, 2000); Redberry

Lake (Saskatchewan, 2000); Lac St. Pierre (Quebec, 2000); Mount Arrowsmith (British Columbia, 2000); South West Nova (Nova Scotia, 2001); Thousand Islands – Frontenac Arch (Ontario, 2002).

Figure 1 - Map of Canada's Biosphere Reserves Source: Canadian Biosphere Reserve Association, 2005.

The scientific literature linking biosphere reserves and climate change monitoring and research is limited to a paper by Hamilton, Whitelaw and Fenech (2001) - a preliminary examination of climate records at five Canadian Biosphere Reserves – and plans surrounding a UNESCO MAB project on climate change and biodiversity at Mountain Biosphere Reserves around the world. The Hamilton et al paper examined climate records for annual trends in temperature and precipitation that provided direction of trends but little information that was useful to environmental managers at Canada's Biosphere Reserves for climate change adaptation (more below).

3. ANALYSIS OF CLIMATE EXTREMES FOR BIOSPHERE RESERVES

Climate can be thought of as an average of the weather over a period of years or decades. It describes the characteristic weather conditions to be expected in a region at a given time of year, based on long-term experience. By international convention, weather observations are commonly averaged over a period of 30 years to produce the statistics that describe the climate "normals" (Phillips and McCulloch, 1972; Gates, 1973; Watson, 1974; Janz and Storr, 1977; Wahl et al, 1987; Auld et al, 1990). These averages are helpful for providing "average" temperatures and precipitation, or when comparing one location to another, but they do not provide the necessary information to assist communities such as Biosphere Reserves in planning for climate change adaptation.

Communities such as Biosphere Reserves need climate information on extremes of climate so that they can determine how they have adapted in the past to these extremes, and how to best plan for these in the future. An international committee of the World Meteorological Organization (WMO) Commission on Climatology (CCl) has an expert group on climate change detection. This group was mandated to develop, calculate, and analyze a suite of climate change indices so that individuals, countries, and regions can calculate the indices in exactly the same way such that their analyses will fit seamlessly into the global picture (Karl et al. 1999).

Many have developed their own indices of climate extremes (European Climate Assessment, 2006; Stardex, 2006; *et al*) totaling over 400, yet the WMO CCl expert team considers a total of 27 indices core indices based on daily temperature values or daily precipitation amounts. Gachon (2005) has identified 18 indices for extreme temperature and precipitation for Canadian regions, some of which can later be used for the validation of statistical downscaling of climate models – a subsequent phase in this climate change and biosphere reserve project.

The results presented in this paper are focused on the Gachon indices. Gachon considered 4 criteria in choosing indices: the indices must represent Nordic climate conditions such as found in Canada; the indices must be relevant to climate change impact studies; extreme indices are relatively moderate (e.g. using 10^{th} and 90^{th} percentiles as opposed to the 5^{th} and 95^{th}); and indices are adapted to the main characteristics of climate conditions at the regional scale. Gachon concludes that these 18 indices "provide a good mix of information – precipitation indices characterize the frequency, intensity, length of dry spells, magnitude and occurrence of wet extremes while temperature indices refer to variability, season lengths and cold and warm extremes in terms of magnitude, occurrence and duration. The Gachon indices are presented in Table 1.

4. HOMOGENIZATION OF CLIMATE DATA

To monitor and detect climate change reliably, the indices should contain variations that are caused by climate processes only. There are two aspects to consider when constructing these indices (Zhang, 2004). First, the original daily data should be homogeneous, i.e. be free of not-climate-related variation. Secondly, the method for constructing the indices should not introduce any additional variation (function of use of calendar years that need to be overcome – see Zhang et al, 2005).

A climate dataset contains climate information at the observation sites, as well as other non-climate related factors such as the environment of the observation station, and information about the instruments and observation procedures under which the records were taken. An assumption is made that the station records are representative of climate conditions over a region when the data are used in climate analysis. This is, unfortunately, not always the case. Zhang (2004) provides two excellent examples:

For example, if an observing station is moved from a hill top location to the valley floor 300 meters lower in elevation, analysis of its temperature data will likely show an abrupt warming at the time of the station relocation. This artificial jump would not be representative of temperature change in the region. Also, consider a station located in the garden of a competent and conscientious observer for 50 years, and suppose a tree was planted west of the garden at the time the observation station was established. The instruments are maintained in good condition and the observer accurately records the temperature in the garden. The tree slowly grows up and shades the observing site during the late afternoon when the daily maximum temperature is observed. As a result, the recorded daily maximum temperature would gradually become lower than that over the surrounding area not shaded by the tree. Thus the station would gradually become less representative of the surrounding area.

A real life example of a Canadian site being moved has been shown by Vincent (1998).

It is therefore important to remove the non-climate factors from the data as much as possible, before the climate data can be used reliably for climate change studies. A great deal of effort has been made to develop methods to identify and remove non-climatic inhomogeneities (see Peterson et al, 1998) and the WMO CCl has developed a set of practical guidelines on how to deal with inhomogeneity problems depending on the circumstances under which inhomogeneity occurs.

5. METHOD

A history of climate extremes (hot-cold, wet-dry) is being built for each Biosphere Reserve in Canada. Observational data from several climate stations are available for each of Canada's Biosphere Reserves (see Figure 7 for example of climate stations around Southwest Nova Biosphere Reserve, Nova Scotia, Canada).

However, a station from Canada's Climate Reference Network close to each of Canada's Biosphere Reserves was selected to ensure the length and completeness of climate records available (see Figure 8 for graphical representation of Table 2). There are 302 Reference Climate Stations in Canada for climate change studies, as well as other climate research (Plummer et al, 2003).

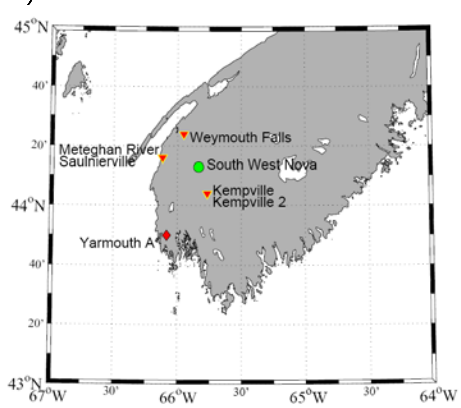

Figure 7 – Climate Stations Around Southwest Nova Biosphere Reserve in Nova Scotia, Canada (circle is biosphere reserve, triangles are climate stations with available data, diamond is Climate Reference Network station)

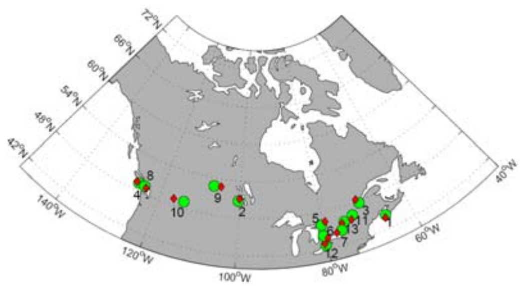

Figure 8 – Climate Reference Network Stations Around Canada's Biosphere Reserves (circles are biosphere reserves, diamonds are Climate Reference Network stations)

At least seventy years of climate data are available for each of Canada's stations in the Climate Reference Network used in this study. The daily maximum, minimum and mean temperatures and precipitation amounts were checked for homogeneity using an R-based toolkit RHTest that uses a two-phase regression technique (Wang 2003) for the detection and adjustment of inhomogeneity.

The homogenized climate data for each Biosphere Reserve was then run through the 18 indices for climate change detection as identified by Gachon (2005). Based on seasonal reporting of indices, this produced a series of over 100 graphs and charts for each Biosphere Reserve. A history is being built that selects the most informative of the graphs to tell a story of when (year and/or season) the Biosphere Reserve experienced climate extremes. The process of graph selection is being documented for each of the 13 Biosphere Reserves, and an overall "approach" to building a history will be formulated.

6. AN EXAMPLE OF SOME PRELIMINARY RESULTS

Using the Southwest Nova Biosphere Reserve as an example, Figure 9 shows the mean temperature from 1941 to 2002 where no discernable trend of increasing or decreasing temperature is apparent.

Examining extremes, however, provides an opportunity to focus on particular years. Figure 10 shows the extreme hot days (3 consecutive days where maximum temperature is greater than the daily normal maximum temperature plus 3 degrees Celsius) at Southwest Nova Biosphere Reserve. It is obvious that 1990 was a year of extreme hot days doubling any other year prior or following.

Figure 11 shows a similar graph for precipitation – the number of consecutive dry days in the autumn when precipitation was less than 1 millimeter. The autumn of 1979 stands out as a particularly dry season, similar only to the autumns of 1964 or 1947.

The community's experience and natural knowledge bases are built using a participatory integrated assessment, a collaborative interdisciplinary research effort which is based on developing a partnership between researchers and stakeholders (Cohen, 2004). This is meant to create an exercise in shared learning. Dialogue processes are critical to this process, extending beyond simply performing an outreach function. In this approach, dialogue contributes important information on how adaptation options may be considered by governments, private enterprises, and community groups.

By showing the community how the climate has changed in the past, the question can be asked as to how they have adapted to these changes. In this example, the past climate highlights a year of extreme hot days just 15 years ago, and 25 years ago for an extremely dry season, within the memory of many biosphere reserve managers. This extreme year may have required intervention from biosphere reserve managers to save agricultural crops, preserve endangered species habitat, or ensure the quality of groundwater. This knowledge, taken together with scenarios of future climate change showing similar extreme hot or dry years in the future (i.e. changed return periods), can identify some adaptation measures that might be taken to ensure that an adaptation infrastructure is in place, or that alternative management of the biosphere reserve occurs. In other words, what lessons did the community learn from the last event that can be drawn on with advanced knowledge about the future to minimize the negative impacts and maximize the benefits from climate change?

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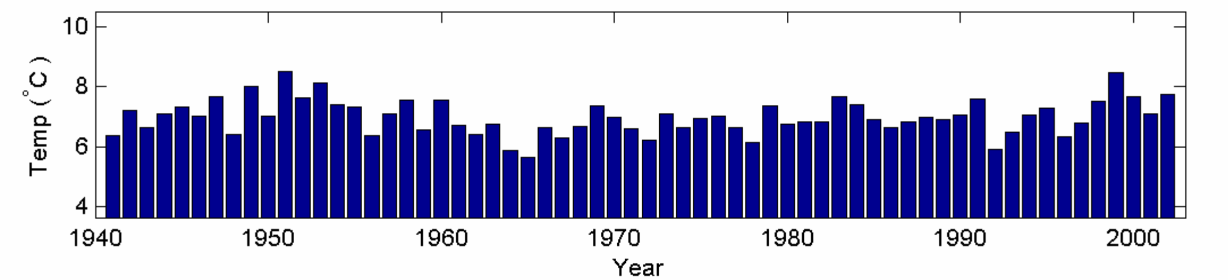

Figure 9 – Mean Daily Temperature of Yarmouth Station A (8206500) from 1941-2002

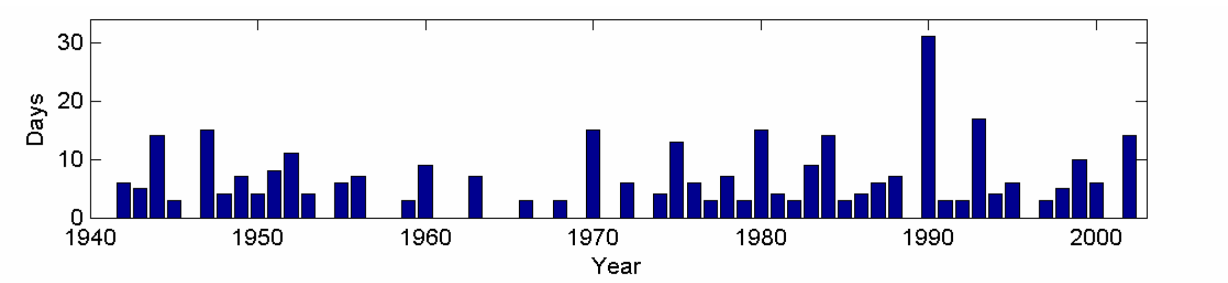

Figure 10 – Annual Extreme Hot Days at Yarmouth Station A (8206500) from 1941-2002

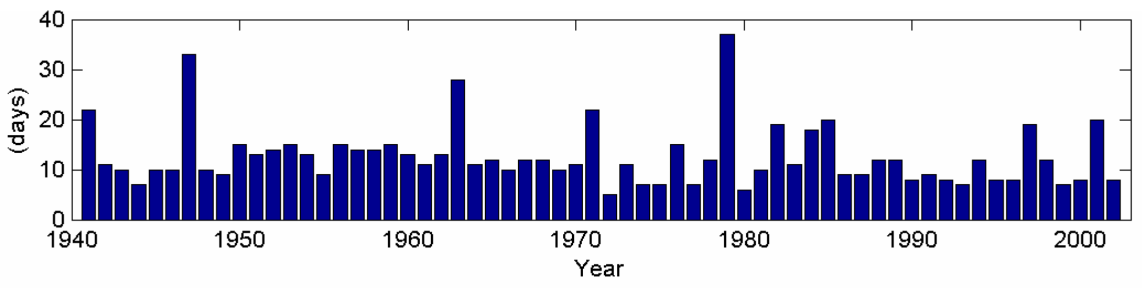

Figure 11 – Consecutive Dry Days (precipitation less than 1 mm) in Autumn at Yarmouth Station A (8206500) from 1941-2002

		DEFINITION	UNIT	TIME SCALE
Precipitation				
Indices				
Frequency		Percentage of wet days (Threshold=1 mm)	% days	Season
Intensity		Simple daily intensity index : sum of daily precip/number of wet days	mm/wet d	Season
Extremes		Maximum number of consecutive dry days (<1 mm)	days	Season
Magnitude		Maximum 3-days precipitation total	mm	Season
and		90th percentile of rainday amount ((Threshold=1 mm)	mm/days	Season
Occurrence		Percentage of days Prec>90th percentile (61-90 based period)	% days	Season
Temperature				
Indices				
Daily variability		Mean of diurnal temperature range	°C	Season
		Percentage of days with freeze and thaw cycle (Tmax>0°C, Tmin<0°C)	% days	Month
Season length		Frost season length :Tday<0°C more than 5 d.and Tday>0°C more than 5 d.	days	Year
		Growing season length :Tday>5°C more than 5 d.and Tday<5°C more than 5 d.	days	Year
Extremes		Sum of sequences > 3 days where Tmin< daily Tmin normal - 5°C	days	Winter
cold & hot		Sum of sequences > 3 days where Tmax> daily Tmax normal + 3°C	days	summer
Extremes		10th percentile of daily Tmax	°C	Season
Magnitude		90th percentile of daily Tmax	°C	Season
and		10th percentile of daily Tmin	°C	Season
		90th percentile of daily Tmin	°C	Season
Occurrence		Percentage of days Tmax>90th percentile (61-90 based period)	% days	Season
		Percentage of days Tmin<10th percentile (61-90 based period)	% days	Season

Table 1 – Gachon Indices of Climate Extremes for Impact Studies of Climate Change for Nordic Countries

Biosphere Reserve	**Area (hectares)**	**Latitude**	**Longitude**	***MSC Station***	**Station ID**	**Latitude**	**Longitude**
South West Nova	1,546,374	44°13'N	65°50'W	Yarmouth A	8206500	43°50'N	66°05'W
Riding Mountain	1,331,180	50°45'N	100°19'W	Dauphin A	5040680	51°06'N	100°03'W
Charlevolx	560,000	47°15' to 48°05'N	69°55' to 71°10'W	Bagotville A	7060400	48°20'N	71°00'W
Clayoquot Sound	349,947	49°00' to 49°35'N	125°25' to 126°35'W	Estevan Point	1032730	49°23'N	126°33'W
Georgian Bay Littoral	342,000	45°55'N	80°25'W	North Bay A	6085700	46°21'N	79°26'W
Niagara Escarpment	190,270	43°10' to 45°15N	79°03' to 81°40'W	Toronto Pear-son Airport	6158733	43°40'N	79°38'W
Thousand Island	150,000	44°20'N	76°10'W	Belleville	6150689	44°09'N	77°24'W
Mount Arrowsmith	118,593	49°07' to 49°23'N	124°06' to 124°40'W	Nanaimo A	1025370	49°03'N	123°52'W
Redberry Lake	112,200	52°42'N	107°10'W	North Battlefield A	4045600	52°46'N	108°15'W
Waterton	52,597	49°00' to 49°12'N	113°39' to 114°10'W	Creston	1142160	49°06'N	116°31'W
Lac Saint-Pierre	48,000	46°02' to 46°16'N	72°39' to 73°10'W	St Hubert A	7027320	45°31'N	73°25'W
Long Point	40,600	42°35'N	80°23'W	Delhi CDA	6131982	42°52'N	80°33'W
Mont Saint Hilaire	5,500	45°33'N	75°09'W	Ottawa CDA	6105976	45°23'N	75°43'W

Table 2 – Linking Canadian Biosphere Reserves to Climate Reference Network Stations